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Appendix D-8



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Unobtrusive Augmentation of Physical Environments

Interaction Techniques, Spatial Displays and Ubiquitous Sensing

ALEX OLWAL

Avhandling som med tillstånd av Kungliga Tekniska högskolan
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Abstract

The fundamental idea of Augmented Reality (AR) is to improve and enhance our perception of the surroundings, through the use of sensing, computing and display systems that make it possible to augment the physical environment with virtual computer graphics. AR is, however, often associated with user-worn equipment, whose current complexity and lack of comfort limit its applicability in many scenarios.

The goal of this work has been to develop systems and techniques for uncomplicated AR experiences that support sporadic and spontaneous interaction with minimal preparation on the user's part.

This dissertation defines a new concept, *Unobtrusive AR*, which emphasizes an optically direct view of a visually unaltered physical environment, the avoidance of user-worn technology, and the preference for unencumbering techniques.

The first part of the work focuses on the design and development of two new AR display systems. They illustrate how AR experiences can be achieved through transparent see-through displays that are positioned in front of the physical environment to be augmented. The second part presents two novel sensing techniques for AR, which employ an instrumented surface for unobtrusive tracking of active and passive objects. These techniques have no visible sensing technology or markers, and are suitable for deployment in scenarios where it is important to maintain the visual qualities of the real environment. The third part of the work discusses a set of new interaction techniques for spatially aware handheld displays, public 3D displays, touch screens, and immaterial displays (which are not constrained by solid surfaces or enclosures). Many of the techniques are also applicable to human-computer interaction in general, as indicated by the accompanying qualitative and quantitative insights from user evaluations.

The thesis contributes a set of novel display systems, sensing technologies, and interaction techniques to the field of human-computer interaction, and brings new perspectives to the enhancement of real environments through computer graphics.

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I would like to first and foremost thank Professor Steven Feiner at Columbia University for his guidance, engagement, and generous support of this work. The opportunity of collaborating with such an inspiring advisor has been a true pleasure and a highly appreciated privilege.

I thank Professor Lennart Johnsson who financially supported my work at KTH and Professor Yngve Sundblad for the much appreciated discussions, joint proposals, and shared interests in visualization and interaction.

The main part of this work was based at PDC at KTH in Stockholm, with large parts conducted at a number of institutions around the world, where I enjoyed many stimulating challenges and enriching interactions with new colleagues. I would like to express my gratitude towards the following institutions, for hosting and supporting the work:

- PDC, Department of Computer Science & Communication, KTH
- Computer Graphics and User Interfaces Laboratory, Columbia University
- Department of Production Engineering, KTH
- Imaging, Interaction and Innovative Interfaces Laboratory, UC Santa Barbara
- Adaptive Systems and Interaction Group, Microsoft Research, Redmond
- VITA group, Linköping University

I would like to thank the many colleagues and collaborators that I have been fortunate to interact with over the years, including: Patrick Baudisch, Andy Beall, Mats Bejhem, Blaine Bell, Hrvoje Benko, Gábor Blaskó, Nicola Candussi, Phil Cohen, Andrea Corradini, Ed Cutrell, Stephen DiVerdi, Arvid Engström, Stefan Evensen, Rogerio Feris, Elias Gagas, Jonny Gustafsson, Sinem Güven, Drexel Hallaway, Anders Henrysson, Susanna Heyman, Ken Hinckley, Hans von Holst, Tobias Höllerer, Edward Ishak, Jacob Jacobson, Ed Kaiser, Maryam Kamvar, Torsten Kjellberg, Lars Kjelldahl, Xiaoguang Li, Christoffer Lindfors, Simon Lok, Lars Mattson, David McGee, Gary Ngai, Axel Nordberg, Mihai Nicolescu, Takashi Okuma, Matthias Pusch, Ismo Rakkolainen, Sajid Sadi, Christian Sandor, Raman Sarin, Jan Stamer, Gert Svensson, Nick Temiyabutr, Matthew Turk, Jan Wikander, Andrew Wilson, Ryuji Yamamoto, Tiantian Zhou, and many others. Lars Winkler Petterson, Otmar Hilliges and Oskar Rönnberg kindly took the time to provide their much appreciated perspectives on drafts of this dissertation.

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I have also had the rewarding experience of supervising numerous ambitious M.Sc. thesis, B.Sc. thesis, and project students, who I thank for their hard work and enthusiasm.

Last but certainly not least, I would like to very much thank my family and friends for supporting my interests and explorations in the sciences. I would like to, in particular and especially, emphasize my gratitude towards my mother Lena, and my grandmother Valentina, for their endless inspiration from my early days.

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My roles in the publications in this dissertation

I am the main contributor to the work in Papers I–IV, VI–VIII, and X–XI.

I initiated the collaboration between KTH and the VITA group at Linköping University, where joint work with the second author led to the results in Paper V.

The work described in Paper IX combined the different authors' expertise and interests in display technology, computer graphics, interaction techniques, and tracking technologies. I am the main contributor to two of the projects described in Paper IX, in which I developed "Consigalo" and "Elastic Surface Deformer". I constructed the custom input device hardware, which included a miniature version of an active infrared LED marker for the tracking system, and two joysticks, which I extended for wireless operation and position tracking. Paper X describes the "Consigalo" system and interaction concepts in more detail.

Papers I and II describe the results from collaborative work on a novel autostereoscopic spatial AR system. I initiated and was responsible for the collaboration with the Department of Production Engineering to develop an AR system based on their display hardware. We collaborated on concept development and project scenarios, as well as on practical issues like hardware configurations and setup. They provided the industrial domain knowledge, expertise in optics and the HOE technology. I developed the system, which integrated with the machine, extracted real-time data, rendered 3D visualizations, and supported interaction. I am the main contributor to Papers I and II, in which Jonny Gustafsson provided the expertise on the display technology, and the co-authors contributed feedback.

The work described in Papers III, IX and X was hosted by University of California, Santa Barbara, while the work in Paper VI was hosted by Microsoft Research in Redmond.

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1 Introduction

1.1 Augmented and Mixed Reality

The goal of Augmented Reality (AR) is to improve and enhance our perception of the surroundings by combining sensing, computing and display technologies.

Most AR research addresses human vision, as it is generally considered to be our most important sense. Visual systems are also the focus in this dissertation, but it is worth noting that other stimuli, such as feedback from auditory, tactile or olfactory displays, may be equally or even more important, depending on the specific scenario and individual.

The characteristics of these systems can be further understood from three classical and widely used criteria for AR systems [Azuma 1997]:

1. "Combines virtual and real"
   AR requires display technology that allows the user to simultaneously see virtual and real information in a combined view. Traditional displays can show only computer-generated images and are thus insufficient for AR.
2. "Registered in 3-D"
   AR relies on an intimate coupling between the virtual and the real that is based on their geometrical relationship. This makes it possible to render the virtual content with the right placement and 3D perspective with respect to the real.
3. "Interactive in real time"
   The AR system must run at interactive frame rates, such that it can superimpose information in real-time and allow user interaction.

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Figure 1. The Sonic Flashlight uses a see-through display to overlay real-time ultrasound images over a patient's body parts. (Images courtesy of George Stetten [Stetten et al. 2001].)

The fundamental idea of AR is to combine, or mix, the view of the real environment with additional, virtual content that is presented through computer graphics. Its convincing effect is achieved by ensuring that the virtual content is aligned and registered with the real objects. As a person moves in an environment and their perspective view of real objects changes, the virtual content should also be presented from the same perspective.

The Reality-Virtuality Continuum [Milgram and Kishino 1994] spans the space between *reality*, where everything is physical, and *virtual reality*, where virtual and synthesized computer graphics replace the physical surroundings. *Mixed reality* is located between them, and includes AR and augmented virtuality.

AR adds *virtual content* to a predominantly *real environment*, whereas augmented virtuality adds *real content* to a predominantly *virtual environment*. Although both AR and augmented virtuality are subsets of mixed reality by definition, most of the research in the area focuses on AR, and this term is therefore often used interchangeably with mixed reality.

AR techniques exploit the spatial relationships between the user, the digital information, and the real environment, to enable intuitive and interactive presentations of data. An AR system can, for example, achieve medical see-through vision, by using a special display in which the images displayed by the computer are seen overlaid on the patient [State et al. 1996, Stetten et al. 2001], as shown in Figure 1 and Figure 2.

Such configurations rely on the proper acquisition and registration of internal medical imagery for the relevant perspective, and careful calibration to establish the



Figure 2. The visualization of a 3D ultrasound scan is registered with a pregnant woman's body, to allow the physician to "look into the body" for a view of the fetus. (Images courtesy of Henry Fuchs and Department of Computer Science, UNC-Chapel Hill [State et al. 1996].)

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geometrical relationship between the display, the viewer, and the patient, to ensure that the correct image is accurately presented.

1.2 Research challenges

The user experience for an AR system is primarily affected by the display type, the system's sensing capabilities, and the means for interaction. The display and sensing techniques determine the effectiveness and realism possible in the blending of the two realities, but may at the same time have ergonomic and social consequences.

The goal of the work described in this dissertation is to enable unobtrusive AR in *walk-up-and-use* scenarios that support spontaneous interaction with minimal user preparation [Encarnacao et al. 2000]. Unencumbering technology is emphasized, avoiding setups that rely on user-worn equipment [Kaiser et al. 2003, Olwal et al. 2003], such as head-worn displays [Cakmakci and Rolland 2006] or motion sensors [Welch and Foxlin 2002]. The system should also, to the greatest extent possible, preserve the qualities of the real space, while augmenting and assisting the user with unmediated view and control. The excessive use of artificial elements, such as visual reference patterns used for tracking, may, for example, have negative side-effects by cluttering or occluding the real environment that the system is meant to augment. Some display technologies may also result in significantly reduced visual quality due to optical properties, or the use of a downsampled view of the real environment.

This work defines an *unobtrusive* AR system to be one that emphasizes unencumbering techniques and avoids changes to the appearance of the physical environment. An unobtrusive AR system must address issues in three areas:

1. Display systems
   The system should merge the real and virtual, while preserving a clear and direct view of the real, physical environment, and avoiding visual modifications to it.
2. Sensing and registration
   The system should present perspective-correct imagery without user-worn equipment or sensors.
3. Interaction techniques
   The system should support direct manipulation, while avoiding encumbering technologies.

1.3 Summary of contributions

This thesis makes contributions in each of the three areas related to unobtrusive AR: display systems, sensing and interaction techniques.

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1.3.1 Spatial display systems for unencumbered AR

The first part of the work (Chapter 3) contributes the design and development of ASTOR and POLAR, two spatial AR display systems that do not rely on user-worn equipment. In contrast to head-worn and handheld displays, *Spatial AR displays* either use large optical elements that are positioned relative to the real environment, or use digital projectors for direct augmentation of real-world surfaces [Bimber and Raskar 2005].

ASTOR and POLAR illustrate the feasibility of AR experiences through see-through displays that are positioned in front of the real environment to be augmented.

ASTOR



The ASTOR (AutoSTereoscopic Optical see-thRough) system is the first autostereoscopic spatial AR system based on a holographic optical element (HOE). It was developed in collaboration with the Department of Production Engineering at KTH.

Paper I and Paper II describe the display system and how it is used to augment the user's view of the operation of an industrial lathe. The display component is integrated with the machine's existing safety glass, and data from the control computer is directly overlaid as 3D visualizations on machine components.

ASTOR demonstrates how the view of a real process can be efficiently combined with computer-monitored information, and shows the directness of presenting this real-time information as overlaid, in-situ, 3D visualizations.

POLAR



Paper III describes the POLAR (Portable, Optical see-through, Low-cost Augmented Reality) system, where portability, low-cost, and commercial off-the-shelf components are emphasized. The work introduces a foldable display system and a hybrid tracking approach that fuses computer vision and infrared distance sensing to enable perspective adjustments based on the user's viewpoint.

POLAR's hybrid tracking technique and modular physical design illustrate how 2D AR workspaces can be created with a minimal set of compact and affordable hardware.

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1.3.2 Unobtrusive sensing of devices and objects

The contributions of the second part of the work (Chapter 4) are two novel sensing techniques that employ an instrumented surface for hidden tracking of active or passive objects. These techniques have no visible sensing technology or markers, and are thus suitable for deployment in scenarios where it is critical to maintain the original visual qualities of the real objects and environments.

LightSense and LUMAR

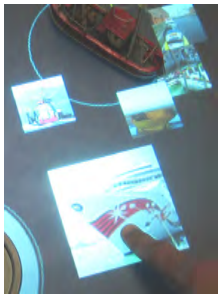


Paper IV presents the LightSense system, which uses two approaches for tracking an unmodified mobile device using light sensors underneath a surface. External tracking of the mobile device's activated camera light allows the device to be moved on the surface, while its display shows dynamic, context-sensitive information about surface items. LightSense enables natural, tangible interaction with unmodified mobile phones, on visually unaltered surfaces.



Paper V describes LUMAR, where the LightSense system is combined with an egocentric marker-based technique, to form a three-layered information space. These layers consist of static printed content, a dynamic 2D space where the device is moved on the surface, and a dynamic 3D space where the device is moved above the surface.

SurfaceFusion



The tracking of physical objects on digital displays often involves custom sensing hardware, visual markers or exotic modifications. In the future, however, many real-world objects can be expected to contain passive electronic tags, based on potentially unobtrusive technology such as Radio Frequency Identification (RFID) [Want 2006, Want et al. 1999]. This work investigates unobtrusive techniques for detecting and tracking such objects.

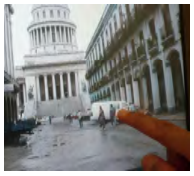
Paper VI presents a hybrid approach in which the fusion of RFID sensing and computer vision enables the identification and tracking of passive, visually unaltered objects on a digital surface. The paper proposes a set of minimal image processing operations that efficiently and robustly classify changes on the surface, and describes a fusion pipeline that synchronizes activities in the radio-frequency domain with activities detected by the camera.

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1.3.3 Interaction techniques for direct manipulation

The third part of the work (Chapter 5) contributes a set of new interaction techniques that were designed to fulfill the previously discussed criteria for unobtrusive AR (Section 1.2). These techniques not only complement the specific display systems and sensing techniques introduced in this work, but most of them are also widely applicable to human-computer interaction in general.

Touch-based interaction



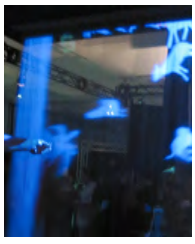
Touch-based interaction is commonly regarded as more direct and intuitive than traditional mouse and keyboard interfaces. User experience for touch-based interaction may, however, greatly vary with the system's sensing capabilities and hardware configuration. Paper VII introduces Rubbing and Tapping, two families of interaction techniques for touch-sensitive surfaces, which use minimal gestures to expand the expressiveness of stylus and finger input. A formal evaluation shows their quantitative and qualitative advantages over existing state-of-the-art techniques for target selection on touch-screen displays.

Interaction with public 3D-displays



Paper VIII provides a qualitative evaluation of techniques that were designed and implemented for novice user interaction with public 3D-displays. The techniques include touch, head tracking, gesture tracking, and control with a mobile device. A qualitative user study indicates an advantage in terms of intuitiveness, ease-of-use and comfort, for both large and handheld touch-screen displays.

Immaterial displays



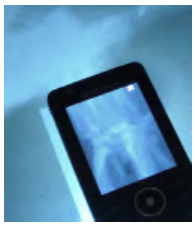
Paper IX and Paper X describe development and interaction explorations on an *immaterial* display that is not constrained by physical surfaces. This new type of display system uses vaporized water to form a projection screen that allows users to walk through and reach through interactive visuals that appear in mid-air.

An existing immaterial display system was extended for dual-sided projection, allowing individual, but synchronized, content to be displayed on each side of the vapor screen. The display system was combined with a 3D tracking system, and custom input devices were built, to enable the exploration of new interaction metaphors. Two applications were developed that exploited the unique capabilities of the vapor display for face-to-face interactions, simulated touch-based interactions, and full 3D interaction. Informal feedback was gathered during a one-

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week demonstration of the system in the Emerging Technologies exhibit at the *ACM SIGGRAPH* Conference in 2005.

Spatially aware handheld displays



Paper XI introduces a framework based on the previous work on spatially aware handheld displays (Paper IV and Paper V) and touch-screen interaction (Paper VII and Paper VIII). It presents a set of techniques that exploit the higher visual and input resolution of a tracked handheld display to improve interaction with a display of larger size, but less dense resolution.

The quantitative and qualitative results from a formal user study show the potential of complementing finger-based interaction on a large touch-screen display with techniques performed on a handheld device.

1.4 Thesis overview

This first chapter presented a brief introduction to AR, the specific challenges in achieving AR without encumbering technology or user-worn equipment, and a summary of the contributions of the thesis. Chapter 2 describes related work in three areas that are fundamental to an unobtrusive AR system: display systems, sensing for perspective-correct imagery, and interaction.

The contributions of the thesis are discussed in Chapters 3–5, which summarize and complement the work in Paper I–Paper XI. Chapter 3 introduces two spatial display systems that augment the environment behind them without encumbering equipment. Chapter 4 presents sensing techniques that can be integrated into an environment to support unobtrusive tracking and detection of devices and objects. Chapter 5 describes four projects that investigate interaction techniques for direct manipulation in unobtrusive AR scenarios.

Conclusions and future work are presented in Chapter 6.

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2 Fundamental technologies

This chapter provides an overview of and describes the related work in three areas that are fundamental to the development of unobtrusive AR technology: display systems, sensing and registration, and interaction techniques.

Display systems merge the view of the real and virtual, while *sensing and registration* makes it possible to render graphics from the right perspective. Direct manipulation and user interface control are enabled through *interaction techniques*.

2.1 Display systems

Combining graphics and the real world

A fundamental characteristic of AR systems is that they allow the user to see a combined view of virtual imagery and real objects.

The display hardware used in these systems can be head-worn (retinal displays, miniature displays, and projectors), handheld (displays and projectors) or spatial (displays or projectors in the environment) [Bimber and Raskar 2005].

The following sections focus on display technology for handheld and spatial AR systems. The first three sections discuss classical AR display technologies in this context, where optical see-through, video see-through and direct projection display systems make it possible to visually merge the real and the virtual. The last section discusses spatially aware handheld displays, which use a tracked display to provide a virtual view of data associated with the real environment. We are particularly interested in the four approaches described in these sections, since they can be used

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in configurations that avoid encumbering technology and visual modifications to the environment.

2.1.1 Optical see-through displays

Optical see-through capabilities are achieved by using an optical combiner, such as a half-silvered mirror or a holographic material.

The role of the combiner is to provide an *optically direct* view of the environment, with a simultaneous presentation of computer-generated imagery. The combiner is typically able to transmit light from the environment, while also reflecting light from a computer display. The combined light reaches the user's eyes. (See Figure 3.)

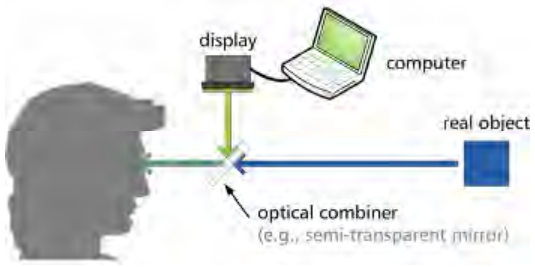


Figure 3. The optical path in an optical see-through display system. The light from the real environment passes through a transparent combiner that simultaneously reflects computer-generated images from a display. The *optically combined* light reaches the user's eyes. (Other optical elements, such as lenses that control the focal distance, are not shown in this illustration.)

Spatial optical see-through systems use situated transparent displays that are integrated with the environment [Bimber and Raskar 2005]. They free the user from worn equipment, but require the display to not only be calibrated with the environment, but also registered with the user to ensure perspective-correct imagery. (See Figure 4.)

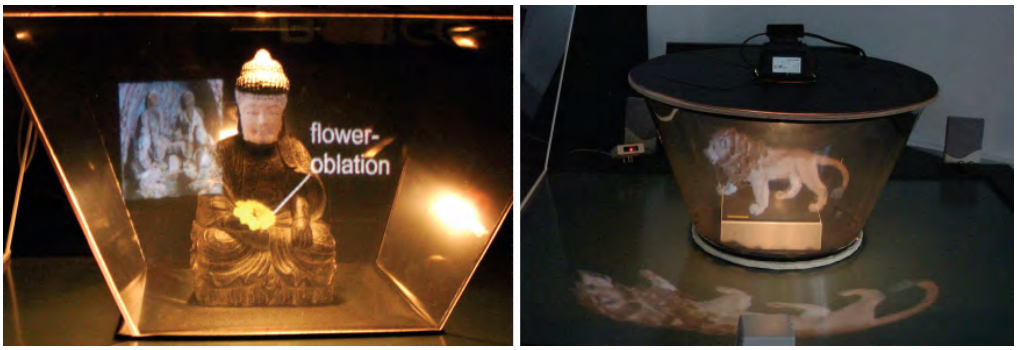


Figure 4. The Virtual Showcase augments physical objects inside showcases with dynamic annotations or related media. The Virtual Showcase is covered with half-silvered mirrors that optically combine the view of the objects with computer graphics reflected from the rear-projected table, on which the showcase is placed. (Images courtesy of Oliver Bimber [Bimber et al. 2003, Bimber et al. 2001].)

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Advantages

+ Direct view of the real physical environment

The main advantage of optical see-through techniques is the directness with which the real environment is viewed. Factors that limit the quality of computer-generated imagery, such as resolution, image quality or system responsiveness, do not affect the view of the real environment. This property may be critical for many applications where a small delay or reduced visibility may not only be distracting, but could even be hazardous [Navab 2003].

Disadvantages

– Reduced brightness

The view of the real environment will suffer a decrease in brightness, depending on the type of optical combiner used.

– Lack of occlusion

The blending of the two light sources means that the computer graphics can become transparent, making it difficult to achieve occlusion effects in many optical see-through systems. Occlusion may however be solved through special hardware that can selectively block the user's view of the physical world [Cakmakci et al. 2004, Kiyokawa et al. 2003, Kurz et al. 2008].

– Need for advanced calibration and/or tracking

Precise calibration and/or tracking are necessary to ensure that the virtual content is correctly registered with the direct view of the real environment.

– Multiple focal planes

The virtual graphics are typically presented in a fixed image plane, unlike the real environment, which has objects at varying distances. The larger the distance between the image plane and a real object, the harder it is to properly accommodate and comfortably perceive a combined view. The user could either shift focus between the two, or choose to have either the virtual imagery or the real objects out of focus. Head-up displays [Wood and Howells 2006], which are often used in aircraft, employ a technique where the virtual image plane is placed at the focal point of the optical system to achieve infinite focus. Recent work has demonstrated the use of liquid lenses to achieve variable focal planes in head-worn displays [Liu et al. 2008].

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2.1.2 Video see-through displays

A popular AR technique is based on a camera that acquires the view of the environment, a computer that adds virtual content, and an ordinary video display that presents the combined view to the user. (See Figure 5.)

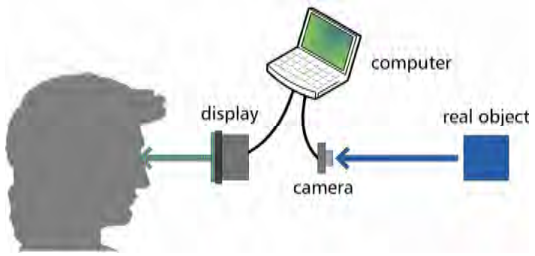


Figure 5. The optical path in a video see-through display system. The view of the real environment is acquired by a camera and is combined with virtual imagery by a computer. The combined video is presented to the user on a computer display. (Other optical elements, such as lenses that control the focal distance, are not shown in this illustration.)

Head-worn displays can use video see-through techniques by placing cameras close to the eye positions. Ideally, two cameras should be used to acquire a stereo view, with one perspective for each eye, but monoscopic single-camera systems are common and easier to design and implement [Takagi et al. 2000].

Some video see-through displays use a camera to capture the scene, but present the combined view on a regular, typically handheld, computer display. A window-like effect, often referred to as a "magic lens," is achieved if the camera is attached on the back of the display, creating the illusion of see-through [Rekimoto 1997, Rekimoto and Nagao 1995], as shown in Figure 6.

It is becoming increasingly popular to directly implement video see-through on mobile devices with built-in cameras, as illustrated in Figure 7. Camera-equipped mobile phones are particularly attractive devices for AR, given their widespread use, connectivity, portable form factor, and rapidly evolving processing and graphics capabilities (e.g., [Henrysson and Ollila 2004, Mohring et al. 2004, Takacs et al. 2008, Wagner et al. 2008a, Wagner et al. 2008b, Wagner and Schmalstieg 2003]).



Figure 6. The NaviCam project illustrates how the camera on a handheld display can be used to recognize features in the environment, such that annotations can be overlaid onto the video feed. (Images courtesy of Jun Rekimoto [Rekimoto 1997, Rekimoto and Nagao 1995].)

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Figure 7. Video see-through AR can be achieved using commercial camera phones. The camera on the back of the device captures video of the real environment, which is used by software on the device to recover the phone's pose relative to tracked features in the environment. This makes it possible to render 3D objects that are registered with the real environment, overlaid on the video that is shown on the phone's display [Henrysson 2007].

Advantages

+ Controlled combination of real and virtual

Rather than optically combining the light from the real and virtual scenes, everything is merged in the computer, since the view of the real world is continuously captured by the camera. This provides greater compositional flexibility, allowing the virtual content to be rendered more realistically with respect to the real environment [Klein and Murray 2008]. The virtual content could, for example, occlude the real environment. The system may also synchronize the real and virtual content, to compensate for delays in the pipeline.

+ Integrated image-acquisition, calibration and tracking

The closed loop of the video see-through system makes it advantageous to use the camera to not only acquire the real scene, but also track features in the environment. Registering the camera's pose relative to the environment greatly simplifies the introduction of perspective-correct virtual imagery in the combined image shown to the user [Kato and Billinghurst 1999]. Image-based techniques may also be exploited to improve registration of the virtual content with the video of the real scene [DiVerdi and Höllerer 2006].

Disadvantages

– Reduced quality and fidelity of the real environment

The major drawback of video see-through systems is their sampling of the real environment at the camera's video resolution, and their dependency on the quality of the image sensor.

The computational load associated with intensive image processing means that most video see-through systems today handle less than 1 megapixel video resolution at interactive frame rates (often 640×480 ≈ 0.3

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megapixels, at 30 frames per second). The quality can of course be improved with better hardware, but this requires additional computational power to avoid reduced performance, and will still result in a significant downsampling of the real environment.

The camera's image sensor not only has less resolution than the human eye, but also differs in sensitivity. This can, for example, affect a video see-through system's performance in low or bright lighting conditions and impact its ability to acquire and present scenes with high dynamic range.

The downsampled, indirect view of the camera plays an important role in the level of immersion and realism a user experiences.

- Potential perspective problems due to camera offset

  Perceptual problems may arise if the cameras are not effectively placed so that their views correspond to those of the user's eyes [State et al. 2005, Takagi et al. 2000].

- Single focal plane

  The combination of real and virtual content into a single image, with a single focal plane, eliminates the focal cues of real-world objects. While stereoscopic systems simulate the disparity between the left and right eye views, accommodation remains inconsistent because everything the user sees is focused at the same distance [Bimber and Raskar 2005]. The typical stereoscopic optical see-through system only suffers from this drawback for virtual content.

- Sensitivity to system delay

  The video see-through imaging pipeline may introduce system delays, which may be unacceptable, or even dangerous, for some applications. In contrast, optical see-through systems always provide a direct view of the real environment.

- Dependency on camera operation

  Video see-through systems rely heavily on the camera's ability to acquire the real scene, and their visual pathway will fail if the cameras, for example, are blocked, overexposed, or lose power.

2.1.3 Direct projection

Augmentation can also be achieved by directly projecting graphics onto the real environment. Figure 8 and Figure 9 show examples of how the real world can be modified through controlled light that alters its appearance [Bandyopadhyay et al. 2001, Pinhanez et al. 2003, Pinhanez and Pingali 2004, Pinhanez and Podlaseck 2005, Pinhanez 2001, Raskar et al. 2004, Raskar et al. 2003, Zaeh and Vogl 2006].

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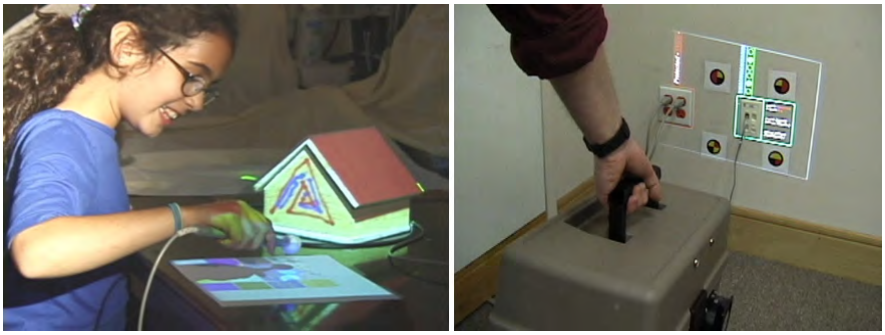


Figure 8. Left: A child uses a tracked brush to apply virtual paint, which is projected onto physical objects. (Image courtesy of Ramesh Raskar [Bandyopadhyay et al. 2001].)

Right: A handheld projector is combined with a camera that identifies elements of interest in the environment and augments them with projected light. In this example, a network socket is augmented with visualizations of network status and traffic. (Image courtesy of Ramesh Raskar [Raskar et al. 2003].)

Advantages

+ Direct integration of the virtual with the real

Direct projection eliminates the need for an optical or video-based combiner, since the light is directly added to the real environment. The integration of real with virtual material takes place on the surfaces of the real environment and their combination is naturally perceived by the user.

Disadvantages

– Dependence on environmental conditions

Direct projection depends on the availability of suitable projection surfaces, and on their geometry and appearance. It also relies on non-conflicting environmental lighting and the absence of objects in the optical path from the projector to the surface, to avoid occlusions and shadows.

– Dependence on projector properties

Parts of a projected image may end up distorted or out of focus if the projection surface is not perpendicular to the direction of projection.



Figure 9. The Everywhere Displays project uses “steerable displays”, where the system’s projector can create augmentations on different surfaces in the environment, while the camera senses the user’s interaction. (Images courtesy of Claudio Pinhanez [Pinhanez et al. 2003, Pinhanez and Pingali 2004, Pinhanez and Podlaseck 2005, Pinhanez 2001].)

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Focusing issues can also occur if the surface is too close or too far away from the projector. In some cases, these issues can be corrected in software [Bimber and Emmerling 2006, Bimber et al. 2005, Grossberg et al. 2004, Raskar et al. 1999a, Raskar et al. 1998, Raskar et al. 1999b, Wetzstein and Bimber 2007] or through the use of special hardware, such as short-throw or laser projectors [Zaeh and Vogl 2006].

2.1.4 Spatially aware handheld displays

An alternative approach to the combination of computer graphics and the real environment is to use a tracked handheld display without optical or video see-through capabilities. This approach can provide useful context-sensitive information by leveraging proximity and relative position to real objects, despite not matching Azuma's criteria for AR systems (see Section 1.1), due to the lack of a see-through display, and less strict requirements for the registration between real and virtual.

Fitzmaurice presented an early prototype of how a tracked display could be moved over a physical paper map, causing dynamically updated information to be presented about the different map areas [Fitzmaurice 1993], as shown in Figure 10.

Advantages

+ **Simplified tracking and calibration**

  Less accuracy is generally needed, since the real and virtual are not visually registered with each other. The tracking resolution is, of course, dependent on the requirements of the application and how densely the real objects are positioned.

+ **Tangible interaction on the surface**

  Tracked displays may compensate for their lack of see-through by supporting placement and manipulation directly on surfaces [Fitzmaurice

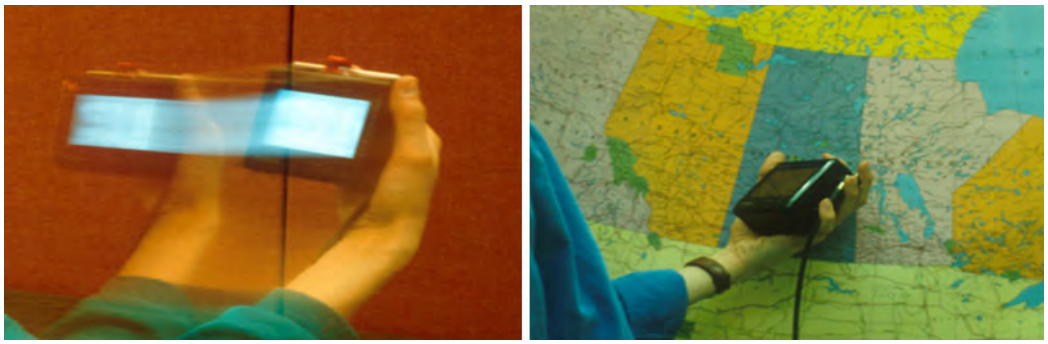


Figure 10. The Chameleon system illustrates how dynamically updated graphics in a tracked display can provide context-sensitive information about real objects underneath. (Images courtesy of George Fitzmaurice [Fitzmaurice 1993].)

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et al. 1995, Ishii and Ullmer 1997] where optical or video see-through capabilities may not always be useful. This applies especially to video-see through systems, since the camera would be either blocked or out-of-focus, when it is placed on, or very close to, the surface.

Disadvantages

- **Less realism**

  The absent visual combination of real and virtual affects the level of realism and can weaken the link between the real objects and their associated digital content.

- **Display occludes the real objects**

  As the display is moved in the environment, since it is not see-through, it may occlude real elements of interest.

2.2 Sensing and registration

Perspective-correct imagery

The geometrical relationship between the user's viewpoint, the display, and the environment needs to be known for accurate and properly aligned combinations of the real and virtual.

There are many different technologies that can be used to recover the position and/or orientation of users, displays and objects in AR systems. Common techniques use ultrasonic, electromagnetic, optical, or mechanical sensing, and can be deployed in an environment to sense and recover the properties of beacons, fiducials, markers and other features, or serve as an infrastructural frame of reference for sensors in the space. *Exocentric* approaches rely on technology in the environment, while *egocentric* approaches are self-contained and independently perform the necessary sensing and computation [Welch and Foxlin 2002].

All approaches to AR typically share a need for the display to be registered with the environment. A static display, such as the Virtual Showcase [Bimber et al. 2003, Bimber et al. 2001], may require only initial calibration. In contrast, a movable display, such as NaviCam [Rekimoto 1997, Rekimoto and Nagao 1995], needs continuous tracking to recover its relative pose to the environment.

Camera-based techniques, as used in NaviCam, have become increasingly popular due to their cost-effectiveness and availability in commercial products (such as portable computers and mobile phones), where they can serve a dual purpose as both egocentric tracking device and video see-through combiner. Their use in AR was further facilitated through the development of ARToolKit [Kato and

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Figure 11. Natural feature tracking techniques make video see-through AR possible without the need for fiducial markers in the environment. Here, a mobile device tracks features on a printed page and overlays registered 3D graphics at interactive frame rates. (Images courtesy of Daniel Wagner and Graz University of Technology [Wagner et al. 2008b].)

Billinghurst 1999], an open source framework for video see-through AR [ARToolKit 2009]. ARToolKit uses camera-based tracking to recover the position and orientation of the camera relative to special fiducial markers in the environment, such that perspective renderings of 3D graphics can be registered with the environment and overlaid on the live video stream. The visual patterns greatly simplify the tracking and reduce the required computational power. Their obtrusiveness can however be avoided thanks to rapid advances in techniques such as SLAM (simultaneous location and mapping) and natural feature tracking [Klein and Murray 2007, Neumann and You 1999, Reitmayr et al. 2007, Takacs et al. 2008, Wagner et al. 2008b]. (See Figure 11.)

The recovery of the user's pose relative to the display may also be necessary for situations where the viewpoint is not fixed. This is primarily an issue for spatial optical see-through displays, where the relationship between the user, the rendered content on the display, and the real environment behind the display change, as the user moves.

The need for user tracking is, however, dependent on many factors, such as how and where the virtual imagery is created and the display's placement relative to the user.

Head-worn displays [Cakmakci and Rolland 2006], for example, are typically assumed to be rigidly positioned relative to the user's eyes, such that the user's viewpoint can be directly derived from the tracked position of the display. Video see-through systems present the combined view in the plane of the video display, updating it only when the relative positions of the camera and the environment change. The same view of the real environment is thus shown on the screen if the user moves, while the camera and display remain stationary. Dedicated user tracking is also not necessary for systems that eliminate dependencies on the user's perspective through direct augmentation of the real environment's surfaces with projected 2D graphics [Bandyopadhyay et al. 2001, Pinhanez et al. 2003, Pinhanez 2001, Raskar et al. 2004, Raskar et al. 2003, Zaeh and Vogl 2006]. The same principle applies to optical see-through displays that are used on the surfaces of real objects to present 2D overlays [Stetten et al. 2001].

Perspective-correct imagery may also be provided without user tracking, through the use of a *multi-view* display system (e.g., [Jones et al. 2007]). Such systems

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render multiple views, where the principle of parallax can limit their respective visibility to certain perspectives. The user will thus only see the appropriate view, when viewing the display from the right position and/or direction, which implicitly avoids the need for tracking. This approach may however result in an increased computational load for the simultaneous generation of multiple views, while also limiting the user to a discrete number of fixed viewpoints [Halle 1997].

Interactive tabletops and surfaces are closely related to AR technologies in their augmentation of the user's interaction with physical objects. Object sensing has been explored using a wide variety of exocentric techniques, where the main challenges lie in the detection, identification and tracking of unique artifacts. Most projects rely on either electronic tags or visual markers for remote identification and tracking [Patten et al. 2001, Reilly et al. 2006, Rekimoto and Saitoh 1999, Rekimoto et al. 2001, Want et al. 1999, Wellner 1993, Wilson 2005].

2.3 Interaction techniques

Direct and unencumbered manipulation

An AR system's interactive capabilities often play a significant role in complementing the display capabilities that help to augment real-world tasks. While the literature has many compelling examples of techniques for exploring interaction in AR scenarios, many of these have unintentional side effects that influence the user's *interaction with the real world*. Problems may be related to ergonomic factors, such as head-worn displays that limit visibility and peripheral vision, systems tethered with cables that constrain movement, or other wearable devices that cover parts of the user's body. Social aspects may also be important, as user-worn technology can be inappropriate in many real-world scenarios.

It may therefore be advantageous to emphasize interactive technologies that avoid such potential conflicts and minimize the negative effects an AR system may have on the user's normal interaction with the real world.

A number of different technologies that can enable interaction, while avoiding encumbering and user-worn equipment, are described in the following sections.

2.3.1 Touch

The direct-manipulative property of touch-sensitive surfaces is often viewed as natural, intuitive and easy to use. Finger- or stylus-based pointing, dragging, tapping and gesturing can be directly applied to graphical objects of interest, without the need for special-purpose devices that users may need to operate in other forms of human-computer interaction [Han 2005, Matsushita and Rekimoto 1997, Paradiso et al. 2000, Rekimoto et al. 1998, Selker 2008]. (See Figure 12.)

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Figure 12. An acoustic tap tracker allows touch-screen interaction in public spaces by sensing the position of knocking actions on glass surfaces. (Images courtesy of Joseph Paradiso [Paradiso 2003, Paradiso et al. 2000].)

Numerous characteristics of the surface can affect the user's experience and performance in finger-based interaction. Improper calibration, parallax between the touch-sensitive layer and display element, low display resolution, low sensing resolution, and occlusion by the user's finger can prohibit accurate and precise interaction. Solid surfaces also typically lack the tactile feedback provided through texture, actuation, physical properties and mechanics of special-purpose input controls. This can be considered to be one of the most serious issues in interaction on touch devices, since technology that provides varying levels of passive or active tactile feedback (e.g., [Harrison and Hudson 2009, Poupyrev and Maruyama 2003, Poupyrev et al. 2002]) is still rare.

2.3.2 Gesture and pose

It may be beneficial to *remotely* sense the user's motion as a complement or alternative to direct touch [Wilson 2004], for example, if a system's particular hardware configuration is incompatible with touch-enabling technology. Public installations can depend on issues such as material characteristics of the window glass, or the requirement for robust technology that is protected from users. Touch-based interfaces may also be inappropriate, or even prohibitive, for certain user scenarios. These could include laboratory work or medical procedures, where the user's hands are occupied or wearing gloves, or the task requires aseptic operation.

The controlled, or semi-controlled, measurement of light is a popular remote sensing approach for interactive applications. The methods vary, for example, based on the type of hardware used, the type of light that is sensed, and whether the scene is actively illuminated by the system.

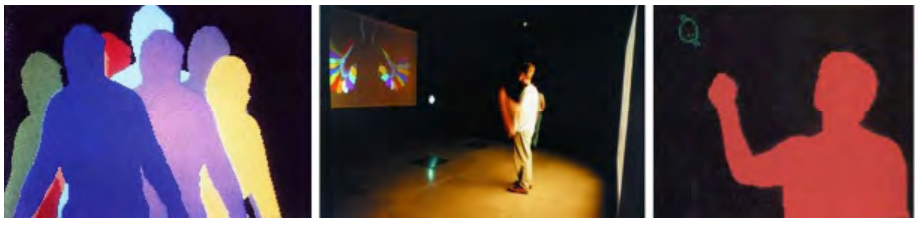


Figure 13. VIDEOPLACE was among the first systems to successfully demonstrate telepresence, gestural control, interactive computer graphics and other important concepts. (Images courtesy of Myron Krueger [Krueger 1977, Krueger et al. 1985].)

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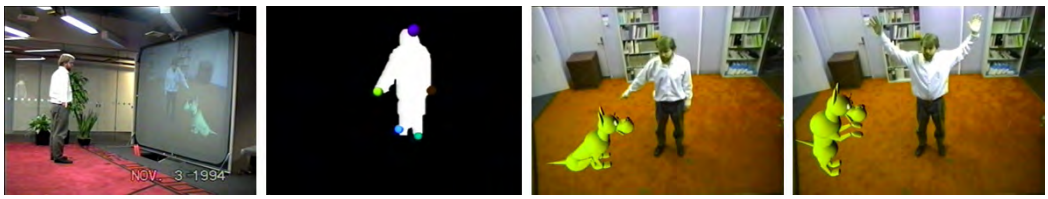


Figure 14. The ALIVE system tracks a user's body parts and supports full body interaction with virtual creatures. (Images courtesy of Alex Pentland, Bruce Blumberg and Trevor Darrell [Maes et al. 1995].)

Basic scene changes may, for example, be detected with an ordinary camera that captures visible light. Such remote sensing approaches can be used for tracking body parts, such as the head or hands, where the resulting detection of postures and gestures may be mapped to explicit interface control [Krueger 1977, Krueger et al. 1985, Maes et al. 1995], as shown in Figure 13 and Figure 14.

An eye tracker, on the other hand, can recover the 3D positions of the user's eyes by illuminating the scene with multiple infrared light sources and capturing the reflecting light from the pupils on an image sensor that senses only infrared light [Tobii 2009]. TouchLight [Wilson 2004], shown in Figure 15, uses two infrared cameras and stereo computer vision to detect the position of the user's hands near the surface of a transparent display.

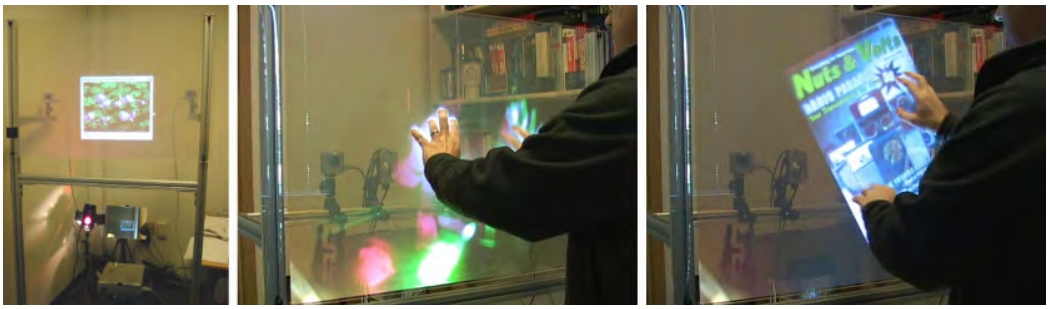


Figure 15. TouchLight uses computer vision to track the user's gestures in front of a transparent display. (Images courtesy of Andrew Wilson [Wilson 2004].)

Gesture-based interfaces are often regarded as natural, intuitive, futuristic or "magical", but there are numerous issues that can complicate their usability. The lack of physical support may, for instance, cause fatigue due to lengthy interactions, unnatural poses, or the recognizer's need for exaggerated motion. The potential difficulty of detecting the start and end of an action is another problem that is often referred to as the "Midas touch problem" in eye tracking [Jacob 1991], which can complicate the distinction between movement and actuation in the user interface.

It is worth noting that sensing a user's movement, gaze or other actions can also be used *implicitly* to increase the level of immersion, through subtle changes or responses in the user interface.

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2.3.3 Handheld devices

There is a distinction between handheld devices, which can be seen as analogous to tools, and user-worn devices, which often serve as accessories that extend our capabilities. How much a device encumbers the user depends, of course, on the specific activity and the device's properties. A wristwatch, for example, may not be disturbing in an office environment, but may be uncomfortable to wear at night and, in contrast to a pocket watch, requires some time and effort for removal. A diving watch is similarly a useful tool underwater, in contrast to the potential problems that could be caused by the use of an ordinary watch.

A handheld device has many benefits that leverage our inherent capabilities to manipulate physical objects with our hands [Fitzmaurice et al. 1995, Ishii and Ullmer 1997, Yee 2003]. Changing grips for better comfort is a natural instinct, and it is often easy to, for example, put down a device, or switch to the other hand, if required. The device's onboard controls can also support a different set of input and output functionality than what is possible with touch or gesture alone. Physical buttons, scroll wheels, joysticks, trackballs, touch-screens, accelerometers, microphones and hardware for vibro-tactile feedback are examples of standard technology in many of today's handheld devices. On-board components may also assist in sensing user activity, as in the case of using accelerometer data for motion sensing [Rekimoto 1996, Wang et al. 2006].

Other benefits are found in multi-user environments, where the devices provide an implicit indication of which persons are in control at the moment. The act of passing a physical device to another person is also a strong metaphor for delegation of control.

The physical properties of handheld devices can, on the other hand, become a problem, as the hardware may not only be costly but also introduces potential issues of damage, wear, loss and theft. Requirements for regular service, such as battery charging, software updates or repair, could have an impact on practical use. Some scenarios might additionally not benefit from limiting the number of simultaneous users by availability and support for specific hardware devices.

Handheld devices can include everything from classical remote controls to advanced mobile devices, with simple behavior that transmits button presses, to complex input/output functionality and spatial awareness.

2.3.4 Speech input

Speech interfaces typically employ a command-based interaction style, where the user executes actions through verbal commands. Interactivity can however also be achieved through analysis of non-verbal features, for example, to provide continuous parameter control [Harada et al. 2006, Igarashi and Hughes 2001, Olwal and Feiner 2005, Patel and Abowd 2007]. Delays in audio processing and the

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inherently limited bandwidth of speech are factors that need to be taken into account for each scenario, as they can affect the system's perceived performance, responsiveness and interactivity.

The issue of ambient noise and conflicting audio is a major challenge in speech interfaces, where the system's ability to focus on the relevant sound source often determines its success in accurately interpreting the user. This has led to various hardware strategies that spatially narrow the system's capture of audio, ranging from array microphones that remotely sense direction, to user-worn microphones that clip onto clothing for advantages of proximity, to body-attached microphones that exploit bone conduction to isolate the user's voice from the surroundings [Basu et al. 2000, Xu et al. 2004].

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3 Spatial display systems for unencumbered AR

The display system is responsible for providing a combined view of the real and virtual, and thus is an essential component in AR technology. The many possible design choices depend on the system's desired characteristics and potential limitations, as discussed in Section 2.1. Scenarios may, for example, vary in how they prioritize properties, such as display configuration, optical qualities, visual resolution, user experience, immersion and ease-of-use.

This chapter describes ASTOR and POLAR, two spatial optical see-through display systems developed for unencumbered optically direct views of the real world with superimposed computer graphics.

3.1 ASTOR

An autostereoscopic optical see-through 3D display system

The goal of the ASTOR project was to enable unobtrusive user experience enhancements by implementing an optical see-through system for AR, in which 3D graphics and a view of the real world could be seen simultaneously, without requiring user-worn equipment [Paper I, Paper II].

Multi-view displays are a class of autostereoscopic displays, where parallax can be used to control which images are seen from a certain viewpoint [Halle 1997]. *Autostereoscopy* is achieved by presenting the user's left and right eyes with individual images of the 3D content from the corresponding two perspectives. Those two images form a stereo pair that is fused by the brain into a perceived 3D image, resulting in the illusion of depth.

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Commercial multi-view displays typically employ optics in front of the display to limit the visibility of certain pixels to specific directions, such that different images are presented to each eye, from the same display surface. Such techniques, which, for example, can be based on a parallax barrier or lenticular sheet [Halle 1997], rely on content that is rendered in a specific format where multiple perspectives are combined into a single image and the resulting resolution often decreases with the number of unique perspectives. They are not directly appropriate for optical see-through AR, as their optics would distort the view of the real world behind the display. A half-silvered mirror could however combine the reflection of such multi-view displays with the view of the real world.

ASTOR instead employs a holographic optical element (HOE) that overcomes many of the previously discussed limitations. The optical properties of an HOE, which allow great flexibility in how light is diffused and reflected, are specified during the holographic manufacturing process. The HOE was developed by colleagues in the Department of Production Engineering, based on the group's previous work on an "Interaction Table" for tabletop Virtual Reality [Gustafsson and Lindfors 2004, Gustafsson et al. 2005].

The HOE used in ASTOR was manufactured to reflect light from multiple projectors, such that individual real images of thin vertical slices are formed, floating in front of the HOE plate. The image from each projector can only be seen from within the corresponding vertical slice, and the system limits the visibility of each of these views to a single eye at a time by using a slice width of 50 mm (which is less than the average interpupillary distance for an adult [Dodgson 2004]). Two horizontally aligned projectors can thus create two separate off-axis projections for autostereoscopy, where each eye sees a uniquely rendered image from the corresponding perspective, as shown in Figure 16.

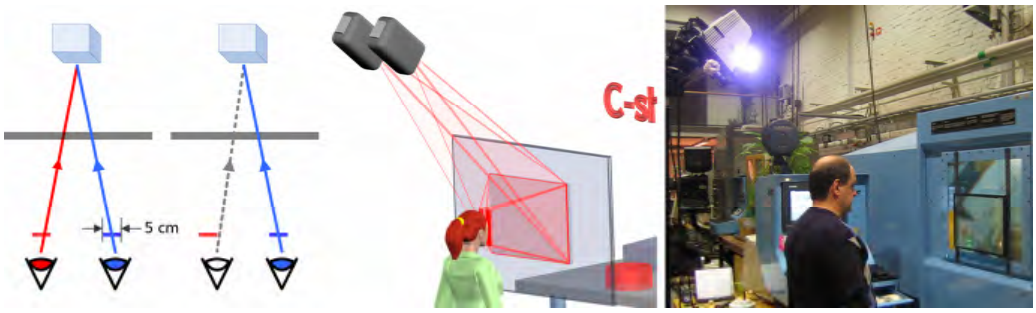


Figure 16. Stereo view: The user sees two individual images when looking through the 50 mm wide vertical slices. Images from the right and left projector are seen through the left and right slices, respectively (colored red and blue for clarity).

Left eye outside: The user has to look from the right direction and through the slice to see an image. Here, the left eye is outside the viewport and thus does not see an image.

Light paths: The light travels from each of the two projectors, reflects off the HOE and reaches the eyes, which are looking through the slices.

Use with industrial machine: The user views the augmented workspace through the HOE, which is installed in the center of the industrial lathe's safety glass.

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Figure 17. The HOE used in ASTOR combines bright computer graphics with high transparency. The HOE's properties allow it to very efficiently direct most of the light from the projectors to the user's eyes. The direct view of the real environment is slightly brighter than the view through the HOE, as indicated by the attached checkerboard pattern. The images were shot through one of the viewing slices under varying lighting conditions.

The setup can be extended with additional projectors, to expand the viewing volume for a single viewer through more stereo perspectives, and to support multiple simultaneous users.

One of the main advantages of using an HOE, compared to a half-silvered mirror, for example, is its superior brightness and contrast [Gustafsson et al. 2005]. It is able to effectively direct a large fraction of the projected light to the user's eyes, which yields high-quality imagery even under significant ambient illumination that would disturb many other displays. The quality of the reflected light is less dependent of the transmitted light, which makes it possible to display bright computer graphics while simultaneously maintaining a highly transparent see-through view of a real environment [Gustafsson et al. 2005]. (See Figure 17.)

The versatility of holographic techniques allowed the HOE used in ASTOR to be manufactured for optimal viewing configurations. In contrast to half-silvered mirrors, an HOE does not require that the light's angle of incidence be equal to the angle of reflection. ASTOR can thus use a custom HOE, where light projected from a 35° angle above the surface normal is reflected out of the display along the normal. This avoids potentially disturbing reflections from the projectors, while allowing the user to comfortably look straight into the real environment behind the display. (See Figure 18.)

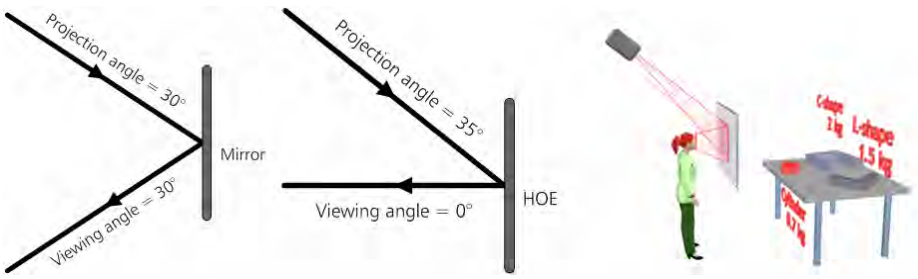


Figure 18. Left: A mirror's angle of incidence and angle of reflection are the same.

Center: The optical properties of an HOE are specified when it is manufactured, allowing flexible configurations that can be adapted to the specific requirements of a scenario.

Right: The HOE used in ASTOR was manufactured for an optimal projection and viewing configuration, where the projectors are placed in a convenient position and the user looks straight through the display.

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Figure 19. Left: The operator of an industrial machine has to simultaneously focus on both the important real-time sensor measurement provided from a control computer, and the view of the workspace.

Right: ASTOR integrates the real-time sensor data as intuitive and natural 3D visualizations, which are overlaid on the corresponding parts of the machine.

The currently monochromatic HOE can also be extended to full color, which would be especially relevant for rendering realistic virtual objects [Gustafsson et al. 2005]. It is worth noting however, that simple monochromatic 3D overlays, which are optically merged with the direct view of the real world, may be perfectly sufficient for augmentations and enhancements in many application scenarios.

The system was applied to an industrial machine, where the operator typically has to focus simultaneously on both the workspace and a computer monitor that shows important real-time measurements from a cutting process. Figure 19 and Figure 20 illustrate how ASTOR can be used to instead integrate the presentation of these measurements with the workspace through real-time in-situ visualizations.

The ASTOR system was developed to receive continuous updates from the industrial machine of important data, such as tool position, RPM, temperature, and cutting



Figure 20. Left: The projectors behind the operator illuminate the HOE with autostereoscopic 3D imagery, which is optically combined with the view of the machine, as seen through the safety glass.

Right: The ASTOR system receives real-time measurements from the industrial machine which are presented as stereoscopic 3D graphics, optically merged with the workspace. The image shows how the cutting forces are rendered as 3D vectors at the tip of the tool (the three components and the resultant of the force).

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forces at the tip of the tool. Figure 20 shows how ASTOR renders the force data as 3D vectors, which are overlaid in 3D at the current tool position to provide the operator with a direct and intuitive representation of the machine's state.

Key features and insights

- ### Direct view of the real workspace

  ASTOR's optical see-through display system preserves a direct view of the real workspace, which can be critical for many real-world tasks, including the industrial scenario presented here.

- ### High brightness and high transparency

  The HOE is more effective than half-silvered mirrors in showing bright computer graphics, while maintaining a clear view of the environment behind the display.

- ### Autostereoscopic 3D

  The system overlays 3D visualizations on the relevant machine parts, such that the user, for example, can follow the tool position in 3D, even if the real tool is cutting inside or behind the workpiece. Autostereoscopy makes it possible to see the 3D visualization at the correct depth, without the need for eyewear.

- ### Multi-view

  The use of additional projectors would increase the number of possible views, which could both provide individual visualizations for multiple people, and more stereo pairs. The view-dependent perspectives and the lack of user-worn equipment make it easy to step to the side for an unaugmented view of the workspace.

- ### Resolution not dependent on the number of perspectives

  Many autostereoscopic systems encode all views in a single image and thus trade display resolution for additional perspectives [Halle 1997]. In contrast, the HOE in ASTOR provides full resolution for each perspective.

- ### Optimal display configuration

  The possibility of specifying projection and viewing angles at the time of manufacture for the HOE allows comfortable viewing directions, avoids reflection from the projectors, and greatly simplifies alignment and integration with existing surfaces. In contrast, half-silvered mirrors require that the angle of incidence is equal to the angle of reflection, which limits the possibilities of alignment between the user, the mirror, and the display element. A half-silvered mirror must always be mounted at an angle with respect to the user to

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support see-through, and would thus integrate poorly with the industrial machine in the discussed setup.

- Tested in an industrial environment

  The ASTOR system was successfully integrated with a fully operational lathe in an industrial environment, which further demonstrates its flexible software and hardware combination that can complement existing work processes without the need to alter them. Only an initial one-time calibration is needed after installation of the rigid setup. Paper I and Paper II discuss numerous additional features that could provide deeper integration with the machine to further amplify the user's understanding of its operation.

Issues

- Limited number of fixed views

  Using the fixed views for an extended period of time could result in fatigue, due to the requirement for the user to stand in a specified position. The slices in ASTOR's HOE are, however, intentionally made sufficiently wide to support a bit of motion and movement, and no negative feedback has been communicated from the different people who have tried the system so far. It would be valuable to formally investigate the ergonomic aspects of the system in future work.

- Scalability

  Multiple perspectives must be simultaneously generated and rendered in parallel, which affects the system's scalability due to limitations in display hardware and computational power. Emerging display technologies and new generations of powerful graphics processors are examples of technologies that may help address this.

- Monochromatic

  The current version of ASTOR provides monochromatic imagery only, but the underlying HOE technology can be extended to full color.

- Horizontal-parallax-only

  The HOE limits the view of each perspective in the horizontal direction. If the user moves inwards or outwards (while viewing the HOE through the slices) the same images will be seen, which can result in misregistration of the virtual content with the real world behind the display. Remote tracking of the user's head or eyes is a well-known approach to address such issues. Paper VIII demonstrates how a 3D camera and remote eye tracker can provide interaction in this type of display system. It would also be straightforward to use them for the tracking of the user's viewpoint to support continuous adjustments of the

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rendered perspectives. Such technologies do, however, typically limit the number of simultaneous users.

- Different focus for real and virtual

  The projected images are focused on the HOE's surface, and the further away the system places the stereoscopically rendered 3D graphics, the more problematic the mismatch between vergence and accommodation will become. This affects how far away real-world objects can be placed, if co-located augmentations are desired [Bimber and Raskar 2005, Schmandt 1983]. Future work includes the investigation of optical techniques that can address this limitation.

- Custom manufacturing process

  The HOE is currently commercially unavailable, and the complicated manufacturing process requires access to special material, a holographic laboratory, and optical expertise.

- Stationary

  The rigid setup with a number of carefully aligned hardware components makes the system suitable primarily for stationary installations.

3.2 POLAR

A portable, low-cost, optical see-through 2D display system

The POLAR system emphasizes low-cost and portability, and is based on a foldable 2D display system [Paper III]. It uses a half-silvered mirror as the optical combiner to merge the virtual computer graphics with the real environment. The half-silvered mirror in this classical optical see-through configuration reflects images that are generated on a computer display, while it also allows light to pass through, for a simultaneous view of the real environment [Schmandt 1983], as shown in Figure 21.

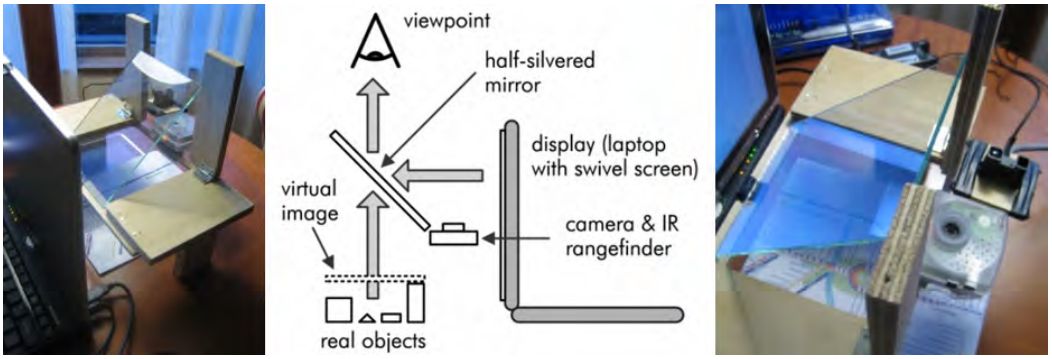


Figure 21. The POLAR system is a compact, portable and low-cost system for spatial AR. It provides overlays in a small workspace underneath the half-silvered mirror.

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Figure 22. Example augmentations (highlighted here with white outline for clarity).
Left: POLAR is used to label components on equipment placed in the workspace.
Right: POLAR provides dynamic augmentations of a paper map, with colored highlights of areas of interest to the user.

The user looks down through the half-silvered mirror, which is mounted at a 45° angle with respect to a vertically placed digital display. The reflected content from the display will appear as a virtual image in a 2D plane below the mirror, superimposed on the view of the real objects, as shown in Figure 22. The height and location of the virtual image plane can be adjusted by varying the distance between the display and the mirror.

This display configuration is sufficient for AR if the virtual image plane is co-located with the real objects, for example, as in the case of the Sonic Flashlight [Stetten et al. 2001].

It is, however, necessary to track the user to enable general scenarios, where the virtual image plane might be placed at a distance from real-world objects. That makes it possible to continuously adapt the rendering of the overlaid graphics to the user's viewpoint if the virtual image plane is located above or below real-world objects. This might, for example, be useful in the case of multiple objects at different heights.

POLAR avoids user-worn equipment and exotic hardware through a hybrid technique that recovers the 3D position of the user's eyes. The system uses an infrared rangefinder to establish the distance to the user's face, which is derived from a non-linear mapping of the sensor's voltages to distance values. POLAR simultaneously tracks the 2D position of the user's eyes in video captured by a standard PC camera, using a software-based eye tracker. The 3D position can then be recovered through trigonometry by combining the distance, the 2D position in the video image, and the known field-of-view of the camera, as shown in Figure 23.

The POLAR system is thus able to provide the user with a perspective-correct overlay, where 2D graphics are superimposed on real objects in the workspace seen through the half-silvered mirror.

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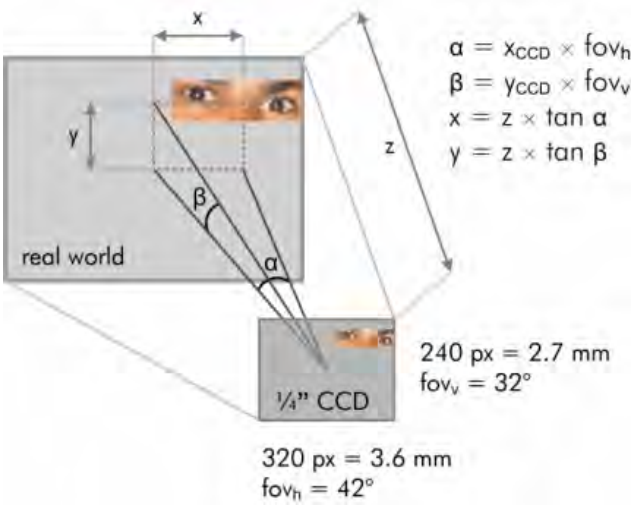


Figure 23. POLAR uses a hybrid tracking technique based on a digital camera and IR distance sensor. The position of the user's eye in the camera image, which are recovered using eye tracking software, are combined with the user's distance (z) to the camera, to establish the 3D position (x, y, z) of the user's eyes in the real world.

Key features and insights

- ### Direct view of the real workspace

  As in ASTOR, a direct optical view of the real workspace is provided, which is a desirable characteristic for many application scenarios.

- ### Color

  Color is supported through the use of an ordinary digital display and a half-silvered mirror, in contrast to the monochromatic graphics on ASTOR's HOE.

- ### Continuous views based on the user's 3D position

  The hybrid technique tracks the user's position unobtrusively, to support perspective-correct overlays during movement, without user-worn sensors.

- ### Adjustable focus plane

  In contrast to ASTOR, where the user focuses on the display surface, POLAR has an adjustable virtual image plane. Like all configurations based on half-silvered mirrors, the location of the reflected virtual image is determined by the distance to the display. It makes it possible to adjust the plane, such that it is as close as possible to the objects of interest, to minimize the conflict between vergence and accommodation [Bimber and Raskar 2005, Schmandt 1983].

- ### Portable

  The compact and foldable physical design, which is easy to assemble and disassemble, simplifies transportation and mobility.

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- Commercially available low-cost hardware

  POLAR emphasizes the advantage in cost and availability of its components, as that expands possible applications and scenarios.

Issues

- 2D overlays

  The system can only show 2D imagery, but could be extended to reflect imagery from autostereoscopic displays. These are, however, rare in portable configurations.

- Reduced brightness and contrast

  Half-silvered mirrors have an inevitable trade-off in the ratio of transmitted and reflected light, and are also sensitive to ambient light.

- Need for tracking

  Ordinary displays can not present different perspectives based on the user's viewpoint, without the use of tracking or additional optics.

- Single-user and limited range

  The system's tracking technique supports only one person at a time, and is constrained by the tracking range of the distance sensor, and the field of view of the camera.

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4 Unobtrusive sensing of devices and objects

The ability to sense physical objects is very useful in AR environments, as it allows the systems to extend beyond solely virtual imagery, to include interaction with physical devices and real-world artifacts. Passive and active objects can be sensed through a wide variety of techniques [Welch and Foxlin 2002].

LightSense and SurfaceFusion are two new exocentric sensing techniques that are introduced in this work's spirit of unobtrusive systems. They share an emphasis on preserving the appearance of the real environment and avoiding visual modification of the objects to be sensed, which makes them suitable for ubiquitous deployments. LUMAR combines LightSense with an egocentric 3D tracking technique for the exploration of hybrid interaction modes that include handheld video see-through AR.

4.1 LightSense

Exocentric sensing of spatially aware handheld displays

In LightSense, a surface with embedded sensing capabilities enables unobtrusive, exocentric tracking of a mobile device. The mobile device can then act as a spatially aware handheld display that provides information about areas underneath [Paper IV]. In contrast to egocentric approaches, all computation and sensing is offloaded to the environment, leaving only the need to communicate the sensed position to the device.

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Figure 24. Left and center: The setup in the PC based version of LightSense. A PC tracks the position and distance of the mobile device's camera light to the surface using an attached camera. The device's position is communicated wirelessly to the device, which allows it to display context-sensitive information about the areas on the surface.

Right: As the mobile device is moved over a route map for the Stockholm subway, it is able to show geographical maps over the area for each subway stop. The user can control the zoom level by moving the device closer to or further away from the surface.

The built-in LEDs that are becoming increasingly common in modern camera phones are used as active markers in LightSense, which makes it possible to track the device without any modifications to it.

Embedded sensors are used to detect the activated LED (camera light or focus light) on the mobile phone. The light sensors in the surface are connected to a processing unit that continuously informs the device of its position through a wireless connection.

4.1.1 Sensing with a PC

Figure 24 shows how a flexible tracking solution is achieved using a PC that establishes the position and size of the light spot as seen from a camera underneath the surface. The data is then streamed wirelessly to the mobile device, for example, over Bluetooth or Wireless LAN. A chain of linked image processing filters isolates the light spot in the camera image. The center of the spot is used for the position, while the distance to the surface is estimated by the size of the spot. (See Figure 25.)



Figure 25. The camera's view of the mobile device's LED light from underneath the surface. The three images show the size of the light spot at different distances to the surface. From left to right: 0 cm, ~10 cm, and ~20 cm.

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4.1.2 Sensing with a microcontroller

A compact, low-cost alternative to camera tracking on a PC is the use of embedded photo sensors that are attached to a microcontroller equipped with a wireless radio. The mobile device's light can, for example, be sensed by light-dependent resistors, where the microcontroller measures and detects their changed resistance on incident light, and wirelessly communicates the information to the mobile device over Bluetooth. (See Figure 26.)

The hardware enables a flat form factor, but with lower sensing resolution than a digital camera's image sensor and without estimation of distance. The setup is thus more appropriate for detecting the mobile device over a discrete number of points, and is also limited in its ability to sense distance. The RFIG lamps project explored a similar approach for projection-based AR [Raskar et al. 2004].



Figure 26. Left: A microcontroller with attached LDR sensors can sense the mobile device's light in discrete positions.

Right: A thin form factor makes a lightweight design possible. A wall-mounted version of LightSense allows the mobile device to provide dynamically updated information about the different boroughs in Stockholm.

Key features and insights

- **Preserves visual qualities**

  The system complements 2D graphics on a static map with a tracking technique that avoids visual alteration, fiducial markers and artifacts on the surface.

- **Tracking on, and near, the surface**

  The tracking technique works well on the actual surface, in contrast to typical egocentric camera-based approaches. This may have advantages in collaborative scenarios, where the supporting surface enables tangible interaction for multiple users. The possibility for moving the device on the surface may also avoid the fatigue that can result from lengthy interactions with devices held in mid-air, which could be a potential issue in handheld video see-through applications.

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- Offloads computation to the environment

  The tracking technique enables spatial awareness on any modern mobile device that supports wireless communication with the tracking system. It is independent of the device's on-board computing power and performance, as all the computation and processing is offloaded to the environment. It can thus co-exist with resource-intensive third-party applications or run in parallel with other tracking techniques, as demonstrated in the LUMAR project. (See Section 4.2.)

- Robustness and protection of the technology

  The surface physically protects the equipment from damage, and at the same time provides robust tracking in controlled conditions, by minimizing the influence of ambient light.

- Unmodified devices

  The system tracks commercially available, unmodified mobile devices with built-in LED lights.

Issues

- Infrastructure and LED tracking

  LightSense depends on active technology in the environment. The alternative sensing technique, based on a microcontroller and light sensors, demonstrates how compact, low-cost equipment, could be used.

  The approach of sensing light also limits the system to mobile devices with LEDs, and to devices that provide software control over it.

  RFID sensing may become an interesting alternative in the future, as it uses flat, passive tags, which can be placed inside objects and surfaces. The Near Field Communication (NFC) initiative specifies the functionality of such sensing for mobile devices [NFC Forum 2009]. This emerging technology could support similar interaction, if it becomes widely available on mobile hardware.

- Limited tracking range and sensed information

  The tracking technique supports sensing of the mobile device's 2D position and an estimate of its distance to the surface. Data can also be encoded in modulated light, which, for example, could allow identification of the device being tracked. Egocentric approaches, in contrast, typically provide full 3D position and orientation, as used in LUMAR (Section 4.2).

- Non–see-through vs. see-through

  The current system was not designed for see-through operation, and as such, inherits the previously discussed limitations of spatially aware handheld

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displays. It does, however, illustrate that see-through capabilities are not always critical for enhancing a physical environment. This is especially relevant in scenarios that provide complementary representations of data associated with a physical location, but where geometrical registrations are of little use. The benefits of registering an abstract map with a geographical map may, for example, not necessarily be important, as in the implemented scenario shown in Figure 24.

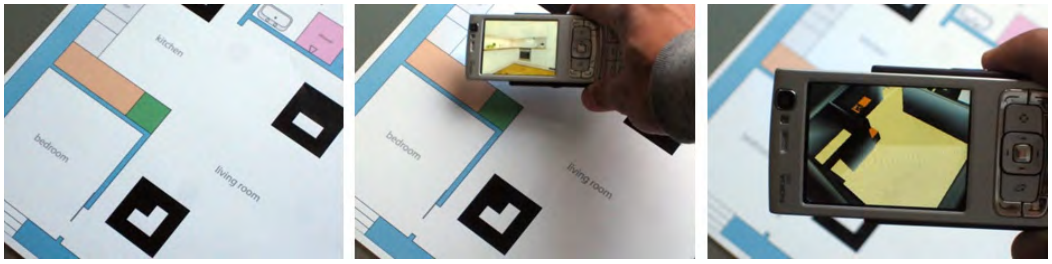
4.2 LUMAR

A hybrid egocentric/exocentric system for handheld AR

LightSense was combined with an egocentric tracking framework to expand the possible interactions of the mobile device. LUMAR [Paper V] uses the UMAR system [Henrysson and Ollila 2004] to provide a 3D video see-through mode when the device is held above the surface and out of range for LightSense. The LightSense framework is used to support tangible interaction with the device on, or near, the surface, where UMAR's camera is blocked, out-of-focus, or loses tracking for other reasons.

UMAR (Ubiquitous Mobile Augmented Reality) brings ARToolKit marker tracking [Kato and Billinghurst 1999] to mobile devices, allowing them to recover their position and orientation with respect to printed reference patterns, such that 3D models can be superimposed and registered with the environment in the live video from the device's camera.

LUMAR (LightSense + UMAR) illustrates the concept of layered information spaces through its different interaction modes, which are shown in Figure 27. The static layer consists of printed media, which can benefit from superior resolution, color



STATIC PRINT DYNAMIC 2D MEDIA DYNAMIC 3D MEDIA

Figure 27. LUMAR provides three types of information layers.

Static print: Although only able to present static information, a high-resolution print has many benefits compared to digital displays, such as its higher quality, low cost and passive nature.

Dynamic 2D media: LUMAR's exocentric tracking makes it possible to complement the map with 2D media when the tracked mobile device is on the surface (where egocentric camera-based tracking fails due to a blocked or out-of-focus camera).

Dynamic 3D media: LUMAR's egocentric framework provides 3D pose tracking and video see-through when the mobile device is held above the surface.

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depth, viewing angles and texture, along with other aspects that influence the perceived quality and fidelity compared to existing digital displays. Its static nature is complemented by one or more dynamic 2D layers, which are enabled through the movement of a spatially aware handheld display on the surface. The information space can be further enhanced through video see-through AR, by superimposing layers with registered 3D data.

Key features and insights

- #### Interaction on, near, and above the surface

  LUMAR leverages the best of egocentric and exocentric techniques by combining the advantages of spatially aware handheld displays (LightSense) with the benefits of handheld video see-through AR (UMAR). The hybrid system fuses the interaction spaces provided by the two techniques, with increased flexibility as a result.

- #### Multiple information layers

  The work presents the possibilities of multiple information and interaction layers, where the different data can be accessed and represented in its most optimal form. Text and detailed graphics, for example, may be well-suited for static print, whereas video and linked content will likely benefit from presentation in dynamic 2D. The video see-through mode complements these with 3D graphics registered with the physical space.

- #### Intuitive transitions

  The user transitions between the different layers through intuitive single-handed movement of the handheld device.

Issues

- #### Markers in the environment

  The egocentric camera-based tracking in LUMAR relies on fiducial markers to recover its position and pose relative to the printed material. The use of these black and white rectangular patterns in the environment conflicts with the desired properties of unobtrusive AR, but was the best technical solution at the time to achieve real-time video see-through AR on mobile devices. The future work in Paper III discusses the extension of this work to techniques based on natural feature tracking, where no fiducial markers are needed. Advances in tracking algorithms and mobile computing have recently made such techniques possible [Wagner et al. 2008b].

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- Limited interaction

  The work focuses on the potential of multiple information layers, but only provides control over perspective and content through device motion.

  Paper XI indicates how touch-screen techniques can provide fast, precise and direct manipulation in these scenarios. Future work would also include investigating complex tasks that require sophisticated interaction techniques, which may span different layers and dimensions.

4.3 SurfaceFusion

Unobtrusive sensing of everyday objects

It is useful to sense passive, everyday objects in AR scenarios, especially with the increased interest in interactive surfaces and displays. Traditional object sensing approaches often rely on complex pattern recognition techniques, active electronics in the objects, or the use of fiducials that alter visual qualities (as in LUMAR, Section 4.2). We can, however, expect that many physical objects will be manufactured with embedded electronics for identification in the near future. Passive RFID was mentioned in Section 4.1, and is an example of such technology, where cheap and small tags can be made invisible to the user, while providing robust identification.

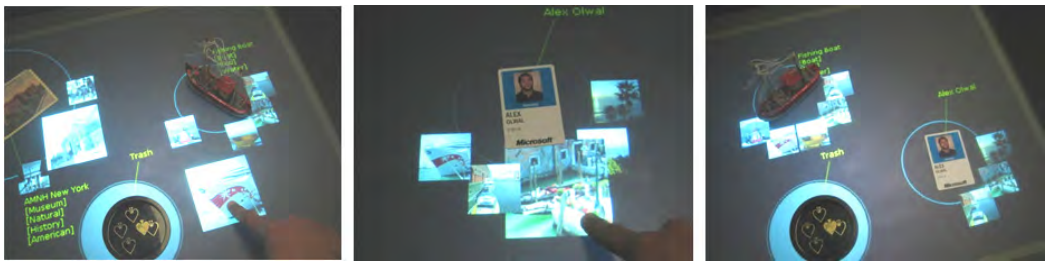


Figure 28. SurfaceFusion's unobtrusive hybrid sensing enables tangible interaction with visually unaltered everyday objects.

RFID technology can only sense the presence of tags in the volume being scanned, but does not inherently recover their position. Computer vision, on the other hand, is well-suited to track shapes and movement with a camera, but relies on complex, computationally expensive algorithms for the recognition of arbitrary objects, where the performance may heavily depend on the changing nature of environmental lighting conditions.

SurfaceFusion introduces an approach, based on activity sensing, that leverages the capabilities of these respective modalities [Paper VI]. A *frame difference algebra* was developed as a means to *visually track* shapes that appear, disappear or move on the surface with minimal assumptions about object appearance, while RFID *identifies* added or removed objects. A fusion pipeline merges the geometry

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recovered from computer vision with RFID presence, such that arbitrary RFID-tagged objects can be tracked and identified without requiring visual markers. (See Figure 28.)

Key features and insights

- **Identification and tracking of everyday objects**

  SurfaceFusion illustrates the power of fusing simple techniques, which allows it to unobtrusively identify and track the position of arbitrary passive objects that contain embedded RFID tags.

- **Preserves object appearance**

  By complementing computer vision with RFID, many negative aspects of fiducial-based tracking are avoided. RFID greatly simplifies the process of identification, while eliminating the need for visual tags.

- **Uniqueness and on-board storage**

  An RFID tag can store large amounts of data, which, for example, can be used to identify far more objects than possible with 2D barcodes of equivalent size.

- **Generally applicable techniques**

  The image processing techniques in Paper VI make very few assumptions about object appearance and are therefore applicable to other activity detection applications.

  Certain scenarios also find unobtrusiveness less important and may instead require, or even benefit, from the use of visual markers. The introduced techniques can in such cases complement the identification and tracking with increased robustness and performance.

Issues

- **Ambiguous actions**

  The current system may encounter ambiguous information from certain event sequences, for example, if two objects are introduced to the system at the exact same time. The sensitivity to this timing is dependent on the system's ability to limit object detection to the surface only, and on the update rate of the RFID reader and the computer vision system.

  These issues may in part be addressed by a global fusion technique, which would resolve ambiguities over a history of events in an integrated on-line probabilistic process, as discussed in Paper VI .

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- Limitations of RFID hardware

  Paper VI discusses several additional methods for extending activity sensing by exploiting properties in the RFID reader and RFID tags. The RFID reader and antennas in the project were however quite limited in their capabilities, and while a set of complementary methods, hardware, modifications and techniques were explored, their practical use was limited to detecting tag presence only. This made it possible, however, to demonstrate the power of the hybrid approach, through the use of basic RFID technology, image processing and the fusion pipeline.

  The modularity of the approach is important as it would be interesting to not only improve existing RFID sensing and computer vision techniques, but also to complement them with other sensing modalities.

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5 Interaction techniques for direct manipulation

This chapter presents a number of interactive methods that complement the displays, view-dependent imagery and sensing methods described earlier. A rich set of techniques provides the user with direct mechanisms for manipulating content through touch, gestures and user sensing.

Section 5.1 introduces novel general techniques that can improve touch-screen interaction, while Section 5.2 specifically focuses on 3D interaction for public see-through displays. Section 5.3 explores the challenges and opportunities made possible by a new type of display system that forms images on water vapor. Spatially aware handheld displays are discussed in Section 5.4 as tools that can complement a larger digital display with high visual fidelity and precise interaction.

5.1 Rubbing and Tapping

Expanding the expressiveness of touch interaction

Traditional touch-screens are limited in their sensing capabilities, which typically allow them to sense only the location of the user's touch, or the lack of contact altogether. The constraint of being able to detect only two states, combined with the device's limited precision, results in fewer input options compared to other pointing devices. A computer mouse can, for example, have several buttons and a clickable scroll wheel, in addition to the precise adjustments that are possible through its relative position sensor.

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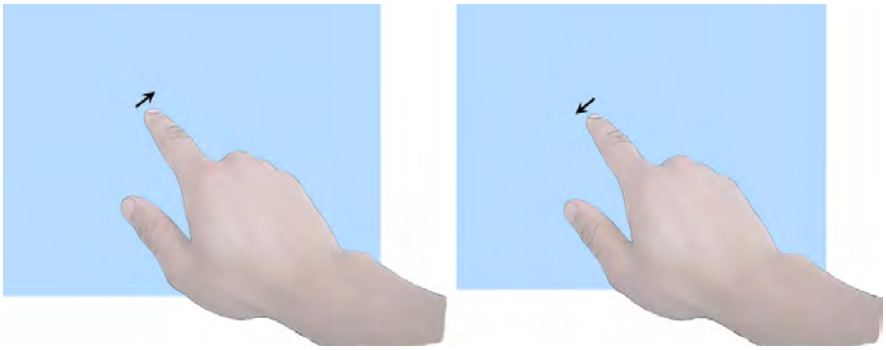


Figure 29. The *Rubbing* interaction technique uses small diagonal rubbing strokes to expand the user's expressiveness on touch-screen displays. The Rubbing gesture provides quick and convenient access to additional functionality, while the user is moving the finger on the surface. *Rubbing* is detected as at least two, short and fast, consecutive diagonal strokes in roughly opposite directions. The arrow illustrates the directions of the two strokes.

Two families of techniques were developed to address limitations in touch-screen interaction [Paper VII]. Both techniques default to regular touch-screen pointing, where their power lies in the ability to expand the expressiveness of interaction through simple gestures. The gestures can be mapped to different actions, which are integrated with standard pointing and dragging, to ensure fluid interaction.

Rubbing is a single-handed technique that uses a series of short and fast, diagonal strokes in roughly opposite directions, to trigger actions. (See Figure 29.)

Consider the three successive cursor position samples: $P_0(x_0, y_0)$, $P_1(x_1, y_1)$, and $P_2(x_2, y_2)$. If $\text{sign}(x_1-x_0) \neq \text{sign}(x_2-x_1)$ AND $\text{sign}(y_1-y_0) \neq \text{sign}(y_2-y_1)$, then (x_1, y_1) ends the previous stroke and begins the next. By classifying the gestures based on the slope of the strokes, two unique actions can be distinguished. The strokes roughly along the lower-left-to-upper-right diagonal (positive slope) are referred to as "Rubbing in", whereas the strokes roughly along the lower-right-to-upper-left diagonal (negative slope) are referred to as "Rubbing out". (See Figure 30.)

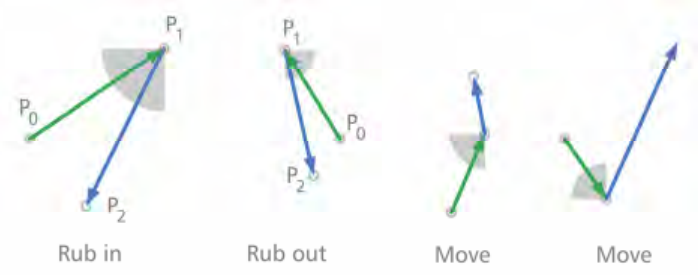


Figure 30. *Rubbing* also requires that the lengths of the strokes (here P_0–P_1 and P_1–P_2) are within the limits of preset minimum and maximum stroke lengths, and are executed sufficiently quickly and in roughly diagonally opposite directions. It is possible to distinguish between two types of gestures based on the slope of the strokes. The two leftmost images illustrate how "Rubbing in"/"Rubbing out" is performed along the diagonal with the positive/negative slope. The second stroke must lie within the 90° sector. The two rightmost images show how ordinary movement (dragging) of the finger on the surface can be supported in the same interaction mode, due to differences in speed, direction, and stroke lengths compared to Rubbing.

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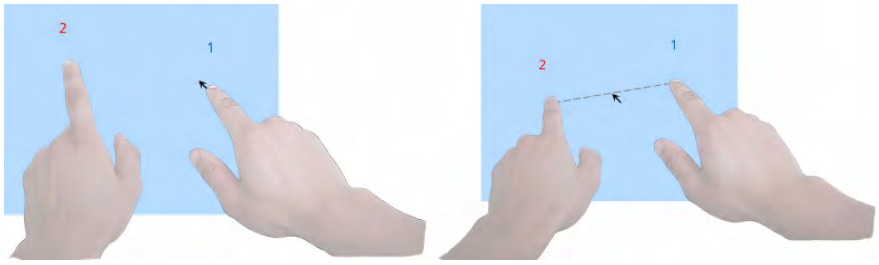


Figure 31. The *Tapping* interaction technique simulates aspects of multi-touch functionality on single-touch displays. The cursor jump that occurs when a second finger touches the screen on many single-touch displays can be detected in software, and mapped to different actions.

Left: The first (1) finger is touching the screen, while the second (2) finger is above the surface. The first (1) finger controls the cursor position (black arrow).

Right: The touch screen reports an average cursor position that lies on the vector between the two touch points when both the first (1) and second (2) fingers touch the screen.

Tapping is a bimanual technique that can simulate certain aspects of multi-touch functionality on many single-touch displays. It exploits the fact that many single-touch displays report an average cursor position when the screen is touched in two locations. The cursor jump that results from a second touch can be detected in software, if the distance between the two touches is sufficiently large [Matsushita et al. 2000]. It is both possible to establish the presence of a second touch, and its relative location to the first touch, since the average position will be located along the vector between the two touch points. The possibility of detecting this event is used for a quick touch-and-release action with the second finger, while the first finger is touching the screen. (See Figure 31.)

Five interaction techniques were designed, using combinations of Rubbing and Tapping to allow the integration of pointing and zooming into a single mode. They were evaluated against two well-known baseline techniques in a target selection task on a desktop touch screen. The results from a formal within-subject user study with twenty participants showed that the best of the introduced techniques were faster, resulted in fewer errors and had a higher user preference [Paper VII], compared to the two baselines.

The techniques were also used in two applications that were developed in this work. Figure 32 shows *TouchView*, an image browsing application, where the Rubbing and Tapping gestures avoid on-screen widgets and make it possible to support fluid interaction through integrated pointing and zooming. *TouchDaemon* is a background application, which was developed to make the techniques available in third-party applications, such as a map application in an unmodified web browser. (See Figure 33.)

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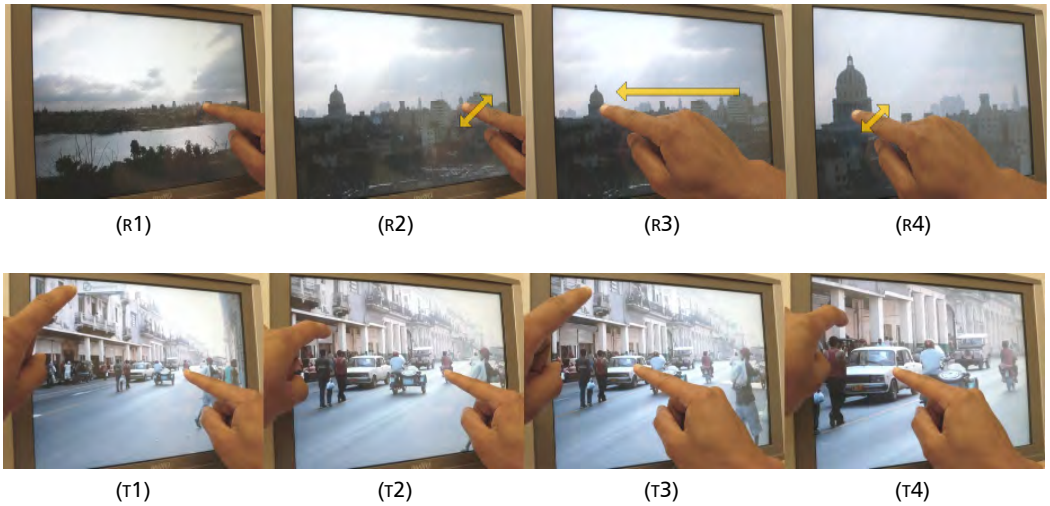


Figure 32. The *TouchView* application employs Rubbing and Tapping to support zooming and panning on images, without requiring menus or toolbars.

Top: (R1) Finger touches screen. (R2) Rubbing actions zoom in on a set of buildings. (R3) Finger is moved to a building of interest. (R4) Additional rubbing gestures zoom in on the building. (Arrows added to indicate finger motion.)

Bottom: (T1) First finger touches screen. (T2) A tap action with the second finger zooms in on a person. (T3) Second finger is released and first finger is moved to the car. (T4) A second tap zooms in again.

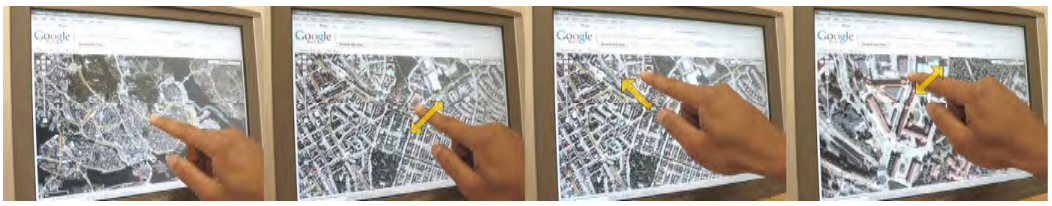


Figure 33. The *TouchDaemon* is an application that runs in the background and listens to the touch-screen input. It can detect Rubbing and Tapping gestures and makes it possible to trigger specific functionality through these interaction techniques in most third-party applications. In this example, TouchDaemon is used to provide gesture-based zoom through Rubbing in an unmodified map application that is running in an unmodified web browser. (Arrows added to indicate finger motion.)

Key features and insights

- ### Fast, precise and consistent performance

  Statistically significant results from a quantitative evaluation show numerous advantages over existing baselines.

- ### Higher user preference

  The majority of users preferred the introduced techniques over baseline techniques.

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- ### Expands expressiveness with simple gestures

  The introduced techniques make it possible to access additional functionality without relying on mode-switches, widgets or user interface elements. The work emphasizes the increased precision and performance possible through simple gestures that can be performed at any time during the interaction on the display.

- ### Integrated pointing and zooming

  Pointing and zooming actions are integrated in a single mode, where the user is always pointing to the target. The two-finger stretching gesture that is popular on multi-touch displays, instead require that the user alternates between pointing and zooming. It also requires that the user actively adjusts to keep the target in the center of the vector formed by the fingers, since the two fingers actually move away from the target in that technique.

- ### Unlimited repetitions

  The techniques make it possible to quickly perform large scale changes, since they were designed for repeated execution, either through repeated Rubbing gestures, or through numerous taps with the second finger, while the user is pointing to the target.

- ### Rubbing: compact, single-finger interaction

  The Rubbing gestures require little space, and are thus also suitable for small screens. They work well near edges and corners, where many other gestural techniques would require an initial translation of the content to the center of the screen. A mobile version of Rubbing for stylus-based operation was included in the study presented in Paper XI.

- ### Compatible with existing hardware

  Rubbing works with any single-touch technology, and does thus not rely on special hardware. It can both be used on finger-sensing displays, as well as with stylus-based technologies.

  Tapping works on technology that reports average positions for two touches, such as today's common resistive single-touch sensors.

- ### Preserves standard behavior

  The techniques do not interfere with or change the standard way touch screens are operated. Instead, their additional functionality is invoked on demand, which allows them to be integrated in most existing touch-screen interfaces.

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Issues

- ### Relative vs. absolute mapping

  The two-finger stretching gestures supported on multi-touch hardware can have an advantage in their absolute, 1:1 mapping of finger movement to geometrical transformations, despite the limitations in how fast they can be performed. The proprioceptive cues are, however, lost in the relative actions of the introduced Rubbing and Tapping techniques.

  It would be interesting to, in future studies, compare the impact of the differences between absolute and relative mappings for various scenarios.

- ### Simplicity vs. guessability

  The techniques were designed to be as simple as possible, in order to provide fast and convenient access to additional functionality. While their mechanisms do not directly map to real-world actions, experiences from the studies and from various demonstrations, indicate that their simplicity allows most people to understand and use them after a brief explanation.

- ### Discrete steps

  The current implementations trigger actions in discrete steps. It would be useful to explore their extension for continuous scale changes, which is technically possible in both Rubbing and Tapping.

- ### Comparison with multi-touch techniques

  The work focuses on general techniques that can be supported on the vast number of existing single-touch displays, as well as in multi-touch systems.

  Important future work includes a formal evaluation of our techniques in comparison with multi-touch gestures.

- ### Tapping: 2 fingers required

  Some users disliked the need for two fingers in Tapping, and this is an interesting issue, where a study comparing single-touch and multi-touch techniques may be able to provide more insight.

- ### Rubbing: risk for fatigue

  Certain touch-screens require hard touches, or use surface material that causes friction during dragging gestures. The resistive touch-screen display used in the study, caused fatigue for some users, who felt skin sensations after the large number of performed trials. It is unclear whether this would also be a problem under normal circumstances, where these gestures would be performed much less frequently.

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Friction is also less of an issue for touch screens that use a glass surface, such as many capacitive or acoustic sensors.

The mobile version of Rubbing, which is used in Paper XI, avoids this problem altogether through the use of a stylus.

5.2 3D manipulation on public see-through displays

Touch, gestures, head movement and remote control

Spatial optical see-through AR systems, such as ASTOR, can integrate the display element with the environment, and allow walk-up-and-use interaction. The potential for damage, breakage and general wear in unstaffed public spaces is, however, often best addressed by making the installed equipment physically inaccessible to users. This means that such setups must provide input devices that work on, or through, the surface, while avoiding the use of external mechanical parts and interference with the view.

Seven interaction techniques were designed, implemented and evaluated in their support of novice user interaction with 3D content on a public 3D display [Paper VIII]. The techniques were designed to allow the user's exploration of different 3D models through translation, zoom and rotation actions.

Two touch-screen techniques were based on gestural manipulation on a transparent single-touch overlay (Figure 34, left; Figure 35, left). Remote-controlled operation was provided in two other techniques through the controls on a wirelessly connected mobile device (Figure 34, center and right; Figure 35, right).

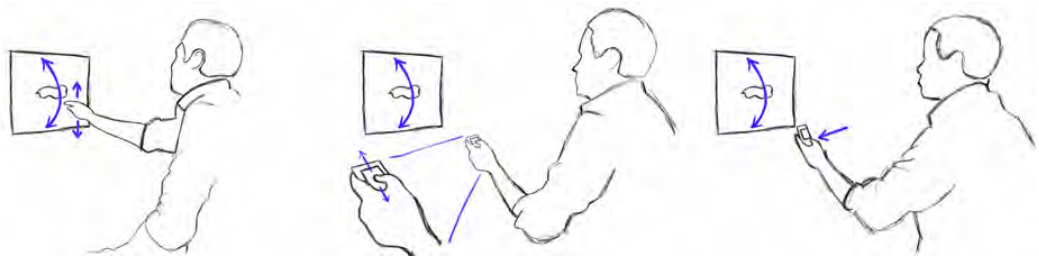


Figure 34. Techniques for interacting with 3D models on a public display.

Left: Touch-screen interaction is supported with on-screen buttons and rubbing gestures. On-screen buttons allow the user to browse different models, and change the mapping of dragging gestures between zoom, translation and rotation. The user can also, at any time, use the rubbing gesture to change the zoom level, as it does not conflict with dragging gestures.

Center: A connected mobile device's touch-screen is used as a remote touchpad for rotation of the model.

Right: All operations can also be accessed using the device's buttons.

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Figure 35. Left: Interaction with a 3D model using techniques on the large touch-screen overlay. Right: Manipulation through the touch-screen of a wirelessly connected mobile device.

In three additional techniques, the horizontal and vertical movement of a tracked mobile device were used as input (Figure 36, left), an eye tracker [Tobii 2009] followed head movement (Figure 36, center), and a 3D camera [ZCam 2009] tracked hand gestures (Figure 36, right).

The first four interfaces supported full manipulation (rotation, movement, zooming, cycling through models) of a displayed 3D model, while the last three only supported rotation about the vertical and horizontal rotation (pitch and yaw). Figure 37 shows the technology used in the study.

A focus group interview was conducted with three representatives from the Vasa Museum. A brainstorming session and discussions of how this technology could be applied to interactive exhibits provided interesting insights and affected the design of the techniques to be tested. The Vasa Museum also provided 3D-scans of sculptures and artifacts, which were used as the 3D models in the study.

A formal within-subject qualitative study with twelve participants was conducted, where each participant explored the possibilities for manipulation and interaction with the 3D models, using all seven techniques.



Figure 36. Sketches illustrating techniques for interacting with 3D models on a public display. Left: Remote sensing of the mobile device makes it possible to rotate the content by moving the device vertically and horizontally with respect to the display. Center: An eye tracker recovers the 3D position of the user's eyes to support rotation through head movement. Right: A 3D camera is used to track hand gestures, where hand motion controls rotation.

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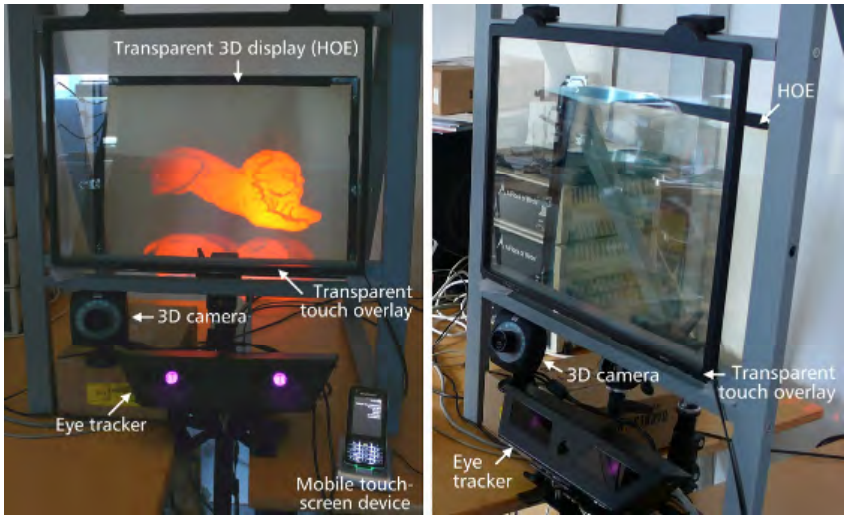


Figure 37. The technology used in the setup consists of a prototype 3D camera, a remote eye tracker, a resistive touch overlay, a mobile touch-screen device, and the HOE from the ASTOR system to provide autostereoscopic 3D imagery.

The results from the study indicated a preference for regular and mobile (remote) touch-screen interaction, which may be attributed to the directness of the tactile and graphical feedback, robust sensing, and users' familiarity with touch-screen technology. Remote-controlled operation using the mobile device's buttons or touch-screen was appreciated, as each individual could choose their own preferred pose for comfortable interaction.

Key features and insights

- ### Interviews with museum staff

  The museum staff provided valuable input regarding use cases, possible scenarios for digital showcases and the importance of unencumbered interaction in public installations.

- ### Potential of unencumbering technology

  The work demonstrates the potential of four technologies (eye tracker, 3D camera, touch sensor, and mobile device) in their ability to support unencumbered 3D manipulation in a public scenario, through the seven implemented interaction techniques.

- ### Advantages of touch-screen interaction

  A qualitative study shows that fluid interaction on the large touch-screen, as well as on the mobile device, was particularly preferred by the participants in the study.

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- Compatible technologies for redundancy or functionality

  While the technologies were explored individually, most of them are compatible with simultaneous operation, and can thus be used in parallel to either support redundant interaction, or to provide additional functionality.

Issues

- Simple interaction

  The work emphasizes interaction for novice users in public scenarios. It would be interesting to address more complex scenarios that require sophisticated interaction techniques, which may be based on combinations of technologies.

- Quantitative study

  This study focuses on the qualitative aspects of the technologies for causal exploration. These insights could now be complemented with a quantitative evaluation that would measure the performance in execution of specific, well-defined tasks. It would be especially beneficial to develop such tasks based on actual requirements, which could come from the museum representatives in the focus group.

- Hardware limitations

  Some users were negatively affected in their interaction by tracking limitations of the eye tracker and 3D camera. Newer hardware with increased robustness, range and performance would likely address this.

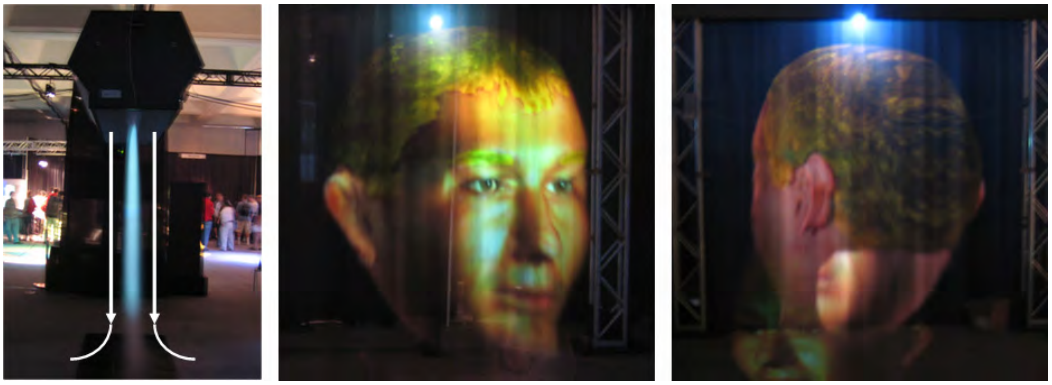
  The current HOE was manufactured for front-projection (to allow integration with the industrial machine, see Section 3.1), which requires equipment on the user's side of the display surface, and also creates potential occlusion problem with the hand during touch-screen interaction. It is, however, possible to manufacture an HOE for rear-projection that would address these issues.

5.3 Immaterial displays

Multi-user, face-to-face, and reach-through interaction

Immaterial displays introduce new challenges and possibilities for human-computer-interaction. They represent a class of output devices in which the display system forms images without relying on physical surfaces or enclosures. The display system in this work is based on the FogScreen device, which produces a diffusion screen through a controlled flow of vaporized water [Rakkolainen and Palovuori 2002]. A hanging ceiling unit emits vaporized water, while simultaneous lamination by continuous air flow on both sides minimizes turbulence and makes it possible to establish a rectangular projection surface. (See Figure 38, left.)

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LAMINAR AIR FLOW FRONT VIEW REAR VIEW

Figure 38. Left: The flow of vaporized water is trapped between two layers of stabilizing air flow, making it possible to create projection screens that users can walk or reach through.

Center and Right: The water particles primarily disperse light in the forward direction, enabling dual-sided projections, where each side can show individual rear-projected content. In this example, a user sees the face of a 3D model from one side, and can walk through the screen to see the back of the head from the other side.

The display's resulting permeability removes many limitations of typical digital displays. Multiple users can casually *walk through* and *reach through* the screen, exchange physical objects from one side to the other, and freely communicate through the projection surface while maintaining visual contact.

Another advantageous aspect for novel interaction is the vaporized water's property of primarily diffusing light in the forward-direction, which means that rear-projected graphics will dominate the imagery on the surface. This allows the use of dual-sided rendering, such that different, but synchronized, rear-projected content can be shown on each of the display's two sides, as illustrated in Figure 38 (center and right). The work explores 2D and 3D dual-sided interaction for immaterial display systems, and resulted in a number of interface prototypes [Paper IX, Paper X]. A commercial 3D tracking system was used to explore isomorphic 3D interaction, as well as simulated touch-screen behavior, which were complemented with visual and auditory feedback. Custom input device hardware was also developed to miniaturize the tracked devices for touch-screen emulation, and to provide a comfortable form factor, with richer input and actuation, for the 3D interface.



Figure 39. Interactive demonstrations for immaterial displays were demonstrated during a week at the Emerging Technologies exhibit at ACM SIGGRAPH 2005. One of the four applications shown was "Consigalo", a multi-user game that specifically focuses on simulated touch-screen behavior, face-to-face interaction, and auditory feedback.

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The prototypes illustrate how engaging interaction can be supported by bringing computer graphics into the physical space, while allowing unrestricted user movement and the support for multi-user, face-to-face interaction without physical limitations, as shown in Figure 39.

Key features and insights

- ### Interactive computer graphics in mid-air

  The system introduces technology that allows interactive computer graphics to seemingly appear in mid-air.

- ### Unhindered reach-through and walk-through

  The system illustrates how new interaction techniques can be designed for unbreakable displays that provide reach-through and walk-through capabilities. The display's immaterial properties simplify collaboration and communication around the content, as no physical barriers constrain verbal communication or movement.

  This can, for example, be advantageous in simulators, where it may be desirable to allow a user's body parts to pass through the display surface.

- ### Face-to-face interaction

  The two-sided immaterial display allows two people to maintain face contact, while discussing synchronized, individual views of computer graphics that appear in-between them.

- ### Accumulated experience for immaterial displays

  The work provides insights from experiences in integrating several 2D and 3D tracking technologies for user tracking and interface control. It also reports on experiments with 2D and 3D rendering approaches and the use of auditory feedback.

- ### Tested with large numbers of users

  The applications were demonstrated during a week at ACM SIGGRAPH 2005, which made it possible to informally evaluate the ease-of-use and intuitiveness of the developed techniques, by observing the large number of users that were able to successfully use the system with no or minimal instruction.

Issues

- ### Display quality

  The display's limitations in fidelity and field-of-view can only be addressed by improvements in the underlying display technology.

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- Formal evaluation

  Future work would include a formal user study that can provide qualitative and quantitative results from interaction techniques specifically designed to exploit the system's immaterial properties.

- Form factor

  The considerable weight and size of the FogScreen device, the two projectors, and the tracking system, are currently limiting factors for widespread adoption of the system.

- No tactile feedback

  Auditory feedback was implemented as a means to partially provide a sense of touching a physical surface. Unconventional string-based haptic devices [Kim et al. 2000] could however be integrated with the system, since there is no physical display surface that would interfere. Such approaches do, on the other hand, have the drawback of limiting the number of simultaneous users.

5.4 Spatially aware handheld displays

Enhancing large touch-screens for precise interaction

Several previously discussed issues, such as parallax, occlusion, calibration and imprecision in finger-pointing, may affect interaction on touch-sensitive surfaces. (See Sections 2.3.1 and 5.1.) Apart from these, it is also worth noting that surface quality, input resolution and robustness can greatly *vary* across different touch technologies.

This work introduces a framework to overcome such issues, by leveraging the capabilities of small, coarsely tracked mobile touch-screen devices [Paper XI]. These



Figure 40. A spatially aware handheld display can complement interactions with a large digital display, by overcoming its limitations in visual output and touch input. In this example, the smaller device has over ten times the visual and input spatial resolution of the rear-projected surface, thanks to its denser arrangement of smaller pixels and touch-sensor elements. Besides improved resolution, it is also clearly shown how the handheld display also has significantly better brightness and contrast. This scenario illustrates how detailed focus can be achieved with the handheld, while the larger screen provides the context for interaction.

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RUB CIRCLING GESTURES DRAG BUTTONS

Figure 41. Four different techniques to improve zooming and target selection on a large digital surface by interacting *through* the mobile device. The first three techniques use the mobile device's touch screen, where three simple gestures provide means for zooming, whereas the last technique relies solely on the mobile device's buttons.

devices typically have considerably higher visual and input resolution than large displays, due to a denser arrangement of the smaller pixel and touch-sensor elements, which are complemented by a rich set of additional on-board sensors and input controls. (See Figure 40.)

The mobile device is tracked using an extended version of the LightSense framework (described in Section 4.1 and Paper IV), where rear-projected imagery and touch sensing replace the static print. Finger-based interaction can thus be performed on a surface with dynamic content, in addition to the mobile interaction.

Four mobile interaction techniques were designed for interaction with the large digital display through the mobile display, which provides a high-resolution view of the content. Three of these techniques were implemented for gestural selection and zooming using the mobile device's touch-screen, while one technique instead used discrete buttons presses, as shown in Figure 41.

The techniques were evaluated in a formal within-subject user study with twelve participants, where two baseline techniques used direct finger-interaction on the large rear-projected screen.

The mobile techniques generally had consistent performance, smaller variations among participants, and a higher user preference, than the finger-based techniques for the large display. However, the characteristics of the hardware configuration and the touch overlay in our setup seem to have negatively affected the performance of the finger-based techniques. It is not always feasible to provide a setup that is ergonomically optimal for all possible users, and the choice of hardware configurations for installed touch screens is likely to be subject to many environmental constraints. Certain scenarios may even prohibit the use of touch altogether, for example, due to installation sites that do not allow exposed display

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surfaces, or the use of protective glass layers that are incompatible with available touch technology.

The study indicates that a coarsely tracked mobile device can avoid such problems, through predictable high-resolution input and output that support personalization and user-specific customization of its behavior.

Key features and insights

- **Spatial awareness for precise interaction in larger context**

  The system preserves the original view of the large digital display, while making it possible to achieve more precise interaction on a smaller screen, which has higher visual and touch resolution.

- **Personalized device — personalized interaction techniques**

  The majority of participants in the study selected one of the mobile techniques as their preferred, but the technique of choice varied. Several of the techniques can coexist in the same mode, similarly to other work in this dissertation (see Sections 5.1 and 5.2), and support either redundant functionality, or different functionality. An important difference compared with the other systems, is that these interaction techniques are running on the user's personal device. It would thus not be unreasonable for the user to customize a preferred technique of choice, just like the device is personalized with ringtones, background images, or text input methods.

- **The power of a coarsely tracked high-resolution viewport**

  The device in the study was tracked with almost a fifth of the resolution (352×288) compared to the finger-based pointing (800×600). The device was, however, able to overcome this limitation through its densely placed pixels and touch sensor elements. The higher quality screen might also have contributed through its better contrast and brightness.

Issues

- **Limited performance on resistive single-touch overlay**

  To address the limitations and issues with the resistive single-touch overlay, it would be valuable in future work to explore similar complementary interactions on multi-touch surfaces.

- **Refined and combined techniques**

  The interaction techniques in this scenario could be combined to support more advanced tasks, and also be extended with possibilities for continuous and elastic control.

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The study identified an easily fixable design mistake, which affected one of the techniques (MobileDrag), where the system's misinterpretation of quick strokes led to high error rates for selections of small targets.

- Hybrid techniques

  Apart from the use of different techniques to trigger the same action (increased redundancy), or support multiple actions in a single mode (increased functionality), it is also interesting to explore techniques that are simultaneously or sequentially performed on multiple displays.

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6 Conclusions and future work

Unobtrusive AR makes it possible to augment our view of the surroundings through walk-up-and-use scenarios that require minimal effort or preparation on the user's part.

The dissertation argues that the strategy of leveraging equipment that is integrated in the environment can, for many scenarios, eliminate the need for encumbering, user-worn technology. It also shows how techniques can be adapted to avoid intrusive modifications to the devices, objects or environment with which the user interacts. The many hybrid techniques described here illustrate how the combination of complementary methods can efficiently surpass their individual capabilities.

The display systems, sensing approaches, and interaction techniques that were designed, developed and evaluated in this dissertation, demonstrate the potential of unobtrusive AR to enable widespread and seamless interaction with real and virtual content.

6.1 Displays, sensing and registration

AR depends on display systems that combine computer-generated virtual imagery with the user's view of a real environment. Unobtrusive AR refines this requirement through its preference for an optically direct view of the real environment, and the avoidance of head-worn displays.

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The directness with which the environment is perceived varies across display technologies and desired qualities. This work identifies spatial and handheld optical see-through, direct projection, and spatially aware handheld displays as particularly interesting display technologies for unobtrusive AR systems.

The camera's sampling of the real-world in video see-through systems, on the other hand, may have numerous negative consequences for the perception of the physical environment. This is, however, primarily an issue for head-worn video see-through displays, which tend to completely *replace* the user's view with augmented video. Handheld video see-through systems instead have the potential to act as viewports that *complement* an optically direct view, given their portability and less encumbering physical form factor.

Besides achieving the visual combination of real and virtual, AR systems also need to register the virtual content with the real, and provide perspective-correct imagery to the user. This thesis introduces combinations of display systems, hardware configurations, and sensing techniques that accomplish this purpose.

The HOE in ASTOR [Paper I, Paper II], is used both as an advanced optical combiner and as the enabling component for the system's multi-view capabilities. The unique characteristics of the system make it possible to simultaneously support flexible display configurations, a high-quality see-through view, and bright computer-generated imagery with high contrast. Its multi-view capabilities allow it to both present autostereoscopic 3D graphics, and support view-dependent imagery without user tracking. The clarity of the optical see-through display is particularly important, since the complementary nature of the monochromatic AR overlays relies on a high-quality view of the real environment. Like most multi-view displays, ASTOR also has limited scalability, due to the computational load and image generation that would be required to support a large number of simultaneous perspectives.

The POLAR project [Paper III] explores mobile scenarios by investigating the use of inexpensive, commercially available and portable technology as an alternative to ASTOR's custom-manufactured HOE. The system compensates for the lack of multi-view capabilities with remote sensing that makes it possible to continuously update the perspective as the user moves. The two interaction techniques in Paper VIII, which were implemented with an eye tracker and a 3D camera, illustrate how classical user tracking could be used to address the fixed number of views that limit the original ASTOR system.

LightSense also exploits remote sensing, but for the unobtrusive registration and tracking of mobile phones [Paper IV]. The environment senses and wirelessly informs the phone of its position on a surface, allowing context-sensitive graphics to be shown in its display. LUMAR combines the exocentric tracking of LightSense with egocentric marker-based tracking, which makes video see-through AR possible

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when the device is held above the surface [Paper V]. LightSense and LUMAR do not provide an optically direct view through their displays, but preserve instant access to an unmediated view of the real environment, either by moving the device out of the way, or by looking to the side of the device's display.

In SurfaceFusion, sensing is used to identify and track arbitrary passive real-world objects without the need for changes to their appearance [Paper VI]. This makes it possible to present associated digital media next to physical objects, which blends the manipulation of real and virtual through touch and tangible interaction.

6.2 Interaction techniques

The potential of perspective-correct augmentation, made possible by AR displays and sensing technologies, becomes even more interesting when extended with intuitive user interaction. The detection of touch, gesture, pose, and speech, or the use of handheld devices, are examples of interaction technology that can support direct manipulation, while avoiding user-worn equipment. These technologies are particularly interesting for unobtrusive AR systems, and led to the implementation of a set of diverse interaction techniques, which were designed for 2D displays, 3D displays, immaterial displays, and hybrid display configurations.

Two new techniques for touch-screen interaction are introduced in Paper VII. The Rubbing and Tapping techniques were specifically designed for precise and fluid interaction. A controlled user study shows that these techniques could allow faster interaction with fewer errors when selecting objects on a desktop display. Rubbing, in particular, was designed to work with any touch-screen display, independent of its size and technology, and was implemented in a number of different systems.

The manipulation of content by novice users on 3D displays is discussed in Paper VIII, with a focus on public installations, in which requirements of unencumbered interaction are similar to those of unobtrusive AR. A qualitative study compared seven interaction techniques for basic manipulations of a 3D model through rotation, zoom and translation actions, which can be achieved without pixel-precise target selection. The techniques were based on touch, remote control with a handheld device, eye tracking, gesture tracking, and device tracking. The study indicates a preference among subjects for touch-screen interaction, due to ease-of-use, directness, tactile feedback, and robustness of the technology.

The experimental design of techniques and applications for a new display type resulted in a number of interesting insights [Paper IX, Paper X]. An immaterial projection screen, which was extended for the support of individual content on each side, enabled a large number of people to simultaneously engage in face-to-face interactions while moving freely in front of, or *through* the display. A series of experiments led to a final design, where a 3D tracking system was used for

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simulated touch-screen behavior, using custom-built miniature markers that could be comfortably held between two fingers. Continuous auditory feedback was designed to vary with the user's distance to the screen and the actions on the surface, to compensate for the lack of tactile feedback. The interface was successfully used by a large number of users of different ages, with no or minimal instruction, during a one-week demonstration at the *ACM SIGGRAPH* Conference in 2005.

Paper XI introduces a framework where a mobile device is used as a precision tool, to enhance both the visual quality of a small portion of a larger digital display, and perhaps even more interestingly, the accuracy with which a user can interact. The work illustrates how limitations of a stationary display can be avoided by extending its capabilities with complementary interaction techniques performed through a tracked mobile touch-screen device.

6.3 Summary of conclusions

This thesis focuses on unobtrusive AR and introduces a number of techniques that address important issues in this area. Many of the presented techniques provide interesting contributions on their own, and can also be generalized to other types of applications and scenarios, as discussed in this thesis, and in full detail in the appended publications.

This work has resulted in five important insights:

1 *Novel, unencumbering display technology can effectively merge virtual imagery with real environments.*

ASTOR (Section 3.1, Paper I and Paper II) describes how autostereoscopic 3D graphics can be merged with an optically direct view of a workspace through the use of a multi-view HOE. It is used to augment machine operation with real-time process data in the discussed examples. POLAR (Section 3.2 and Paper III) enhances small workspaces with 2D graphics and avoids user-worn equipment through remote tracking. Techniques for immaterial displays (Section 5.3, Paper IX and Paper X) show new possibilities for bringing interactive computer graphics into a physical environment.

2 *Exocentric techniques can be advantageous in their ability to sense unmodified devices and visually unaltered objects, while preserving the appearance of the real environment.*

LightSense (Section 4.1 and Paper IV) and SurfaceFusion (Section 4.3 and Paper VI) introduce techniques that enable surfaces to track mobile devices and everyday objects, while preserving their appearance and avoiding modifications.

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3 *Hybrid approaches can expand the possibilities for interaction and remove the need for intrusive technology by combining sensing methods, display technologies and interaction techniques.*

POLAR fuses computer vision and basic distance sensing to achieve low-cost 3D tracking of the user (Section 3.2 and Paper III), while SurfaceFusion combines RFID sensing and computer vision to track visually unaltered objects (Section 4.3 and Paper VI). LUMAR leverages the best of egocentric and exocentric techniques by using a hybrid approach (Section 4.2 and Paper V). Section 5.4 and Paper XI describe how a spatially aware handheld display can complement the interaction on a large digital display, with more precise input and improved visual fidelity.

4 *Many different display configurations can benefit from important qualities of touch-based interaction, such as directness, robustness, predictability and feedback, while avoiding the need for user-worn equipment.*

The benefits of touch-screen interaction are discussed in Chapter 5. The results from the study in Paper VIII (Section 5.2) indicate an advantage of touch-screen interaction for simple 3D manipulations on public see-through displays, compared to gestures, head motion and device movement. The positive user feedback from the immaterial display system's simulated touch-screen behavior is also encouraging (Section 5.3, Paper IX and Paper X). Paper XI (Section 5.4) describes how techniques that use touch or button input on a mobile device can overcome the limitations of a large touch-screen. The dissertation also introduces two new techniques, Rubbing and Tapping, and demonstrates how they can expand the expressiveness of general touch-screen interaction (Section 5.1 and Paper VII).

5 *Unobtrusive methods can coexist with other interactive techniques, while emphasizing minimal interference with the real-world procedures that they augment.*

The systems introduced in this dissertation minimize interference with the user's view of the display (Chapter 3), avoid changes to the visual appearance of the physical environment (Chapter 4), and emphasize unencumbered means for interaction (Chapter 5). Their unobtrusiveness also simplifies integration with other techniques to achieve redundant or complementary functionality.

6.4 Future work

We can expect important technological advances in the near future that will have significant impact on the areas that this thesis has discussed.

Developments in imaging technologies will continue to generate smaller, less expensive and better performing components for digital projectors, displays and optics, with direct benefit to the display systems that are introduced in this work.

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Increasingly efficient image generation will enable multi-view systems, like ASTOR, that are more compact, support a large number of simultaneous viewers, and exhibit full-color capabilities that improve the quality of virtual content.

The rapid improvements in computational power and camera hardware on mobile devices already allow the use of sophisticated computer vision for sensing, detection and tracking of real-world events, making an even more mobile and low-cost version of POLAR feasible. Advances in performance are also critical to the shift from marker-based techniques, as used in LUMAR, to natural feature tracking [Takacs et al. 2008, Wagner et al. 2008b], for mobile video see-through AR. An increase in sensors that are ubiquitously deployed in the surrounding environment will provide the infrastructure for the type of interaction made possible by LightSense. It is also likely that a wide range of new sensing technologies, such as NFC [NFC Forum 2009], will find their way into the mobile devices, which will lead to improved spatial awareness, while new output mechanisms, such as embedded projectors and tactile displays, will increase their expressiveness.

SurfaceFusion was developed with an expectation that the vast majority of everyday objects will contain embedded passive electronics in the near future, where the increased sophistication in the surfaces that sense them will enable radical new forms of interaction. Many surfaces will also embed spatial optical see-through displays, like ASTOR and POLAR, for intuitive augmentation of real-world processes behind them. Examples could range from laboratory and industrial workspaces to shopping windows and museum showcases [Bimber et al. 2003, Bimber et al. 2001]. Immaterial displays have the potential of bringing virtual images into the real environment, where the unrestricted movement around the content they present provides unique possibilities for collaboration and natural communication.

This research has demonstrated the potential of techniques for visual augmentations and interaction that maintain real-world qualities, preserve the mechanisms of current methods, and leverage the advantages in existing procedures.

The presented techniques have been illustrated with prototypes based on examples from industrial scenarios [Papers I and II], field work [Paper III], map navigation [Papers IV and V], information exchange [Paper VI], archeological visualization [Paper VIII], medical imaging [Paper XI], and various forms of media manipulation [Papers IV–XI]. It is desirable to now apply the insights gathered in this thesis, to develop and extend these prototypes and concepts for real-world use.

The general characteristics of these emerging techniques allow them to be applied to a wide range of real-world problems, and many scenarios are expected to benefit from continued research in combining, developing and refining the techniques introduced in this thesis for even more complex and advanced interactions.

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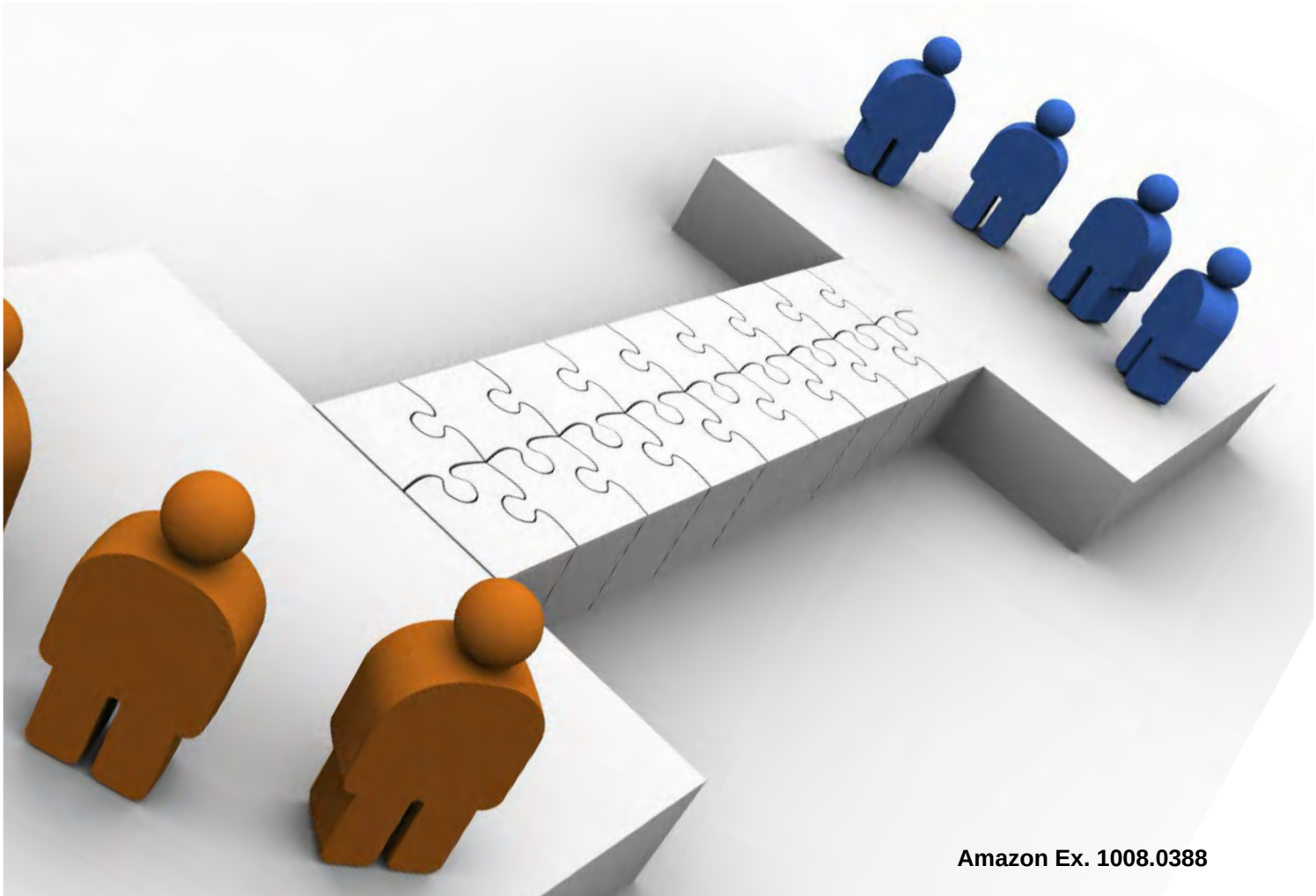
Appendix D-9

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First Workshop on Social Interaction in Spatially Separated Environments

Falko Schmid • Tobias Hesselmann • Susanne Boll
Keith Cheverst • Lars Kulik
(Eds.)



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Editors

Falko Schmid
University of Bremen
P.O. Box 330 440,
28334 Bremen, Germany
schmid@informatik.uni-bremen.de

Tobias Hesselmann
OFFIS Institute for IT
Escherweg 2
26121 Oldenburg, Germany
tobias.hesselmann@offis.de

Susanne Boll
University of Oldenburg
Escherweg 2,
26121 Oldenburg, Germany
boll@uni-oldenburg.de

Keith Cheverst
Lancaster University
South Drive
Lancaster, LA1 4WA
United Kingdom
kc@comp.lancs.ac.uk

Lars Kulik
Department of Computer Science
and Software Engineering
The University of Melbourne
Victoria 3010, Australia
lkulik@unimelb.edu.au

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Mobile Devices and a New Understanding of Presence

Karsten Weber
Technical University Berlin
Computers and Society, FR 5-10,
Franklinstrasse 28/29, 10587 Berlin, Germany
kweber@cs.tu-berlin.de

ABSTRACT
Mobile devices help people to stay connected across huge distances and to socially interact while in spatially separated environments. However, compared to face-to-face- interaction, communication and interaction via mobile phones currently are still restricted. Therefore, an idea of Mann, Fung, and Lo concerning cyborglogging with camera phones shall be taken a step further. A scenario is described in which a modified version of their design is used to support social interaction across the borders of spatially separated environments in a new manner. It shall be argued that this might create a new understanding of being present at a certain place while at the same time it raises questions concerning privacy, surveillance and authenticity of experience.

Author Keywords
Mobile Devices, Epistemology, Presence.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI):

H5.1. Multimedia Information Systems: Artificial, augmented, and virtual realities.

General Terms
Design, Human Factors.

INTRODUCTION: SURVEILLANCE AND CONTROL
Since several years, surveillance and control is a pretty hot topic in scholarly as well as in political debates. To some extent, the 9/11 incident gave birth to these discussions and debates, at least on the political level. However, research on issues of surveillance and control in modern or, as some would say, postmodern societies began much earlier than 9/11. In many respects, one could say that Michel Foucault started this kind of research with the publication of his book “Surveiller et Punir. La Naissance de la Prison” in 1975 [6]. And if one takes the scholarly debates concerning privacy into account, one might say that research on surveillance and control started much earlier, for

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instance with Samuel D. Warren and Louis Brandeis' hallmark paper "The right to privacy" [18], published in 1890.

A large part of this ongoing debates deal with the relation of the state and its citizens. According to Foucault and many other scholars, surveillance and control are methods to govern people. From this point of view, surveillance and control are understood as something repressive, as methods to force people to do things they otherwise would not do. Other scholars like David Lyon stress that surveillance and control make possible social sorting [9] which means that certain people at certain places are labelled as "[…] 'undesirables' by examining individuals' immediate attributes for disliked characteristics. A person might fall into a pariah category because of what she is wearing, who she is "hanging out" with, or her demographic category." [8, p. 122], as Kang and Cuff puts it.

Common understanding of surveillance and control most frequently implies that there is some kind of Orwellian 'Big Brother' who is watching us. Regularly, state authorities like the police or secret services are identified as Big Brothers, but insurance companies, search engine providers like Google and companies running social networks like Facebook – generally speaking private companies – are also very often mentioned. These actors collect, process, and store huge amounts of personal related information and use it in their own interest. Compared to them, we as citizens or consumers are relatively powerless.

SOUSVEILLANCE AND EQUIVEILLANCE

To abate or even abolish this asymmetric power relation, Steve Mann [10, p. 620] suggests that people should employ information and communication technology for the purpose of 'sousveillance' which "[…] refers both to hierarchical sousveillance, e.g. citizens photographing police, shoppers photographing shopkeepers, and taxi-cab passengers photographing cab drivers, as well as personal sousveillance (bringing cameras from the lamp posts and ceilings, down to eye-level, for human-centered recording of personal experience)." Additionally, Mann, Fung, and Lo [12, p. 177] coined the term 'equiveillance' to emphasize "[…] a peer-to-peer approach that decentralizes observation to produce transparency in all directions."

Briefly speaking, sousveillance and equiveillance are characterized by two aspects. The first one must be understood in a political sense as already pointed out: Sousveillance and equiveillance shall wane or eliminate an asymmetry of power between, for example, state authorities and citizens. Each and every citizen shall be empowered to employ the same surveillance measurements as state authorities and companies do. The second aspect must

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be understood in more individual as well as social terms: Mann and his colleagues would like to use technology for artistic reasons, to create some kind of multimedia diaries – called 'cyborglog' –, and for purposes concerning social interaction. They demonstrate that ordinary mobile phones can be employed for cyborglogging or 'glogging'. In principle, they created a client-server-architecture with mobile phones as clients with which pictures can be taken and text can be entered. Pictures and text are sent in realtime to a server on which they are stored. Users of these servers now can access those contents using a web browser in real-time, too. The authors stress [12, p. 178] that "[i]n contrast to other photosharing sites, where images are uploaded from PCs, 'glogger uses camera phones which are commonly carried by people in their day to day lives in real-time." A Microsoft Research project called "SenseCam" realizes a somehow similar approach although in this case no automatic transmission of photos to a website takes place; instead the photos are stored within the camera.

Mann, Fung, and Lo also discuss the social, moral, and legal aspects of the technology they developed. With regard to the paper at hand one of the most important aspects they bring up is that the cyborglogging system as well creates an asymmetric power relation although it was supposed to mitigate such asymmetries. This accrues from the fact that only the person who wears and utilizes the mobile phone actually knows whether it takes pictures or not. This raises moral and legal concern, as Mann, Fung, and Lo admit [12, p. 179]: "Naturally, as with any new technology, there will be both advocates as well as opposers. When faced with the moral or ethical dilemma of when to run 'glogger, we consider, as a base-level of operation, the notion of equiveillance. Equiveillance doctrine says that as long as surveillance is present in the environment, that a person ought to have a moral and ethical right to engage in sousveillance."

From the point of view of an ethicist it must be stressed that Mann, Fung, and Lo's position seems to be somehow naïve and therefore must be challenged. For the presence or absence of a moral right does not depend on whether others act according equivalent moral rules. To put it a bit exaggerated but bringing it to the point: One does not have the right to misbehave just because there are people who behave in a morally wrong way. Additionally, it has to be stressed that in some countries, for instance Germany, under certain circumstances it is legally prohibited to take pictures of persons without their informed consent (§823 BGB; §201a StGB; §§22-24, 33, 37, 38, 42-44, 48, 50 KUG). But although these moral and legal aspects are most interesting as well as important, here they shall not be examined anymore.

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MOBILE PHONES AND REAL-TIME VIDEO STREAMING

In earlier papers (e.g. [11]), Steve Mann already brought up the idea of "continuous lifelong capture of personal experience" using video technology. Other scholars mentioned technologies that could be employed to share experiences and to communicate and interact across the borders of spatially separated environments (cf. [2], [15]). These ideas and conceptions now shall be put a step further. Let's suppose the following scenario: K. is carrying a Bluetooth headset equipped with a microphone, earphones, and a small head mounted camera. Compared to Mann, Fung, and Lo's setting this would assure that the camera would have almost exactly the same perspective as the person carrying it. A modified version of the technical infrastructure that Mann and his collaborators presented might be used to transmit and receive video streams in realtime from one 3G mobile device to another or even to a couple of them. Received video streams may be projected on any suitable surface employing a micro beamer. Another option would be to utilize a Tablet PC to show video streams and to transmit own content. A bit more high-tech would be to use head mounted displays.

A first or simple version of this technology would merely transmit video streams and the respective sound; however, it certainly would be possible to augment the visual and acoustic channel with other sensory input, for instance from haptic interfaces, or data concerning environmental conditions such as temperature or humidity. It might also be useful to transmit data about the physiological conditions of users. Yet, it would be rather easy to monitor heart beat frequency, blood pressure, and the like, but it would be much more difficult to bring these data to the attention of the receiving person in an adequate and effective way: Just showing numbers on a display would not provide for a real experience.

In some situations it might be very useful to record all the above mentioned information in order to evaluate and review them later on, for instance in case of emergency rescue, law enforcement, or even combat missions. However, this kind of usage shall not be discussed further. Instead, the real-time application of such technology shall be evaluated.

Although persons using this setting might be spatially separated by huge distances for them it would be possible to interact with each other in a pretty new way: They would hear and see what their peers would hear and see and vice versa. In fact, one could say that although a person not really resides at a place she is present. This concept shall be called 'virtual presence'. The difference compared to 'telepresence' or 'copresence' is that these generally require using video-conferencing equipment that is located in a particular

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room (cf. [17]). Moreover, at least the more simple technical solutions of virtual presence would utilize already existing consumer products. However, it must be stressed that not the technology itself shall be focused here but its epistemological consequences.

A NEW UNDERSTANDING OF PRESENCE

It is obvious that a technology like virtual presence would make moral and legal questions as pressing as the original concept of Mann, Fung, and Lo, particularly with regard to surveillance and control, privacy and data protection. It has to be stressed that the new setting would not abolish the asymmetric power relation between the person employing virtual presence and those who are pictured as long as no additional technological measurements are utilized or respective social rules are enforced. However, such aspects shall not be discussed any further in the paper at hand. Rather, the epistemological consequences of virtual presence shall be evaluated.

The major appeal of virtual presence surely would be that in principle we would be able to communicate and to interact with persons spread across spatially separated environments all over the world; we could 'attend' any event anytime anywhere. But as the famous Science Fiction writer Isaac Asimov already described in 1957 in his novel "The Naked Sun", our understanding of being present might change dramatically: 'to be present' and 'to reside' then would mean something completely different. Furthermore, virtual presence might change our understanding of reality, particularly if high-tech equipment as mentioned above would be utilized.

Indeed, the idea that a mind-independent reality does not exist is widespread among social scientists and philosophers (e.g. [1]). But even if one sticks to the idea that there is a mind-independent reality most scholars would agree that to a certain extent our experience of reality is a theory-driven creation, construction, or fabrication of our brain determined by our knowledge, prejudice, and expectations. What we, for instance, see is not something like a representation of the world as it is but rather an image that, to a large extent, our brain creates. Moreover, it is widely accepted among most scholars that media of any kind strongly influence the process of constructing a worldview. Therefore, since virtual presence is a kind of media, it would affect our worldview, too. But the totality of virtual presence seems to introduce a leap in quality if compared to other media like broadcasting or television. If anything, the experience of virtual presence might only be weighed against the total immersion that can take place while playing computer games or going through virtual realities (cf. [3]).

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One other difference compared to media like broadcasting or television is that it would not make sense anymore to talk about content of (digital) media. For this content will be integrated in our own experience in such a way that one cannot talk about a representation or mapping of reality (cf. [12, pp. 200]). Hence, at least to some extent, the dualism of I and world might be abrogated because the distinction of world on the one hand and information or knowledge about the world on the other hand could not be drawn anymore. Virtual presence just might taken for granted the same way like today the possibility to talk with distance others via mobile phone. Current findings already suggest that using mobile phones shows deep impacts to psychological traits of their users [cf. 16]. At least it can be stated that virtual presence probably would blur the borders of virtual and embodied or physical space and would help to create what often is called 'hybrid space' [cf. 4]

TRUTH AND FALSITY OF IMAGES

In his famous novel "1984" George Orwell not only described a society characterized by ubiquitous surveillance and control but he also depicted the methods of historical misrepresentation by manipulation of documents of any kind. One of these methods is photomontage. In our times we know the verb 'to photoshop': Its use shall indicate that a digital picture was modified to increase, for instance, its quality. But pictures can be manipulated to the extent that they do not show truth anymore.

It is seductive to believe that as long as we know all steps of the production and reproduction of a picture – or any other kind of document that shall represent reality – we would be able to authenticate the validity of this particular picture. But even if we assume that a picture actually can represent reality, we have to learn that the validity of a picture must be authenticated not only by technical means but by socially defined rules. As observers we must rely on that a picture in fact shows reality as it is. In this regard, Escudero Chauvel [5] coined the term 'media contract' for the rules which shall authenticate the validity of documents that shall represent reality. In case of, for instance, traditional journalism, one might say that this media contract actually more or less performs successful. But one could be skeptical whether equivalent rules can be defined, implemented, and enforced in the case of virtual presence.

For one has to learn that virtual presence probably will come together with the disposability of huge computing capacities on the server side as well as on the client side. Current mobile devices already provide for computing power comparable to that of personal computers less than five or six years ago. The respective computing power would suffice to employ at least simple

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real-time video manipulation and filtering. Moreover, on the server side cloud computing can provide for pretty cheap and massive computing capacities. These can be utilized to manipulate transmitted pictures and video streams in real-time or with minute delays only. For the recipients of such content it would be very difficult or even unfeasible to determine whether it is authentic or manipulated.

Hence, from the point of view of epistemology it might be still possible to determine what is real and what is a construction based on technology. But reasonably, one might be skeptical whether we as users of virtual presence would be able to decide if the transmitted information is authentic or manipulated.

FURTHER RESEARCH

As previously pointed out, technologies like virtual presence raise serious moral and legal questions concerning privacy, data protection, power relations, and the like that could not have been discussed in the paper at hand. To answer those questions, at first it would be necessary to clarify which moral and legal norms and rules would be affected by virtual presence. But additionally, it would be mandatory to evaluate users expectations, hopes, fears, and of course reactions with regard to such a technology because it would not make sense to be concerned about virtual presence if its potential users would decline to apply it.

Furthermore, bandwidth available for consumers using mobile devices would allow for services that would not only employ visual and acoustic channels for communication and interaction. Technology could provide for other sensory input applying, for instance, haptic interfaces. Therefore, it would be essential to empirically evaluate which interfaces in which situations and for which uses cases would be most appropriate for interaction across spatially separated environments.

CONCLUSION

Mann, Fung, and Lo's conception of a technology that makes feasible sousveillance and equiveillance was presented to show that ubiquitous computing technology not necessarily supports surveillance and control in an Orwellian sense. Virtual presence as a modification and extension of the cyborglogging design was introduced which shall support communication and interaction of persons residing in spatially separated environments. It was demonstrated that without further technological means or respective social rules the new setting raises the same moral and legal concern as Mann, Fung, and Lo's design. Moreover, it was talked about epistemological theories of reality and that our understanding of presence would substantially change if virtual pres-

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ence would be employed. Finally, it was stressed that users of virtual presence probably will not be able to determine whether that what they experience would be an authentic or manipulated reproduction of reality.

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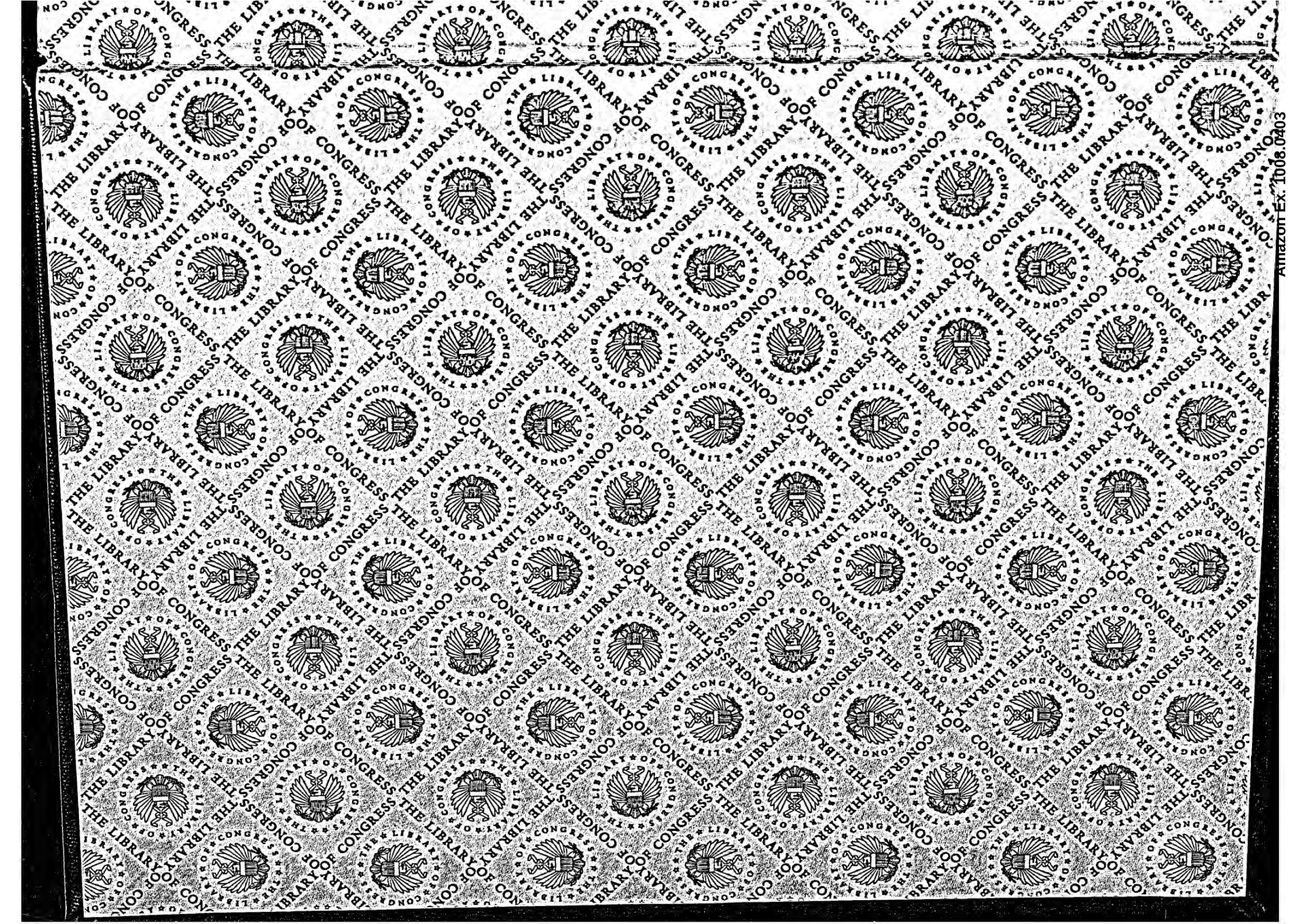
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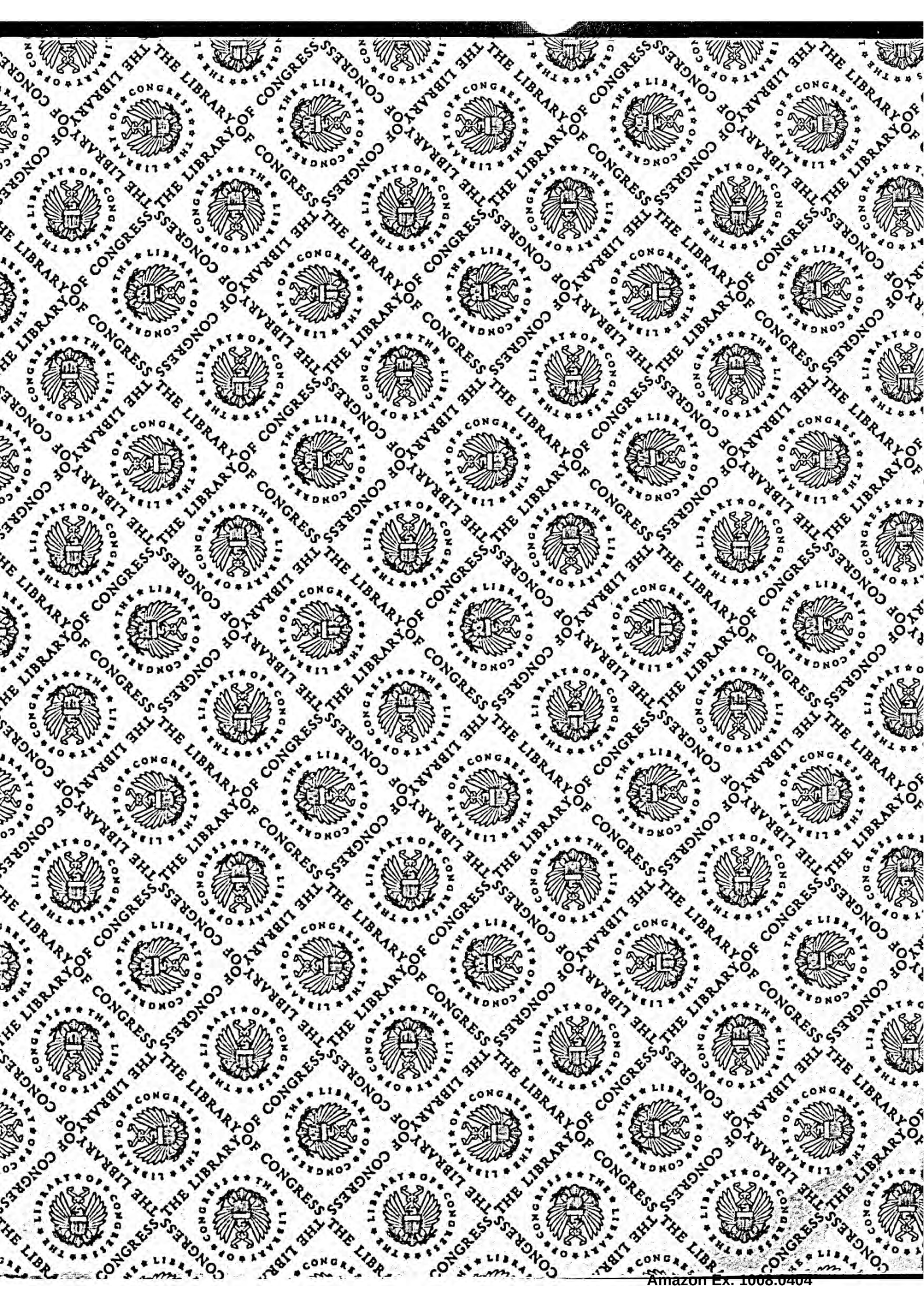
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Robot-Augmented Communication: A Remote-collaboration System based on a Shared Field of View in Real Space

Tamotsu Machino, Yoshito Nanjo, Yoshimasa Yanagihara,
Hiroaki Kawata, Satoshi Iwaki, and Ken-ichiro Shimokura
Human Interaction Project, NTT Cyber Solutions Laboratories
3-9-11, Midori-Cho, Musashino-Shi, Tokyo, Japan
{machino.tamotsu, nanjo.yoshito, yanagihara.yoshimasa,kawata.hiroaki, iwaki.satoshi, k.shimokura}@lab.ntt.co.jp

Abstract - **To create a more efficient environment in which to perform remote maintenance, the authors propose a novel collaboration concept, called robot-augmented communication (RAC). In RAC a maintenance robot and an on-site human worker are assisted by another skilled human operator at a remote support center. By emphasizing the intentions of the remote supporter through robot functions that cannot be imitated by humans, RAC can provide effective support for the on-site worker. In the present study, as the first manifestation of RAC, featuring the projection capability of a maintenance robot, a prototype remote-collaboration system named SCOPE (sight collaboration by projection effect) was developed. This system consists of a projector unit with a camera, a multiple control unit (MCU) for video/voice communications, and PCs connected via a network. It has three key functions: creating a shared field of view between a remote supporter and an on-site worker, keeping meta-information related to objects in real space, and projecting meta-information onto the objects. The effectiveness of these functions was evaluated by experiments on two fundamental tasks—"comprehending a target object" and "transmission of instruction details"—involved in a typical maintenance operation. The experimental results show that each function is effective in shortening the time taken to perform the maintenance operation.**

Index Terms - Remote collaboration, Shared field of view, Meta-information, Information projection

I. Introduction

In recent years, the number of experienced workers in manufacturing industries has been declining; thus, how to perform swift and efficient maintenance with a small number of experienced workers in a factory has become a serious problem. Under these circumstances, development of a "remote-maintenance" environment utilizing networks and information technology (IT) become more and important from now onwards. As regards this problem, the following two approaches have been conventionally taken.

- Perform on-site maintenance operations by dispatching autonomous robots to the site or by utilizing remote-control operation technology [1] [2]
- Dispatch an unskilled worker to the site and assist the worker in performing maintenance operations by another skilled supporter in a remote support center [3][4][9]

As regards the first approach, a robot is an effective tool for working in limited spaces in which people cannot enter. However, in consideration of problems such as time lags in network communication and the current level of autonomous operability of robots, it is clear that this robot approach cannot reach the level of operability possible by dispatching a human worker to perform on-site maintenance. As regards the second approach, various attempts to assist an unskilled worker using video transmission and IT methods are being performed. However, such attempts have found that the on-site worker not only has to carry heavy IT devices like wearable PCs but also the intentions of the remote supporter are often not sufficiently transmitted. Under these circumstances, the mental as well as the physical burden on the on-site worker becomes a serious problem.

In recent times, application of robot technology has not stopped at industrial fields; it has also spread to the home and office. At the same time, research on communication and cooperative working under the assumption of harmonious coexistence of humans and robots is continuing apace. As regards this research, the roles and tasks of humans and robots are clearly defined, each other's weak points are interpolated, and relationships between them are formulated. In the current report, attention is focused on this interpolation relationship between humans and robots, and the role and necessary functions of a robot for remote maintenance are discussed.

In section 2, the advantages and disadvantages of the two approaches mentioned above are compared, and then section 3 introduces a new concept called "robot-augmented communication"—namely, a way of redeeming these advantages and disadvantages by extending the skills of a distant skilled worker to a work site through on-site communication between an unskilled worker and a robot. After that, section 3 explains the hypothesis concerning the essential requirements for robot-augmented communication, and then describes a test system—called SCOPE (sight collaboration by projection effect)—for providing a shared field of view in real space. Section 4 then presents the results from experiments with the SCOPE system, and Section 5 wraps up this report with our conclusions and future study direction.

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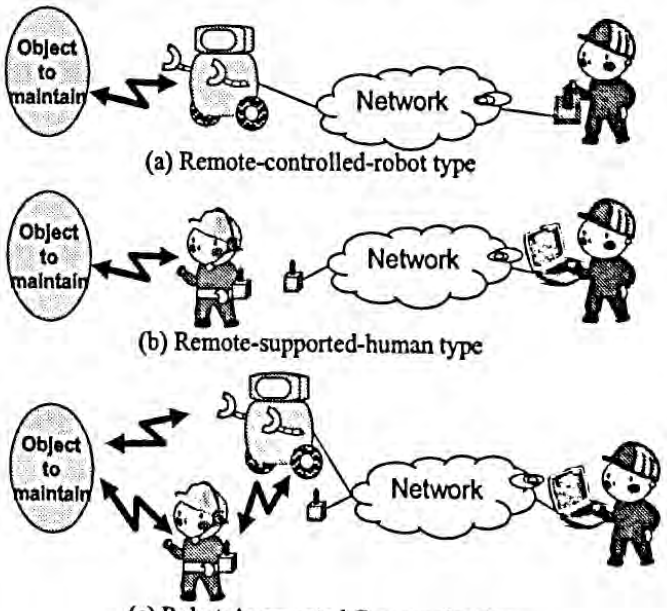
II. ROBOT-AUGMENTED COMMUNICATION

As mentioned above, in the case that a skilled worker is not present at a work site, there are two ways of handling maintenance: either remotely operate a robot and devices at the site (see Fig. 1(a) below) or dispatch an unskilled worker to the site and remotely instruct him to perform maintenance operations from a distance (see Fig. 1(b)). In the case of Fig. 1(a), the robot and a person (i.e., the skilled operator) cooperate through a network in such a way that the robot interacts with the outside world. On the other hand, in the case of Fig. 1(b), two people (the skilled operator and the unskilled worker) cooperate through a network, and the unskilled worker interacts with the outside world. Each of these two cases—namely, the robot or the person handling the on-site operation—has its own advantages and disadvantages as explained below.

1.(a) Remote-controlled-robot type: Robot operation (e.g., in terms of power and information-processing capability) can surpass that of a human operator, but the present level of autonomy of current robots is low and cannot match the operation skill of the remote skilled worker.

1.(b) Remote-supported-human type: Generally decision capability of a person in response to site conditions is much better than that of a robot, but under the present state of communication between a on-site work's side and a supporter's side, it is difficult to sufficiently convey the intentions of the remote supporter (skilled operator) without putting undue stress on the unskilled worker. For example, due to the time-delay of a network, the supporter's intention often cannot be transmitted rapidly and smoothly.

With the drawbacks of the above two approaches in mind, and aiming at extending the skill and ideas of a remote supporter to cover work sites, where specialized robot functions such as high-level information processing are particularly applicable, we are proposing a new form of collaboration between a robot and an on-site worker (who has a high decision capability). Since we have extended communication by means of a robot's functions, we call this collaboration set-up "robot augmented communication" hereafter. As shown in Fig. 1(c), by actively utilizing interaction between an on-site worker and robot functions that cannot be imitated by humans, robot-augmented communication provides effective support by emphasizing the intentions of the remote supporter through the robot.



(a) Remote-controlled-robot type

(b) Remote-supported-human type

(c) Robot-Augmented Communication

Fig. 1 Set ups for remote maintenance.

In the case of a remote support for on-site worker, two examples utilizing robots are GestureMan [5] developed by Kuzuoka et al. and C-term [6] developed by Mikawa et al. These systems, in which robots with mechanisms of some kind or other mediate between remote supporters and on-site workers, aim to smooth communication between these parties, and share the same fundamental research goals. However, the main point of these systems is to get the robot to re-create the behavior of the remote supporter; they have not been developed from the viewpoint of actively utilizing the functions of robots that humans cannot imitate.

Furthermore, as regards applications in fields apart from remote maintenance, such as InterRobot [7] developed by Watanabe et al. and Alter Ego Interface [8] developed by Hiraiwa et al., although experiments are being performed on attaining smooth communication through robots in distant places, the main thrust of these researches—namely, as in [7] and [8] directly recreating the behavior of humans—is different from our principle aim.

III. SCOPE: A SYSTEM FOR SUPPORTING A SHARED FIELD OF VIEW IN REAL SPACE

A. *Functions required by robots*

As robot functions that seek to surpass the ability of humans, mechanical support by power assistance and intellectual support by high-level information processing are two good examples. These functions must be selected in response to the target operation. As regards the current work, we are aiming at remote maintenance work as the target operation, and with realizing our goal of "robot-augmented communication" in mind, we are focusing on precise transmission of the intentions of a remote supporter to an on-site worker. In our previous work, we developed a remote-supported-human-type system called Field-AID [3]—which has the collaboration function utilizing multi-point video and voice communication. According to the experimental results on remote collaboration operations using Field-AID, the following key issues must be addressed in order to make remote collaboration more effective.

(A) Whether the object indicated by the remote supporter is within the field of view of the on-site worker or what is in the field of view are unclear.

(B) The relationship between the information presented by the remote supporter and physical objects at the on-site worker's side is undefined.

(C) Devices worn by the on-site worker (i.e., a head-mounted display and a wearable PC) exert a heavy load.

As regards tackling issues (A) and (B), we set up a particularly effective hypothesis called a "real-space

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information presentation function," as explained in the following key points and shown schematically in Fig. 2.

(1) Shared-field-of-view function: Share a target object perceived in the field of view of an on-site worker with a remote supporter.

(2) Indexing function: From a remote place, affix information to objects in on-site real space or in specified locations.

(3) Superimposed-information function: Information is presented directly in real space, where it can be selected and manipulated.

As regards the solution to issue (C) stated above, by fitting a projector and a camera to a mobile robot, and turning over the function of presenting information in real space to the robot itself, we are able to realize the functions stated above. That is to say, the functions that a person cannot perform themselves—such as presenting information in real space—are given to the robot. In addition, as for operations in the real world, since the working space is not always spatially fixed, so a projector fixed in one place is inadequate. By having the robot move in real space, we can expect that the on-site worker will not have to wear information devices and spatial limitations in the working space will be eliminated.

With realizing the above-mentioned functions in mind, we considered a method using a head-mounted display (HMD)—often used in the fields of mixed reality (MR) and augmented reality (AR)—for superimposing meta-information onto a target object. However, in the case of using a current HMD, issue (C) remains unsolved; therefore, we consider that the method proposed here—namely, utilizing a projector—is more effective.

B. *System for hypothesis testing*

1) System configurations

To test the hypothesis outlines in the previous section, we developed a remote-support system called SCOPE (sight collaboration by projection effect) for providing a shared field of view in real space. Fig. 3 shows the configuration of this system schematically.

Under this configuration, a multi-point video/voice transmission server is connected via an IP network with client PCs set up respectively on the supporter's side and the on-site worker's side. The server can also function as a database server for managing attribute information (mentioned hereafter). The video/voice transmission unit utilizes NTT-IT's teleconferencing service called Meeting Plaza.

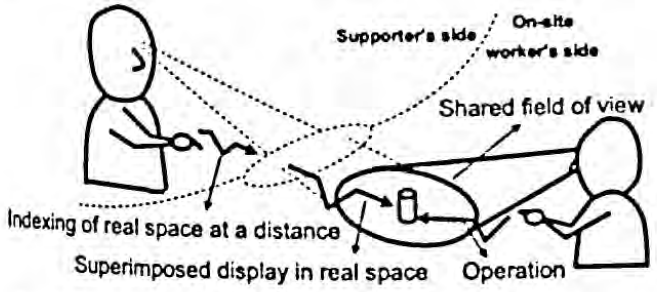


Fig. 2 Image of remote support to provide a shared field of view in real space.

On the on-site worker's side, a camera and a projector are integrated as one, and an incorporated stepping motor enables the camera's viewing field and the projected images to rotate around the vertical axis. To attain the capability of a "shared viewing field" as explained later, the domains of the viewing fields of the camera and the projector are adjusted so that they line up as one. Furthermore, in this study, major emphasis is placed on verifying the function of presenting information in real space, and it is assumed that the number of degrees of freedom of the robot is only one.

Since the on-site worker is not wearing a "wearable" PC, operating the client PC while working is difficult. Accordingly, a laser pointer is set up as an input interface. By means of image-recognition processing on the position of the laser pointer, we experimentally implemented a manipulation function equivalent to the mouse on the client PC.

2) Shared-field-of-view function

During remote collaborative operations, one scene that often occurs is the remote supporter giving instructions to the on-site worker verbally. As long as the remote supporter and on-site worker share common information about the targeted object, specifying the targeted object and giving manipulation instructions are relatively easy. However, if that is not the case, indicating relative directions like "on the right" is frequently used. At such times, the remote supporter's viewing field becomes essential information from the viewpoint of the on-site worker.

In the SCOPE system, by unifying the camera's viewing field and projector's projection area and displaying a frame on the projected images, it is possible to present the remote supporter's viewing field to the on-site worker.

3) Indexing function

Information needed for carrying out operations (referred to as "attribute information" hereafter), is affixed to the target object in terms of position coordinates in the working space, controlled, and displayed as occasion demands. In the developed system, five kinds of fool-proof information are conveyed: text, still images, video, sound, and program administration. Programs are looked upon as attributed

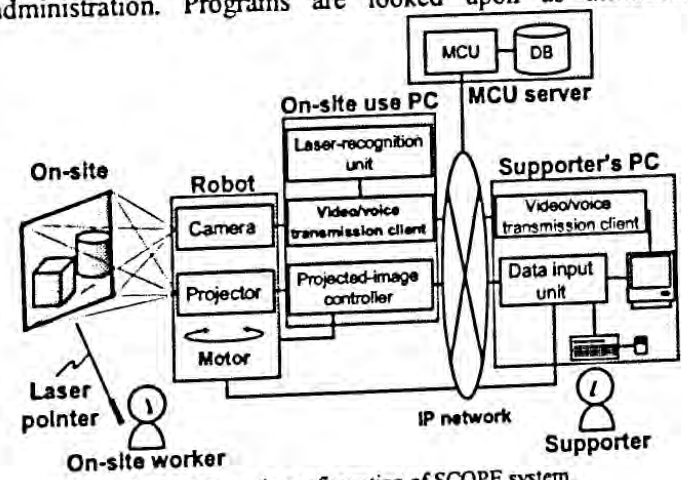


Fig. 3 Schematic configuration of SCOPE system.

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information and foolproof, so they can be executed and terminated on the on-site worker's side. The location of related attributed information affixed to the target object is marked as a graphical image with a circular form (known as a "projected object"). For example, in a scene in which a chemical solution is selected from a shelf of items, attribute information is recorded as its characteristic properties and appropriate handling procedures, and a projected object is displayed at the location of the bottle containing that chemical. By manipulating the projected object, the display status of attribute information can also be manipulated. On the on-site worker's side, the laser pointer is used to manipulate the projected object; on the supporter's side, the projected object is shown on a communication screen displaying images transmitted from the on-site worker's side and manipulated by PC mouse (see Fig. 4). Records of the attribute information can then be processed and analyzed by various GUIs on the supporter's side communication display.

4) Superimposed-information function

As regards the SCOPE system, the camera and projector on the on-site worker's side can be manipulated from the supporter's side, and the domains of the viewing field and the information presentation can be changed. In this case, the movement of the motor and the projected image plane of the connected projector are compensated, and the projected object and the attribute information can be presented in real space in a stationary manner. This function enables the on-site worker to intuitively recognize the relationship between a stationary object in real space and its attribute information.

5) Other functions

By projection of images to the on-site work's side by moving the mouse of the remote supporter's client PC, an action referred to as "pseudo-finger pointing" is performed. The mouse-cursor mode can be selected to show or hide the track of the cursor. Accordingly, by choosing to show the cursor tracks, it is possible to write simple text and draw signs in real space. Moving the operation target object in this way is exploited when the operation instructions involve directions.

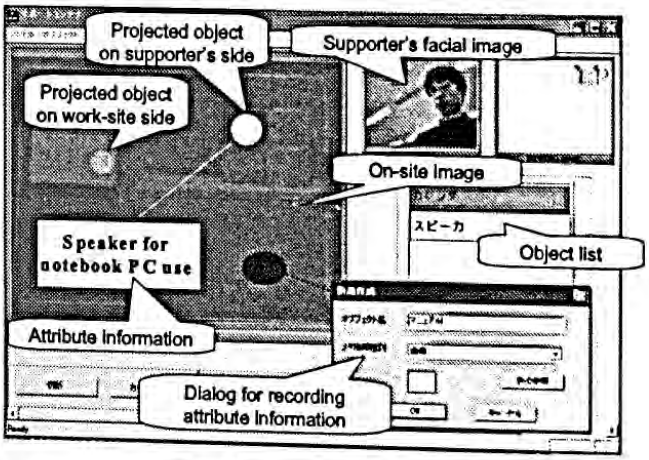


Fig. 4 View of a support screen.

IV. Verification Experiments

A. Verification of shared-field-of-view function

1) Experimental aims

In the most cases of receiving instructions regarding equipment maintenance work from a skilled worker at a remote support center, first, "comprehending the target object"—namely, mutually recognizing the place to be the target of instructions—is carried out. After that, "transmission of instruction details" is performed. In this section, taking up the "comprehending the target object" phase just mentioned, we aimed at verifying the effectiveness of the shared-viewing-field function experimentally. Accordingly, by means of remote indication utilizing the shared-field-of-view function of SCOPE, we measured the time taken for the on-site worker to comprehend the indicated target object and, thus, estimated the worker's efficiency.

2) Experimental method

The experiments consist of one person as the on-site worker and another person as the remote supporter. The task of the worker is to pick out a target object stuck to a wall by following instructions from the remote supporter, and then stick that object in a different place. As target objects, 20 cards painted with various graphical forms were stuck to a wall on the worker's side; the same cards were also laid out on the supporter's side. The supporter arbitrarily chose five cards from the 20 and then instructed the worker to pick out these cards in sequence. The graphics on the cards were framed by random free-form curves. A scene from one of the experiments is shown in Fig. 5.

Table I lists the four sets of conditions set up for the experiments. Under conditions 1 and 2, the shared-field-of-view function of SCOPE is used to indicate the target object. Under condition 1, by displaying the PC mouse cursor, specified points within the shared viewing field can be pointed out. Under condition 3, only conventional video and voice communication is used to give instructions. And under condition 4, instructions are given by voice—via telephone—

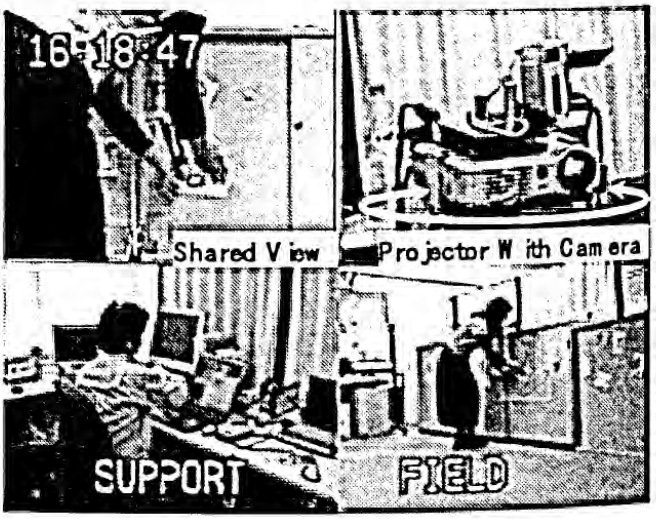


Fig. 5 Scenes of verification experiments.

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TABLE I
EXPERIMENTAL CONDITIONS FOR VERIFYING SHARED VIEWING FIELD

	Voice	Image	Viewing field display	Cursor display
Condition 1	Yes	Yes	Yes	Yes
Condition 2	Yes	Yes	Yes	No
Condition 3	Yes	Yes	No	No
Condition 4	Yes	No	No	No

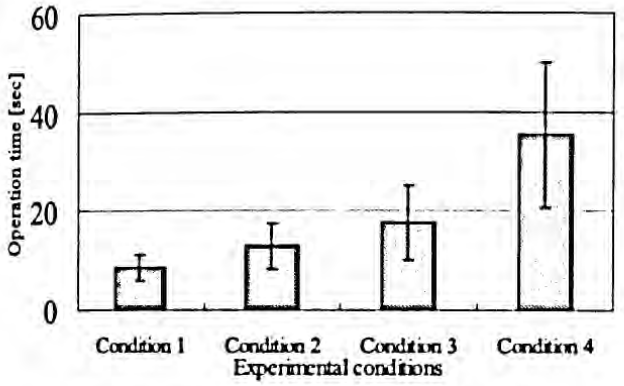


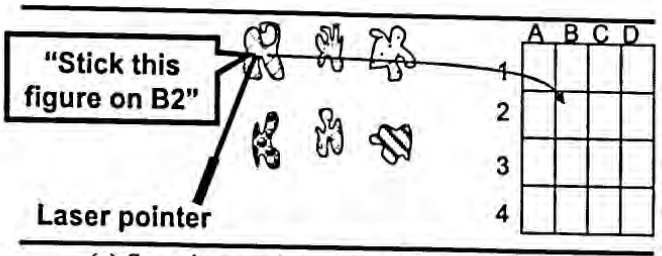
Fig. 6 Experimental results on shared viewing field.

only. A group of four people were used as subjects in experiments under all four conditions.

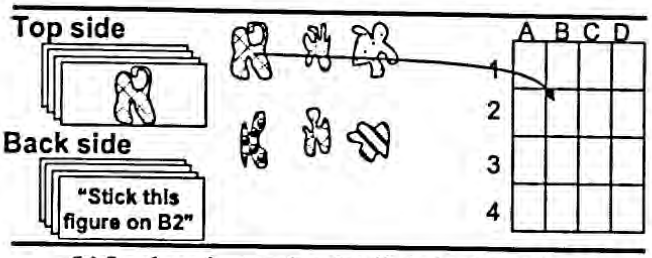
3) Experimental results and discussion

The time taken from the beginning of the supporter's explanation about the target object until the worker sticks that object at the specified point is taken as the "operation time." The mean values and standard deviations of the measured operation times under the four test conditions are plotted as bar graphs in Fig. 6. It is clear that compared to the operation time for the voice-only condition 4, the times get shorter and variation gets lower as more functions are added (i.e., conditions 3 to 1). Moreover, the results confirm that utilizing the shared-field-of-view function of SCOPE (i.e., conditions 1 and 2) shortens the time required to identify the target object.

Furthermore, as for the result under condition 4—which shows a large variation—even with voice instructions only, some short operation times are shown. This is because in some cases the graphic symbols framed by random curved lines remind both the worker and the supporter of familiar shapes (e.g., the shape of a prefecture boundary or an animal). That is to say, it is sometimes the case that an operation can be sufficiently carried out by listening to voice instructions alone. This means that, as regards remote collaboration operations, in the case that both the worker and supporter are skilled workers, they both understand common technical jargon, and voice communication only is sufficient. On the other hand, under the noise of a factory environment, it is difficult to hear voice instructions, and language barriers can sometimes arise during interactions with overseas locations. In these problematic cases, we consider that the shared-field-of-view function will demonstrate its effectiveness.



(a) Superimposed display of instruction details



(b) Look up instruction details in booklet of cards

Fig. 7 Method used for Test 1.

B. Verification experiments for indexing and superimposed-information functions

1) Experimental aims

The aim of these experiments was to verify the effectiveness of the indexing and superimposed-information functions under the assumptions described in section 3. Accordingly, taking up the phase "transmission of instruction details" mentioned previously, we set out two tasks for testing. In experiment 1, the "ease of transmission" of the instruction details within the time taken to understand them was evaluated. In experiment 2, the "memory retainability" of the instruction details (i.e., how easily they are retained) within the time required to perform the operation was evaluated.

2) Experiment 1: Ease of transmission of instruction details

As target objects, 16 cards each drawn with a different graphic figure are stuck to a wall, and each card is fixed with corresponding instructions. The worker thus performs operations according to these 16 sets of instructions. As shown in Fig. 7, the worker transfers each card to a specified position on a four-by-four matrix, and by following the two different instruction methods only, the worker correlates the cards on the matrix. In method (a), the indexing function of SCOPE is used beforehand to record the instructions on the cards in text. When the card is pointed out by laser pointer, the recorded instructions are superimposed onto the card. In method (b), a booklet (or "manual") of cards, each drawn with the same graphic figures as the cards stuck to the wall, is used, and the instructions for each card are written on it's back face. By looking though the manual, the worker can search for the instructions corresponding to a certain figure. In the experiments, three subjects performed the tasks using method (a) and method (b).

3) Experiment 1 results and discussion

In the two cases—either (a) superimposing the instructions on the cards or (b) looking up the instructions in

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TABLE II
RESULTS OF EXPERIMENT 1

Test subject	(a) Superimposition display method (operation time in sec)	(b) Card booklet (manual) look-up method (operation time in sec)
1	157	380
2	175	295
3	159	290

the booklet—the time taken to lay out all 16 correctly is taken as the "operation time," and the measured operation times for the three subjects using each method are listed in Table II. For all subjects, it is clear that the operation time is shorter when they use method (a). Moreover, the time required to record the instructions by using the SCOPE indexing function is 640 seconds (i.e., an average of 40 seconds per card). In regards to the instruction recording, although the time required to record the instructions can be reduced by improving the user interface, the time that goes with an increased number of recordings is thought to be considerable. From the viewpoint of the worker, it is necessary to take into account not only the operation time but also the time required for preparation. Nevertheless, in the case that instructions recorded once are used any number of times or in the case that the operation time should be shortened even a little under a poor factory environment, the indexing function is effective.

4) Experiment 2: Memory remnants of instruction details

In this experiment 2, 48 cards are stuck to a wall, and a memory game is played. One of the 24 letters of the alphabet is stuck to each card, creating 24 pairs of cards with the same letter. The worker chooses two cards at a time, and using either method (c) or (d) below, verifies the details associated with each card, and performs operations created by the pairs.

(c) Cards are selected by laser pointer, and their descriptions (letters of the alphabet) are superimposed on them. In the case that the selected cards are not a matching pair, the description of those cards are not displayed.

(d) Cards are selected by laser pointer, and their descriptions (letters of the alphabet) are given by voice.

Each of three subjects performed the task once using method (c) and once by (d).

5) Experiment 2 results and discussion

The time to complete matching of all the cards is taken as the operation time, and the measurement times are listed in Table III. In the case of all the subjects, the operation times are shorter when they perform the task using the superimposition method (see (c) above). According to the post-experiment impressions of the subjects, using the voice-only method (see (d) above) was often stressful. In the case of a memory game like this, if a card flipped over once does not form a pair, that card has to be kept in mind. The experimental results suggest that the superimposition method makes it easier for the subject to memorize the cards. In the case that support is given from a skilled worker at a distant location, if a problem can be handled only once, it is sufficient

TABLE III
RESULTS OF EXPERIMENT 2

	Subject	Operation time
Superimposed display (method (c))	1	10 min 41 sec
	2	24 min 38 sec
	3	13 min 01 sec
Voice presentation (method (d))	1	15 min 36 sec
	2	30 min 31 sec
	3	17 min 35 sec

to give instructions and guidance by voice. However, in the case that an on-site worker has to repeat the same operation at a later date, if the superimposition method was used, the on-site worker gets a deeper understanding of the operation details and will find it easier to remember them for future operations. This intriguing result thus shows the advantage of the superimposition method.

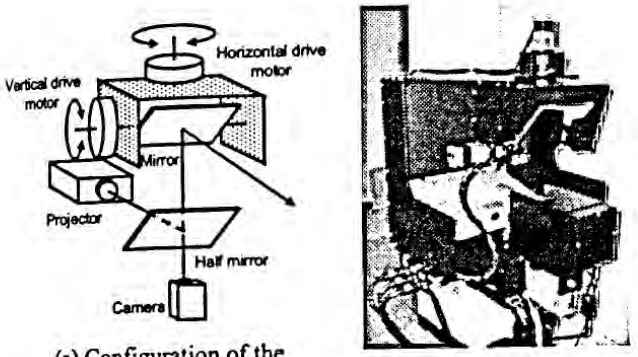
C. Discussion on multiplying the number of degrees of freedom of the robot and related future work

In the current study, we took up the function of displaying information in real space as a robot function for extending communication, and we verified the effectiveness of this method in the previous sections. As for the robot's motion mechanism, only one degree of freedom (i.e., rotation about the vertical axis) was dealt with. However, as mentioned in section 3, if we assume operations in the real world, to achieve unrestricted operation in free space, it is necessary to increase the robot's number of degrees of freedom, especially concerning it's mobility. Accordingly, in the following discussion, we examine the challenges concerning equipping a mobile robot with the capability of displaying information in real space.

As regards our SCOPE system, to achieve the capability of a shared field of view, as shown previously in Figure 3, a camera and projector are unified as one in order to bring together the camera's viewing field and the projector's projection field. In the case of this method, the distance to the projected image is assumed to be constant. However, in the case of a mobile robot, this distance is variable. This means that, in accordance with the degree of this variation, calibration must be performed to match up the camera's viewing field and the projector's projection field. By skillfully aligning the optical axes of the camera and projector mechanically, as shown in the set up in Fig. 8(a), even if the distance to the target object varies, the viewing field and projection field are kept together. An external view of our prototype camera/projector with a combined optical axis is shown in Fig. 8(b). In our future work, we plan to mount this camera/projector on a mobile robot and investigate its effectiveness.

In regards to SCOPE, by realizing the functions for information indexing and superimposition, and correcting the projected image plane in accordance with the variation of the camera's orientation, projected objects and attribute information can be presented as still images in real space. With this method, it is assumed that the camera's orientation is

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(a) Configuration of the projector and camera

(b) External appearance

Fig. 8 Projector and camera with unified optical axis.

known. In the case of mounting the camera on a mobile robot, the location of the robot itself must be obtained, and the projected image plane must be corrected according to that location. In the system targeted in the current study, since it is expected that a human worker can do corrections (for example, adjustments by a remotely located skilled worker on the position of the projected object), there is a good chance that the accurate position of the robot itself cannot be acquired. From now onwards, firstly, we plan to establish the capability of correcting the projected image by utilizing existing identification methods for acquiring a robot's own location, and then verify these methods experimentally.

V. Conclusions

The concept of "robot-augmented communication" was introduced in this study. Involving cooperation between an unskilled worker and a robot on-site, this concept aims at a collaboration set up in which a skilled worker remotely located from a work site supports an on-site worker by communicating his intentions through a robot. Incorporating three essential functions that a robot must be fitted with, namely, shared field of view, information indexing, and superimposed presentation, the constructed SCOPE (sight collaboration by projection effect) system demonstrated that these functions shorten the on-site operation time. Furthermore, we discussed problems in regard to equipping a mobile robot with the function for presenting information in real-space. From now on, we plan to mount such a real-space-information-presentation function—which combines the optical axes of a camera and projector—on a mobile robot, and while verifying this function, we will examine ways of handling the challenge of identifying the robot's own location.

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Appendix E-2

Robot-Augmented Communication: A Remote-collaboration System based on a Shared Field of View in Real Space

Tamotsu Machino, Yoshito Nanjo, Yoshimasa Yanagihara,
Hiroaki Kawata, Satoshi Iwaki, and Ken-ichiro Shimokura
Human Interaction Project, NTT Cyber Solutions Laboratories
3-9-11, Midori-Cho, Musashino-Shi, Tokyo, Japan
{machino.tamotsu, nanjo.yoshito, yanagihara.yoshimasa,kawata.hiroaki, iwaki.satoshi, k.shimokura}@lab.ntt.co.jp

***Abstract* - To create a more efficient environment in which to perform remote maintenance, the authors propose a novel collaboration concept, called robot-augmented communication (RAC). In RAC a maintenance robot and an on-site human worker are assisted by another skilled human operator at a remote support center. By emphasizing the intentions of the remote supporter through robot functions that cannot be imitated by humans, RAC can provide effective support for the on-site worker. In the present study, as the first manifestation of RAC, featuring the projection capability of a maintenance robot, a prototype remote-collaboration system named SCOPE (sight collaboration by projection effect) was developed. This system consists of a projector unit with a camera, a multiple control unit (MCU) for video/voice communications, and PCs connected via a network. It has three key functions: creating a shared field of view between a remote supporter and an on-site worker, keeping meta-information related to objects in real space, and projecting meta-information onto the objects. The effectiveness of these functions was evaluated by experiments on two fundamental tasks—"comprehending a target object" and "transmission of instruction details"—involved in a typical maintenance operation. The experimental results show that each function is effective in shortening the time taken to perform the maintenance operation.**

Index Terms - Remote collaboration, Shared field of view, Meta-information, Information projection

I. INTRODUCTION

In recent years, the number of experienced workers in manufacturing industries has been declining; thus, how to perform swift and efficient maintenance with a small number of experienced workers in a factory has become a serious problem. Under these circumstances, development of a "remote-maintenance" environment utilizing networks and information technology (IT) become more and important from now onwards. As regards this problem, the following two approaches have been conventionally taken.

- Perform on-site maintenance operations by dispatching autonomous robots to the site or by utilizing remote-control operation technology [1] [2]
- Dispatch an unskilled worker to the site and assist the worker in performing maintenance operations by another skilled supporter in a remote support center [3][4][9]

As regards the first approach, a robot is an effective tool for working in limited spaces in which people cannot enter. However, in consideration of problems such as time lags in network communication and the current level of autonomous operability of robots, it is clear that this robot approach cannot reach the level of operability possible by dispatching a human worker to perform on-site maintenance. As regards the second approach, various attempts to assist an unskilled worker using video transmission and IT methods are being performed. However, such attempts have found that the on-site worker not only has to carry heavy IT devices like wearable PCs but also the intentions of the remote supporter are often not sufficiently transmitted. Under these circumstances, the mental as well as the physical burden on the on-site worker becomes a serious problem.

In recent times, application of robot technology has not stopped at industrial fields; it has also spread to the home and office. At the same time, research on communication and cooperative working under the assumption of harmonious coexistence of humans and robots is continuing apace. As regards this research, the roles and tasks of humans and robots are clearly defined, each other's weak points are interpolated, and relationships between them are formulated. In the current report, attention is focused on this interpolation relationship between humans and robots, and the role and necessary functions of a robot for remote maintenance are discussed.

In section 2, the advantages and disadvantages of the two approaches mentioned above are compared, and then section 3 introduces a new concept called "robot-augmented communication"—namely, a way of redeeming these advantages and disadvantages by extending the skills of a distant skilled worker to a work site through on-site communication between an unskilled worker and a robot. After that, section 3 explains the hypothesis concerning the essential requirements for robot-augmented communication, and then describes a test system—called SCOPE (sight collaboration by projection effect)—for providing a shared field of view in real space. Section 4 then presents the results from experiments with the SCOPE system, and Section 5 wraps up this report with our conclusions and future study direction.

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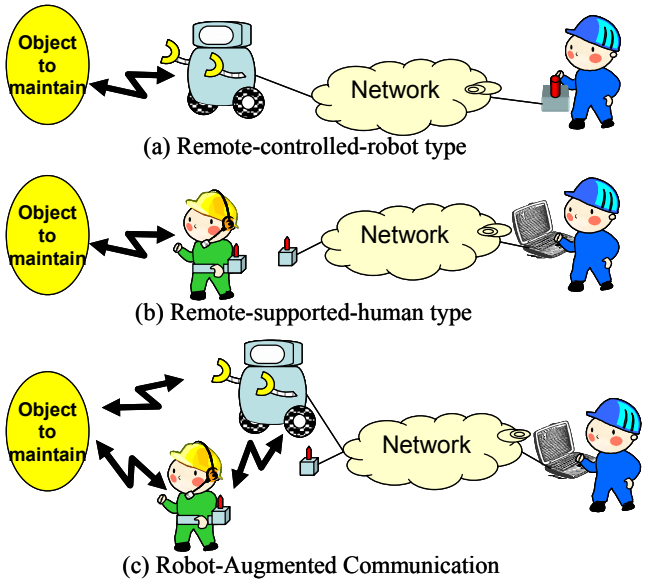
II. Robot-Augmented Communication

As mentioned above, in the case that a skilled worker is not present at a work site, there are two ways of handling maintenance: either remotely operate a robot and devices at the site (see Fig. 1(a) below) or dispatch an unskilled worker to the site and remotely instruct him to perform maintenance operations from a distance (see Fig. 1(b)). In the case of Fig. 1(a), the robot and a person (i.e., the skilled operator) cooperate through a network in such a way that the robot interacts with the outside world. On the other hand, in the case of Fig. 1(b), two people (the skilled operator and the unskilled worker) cooperate through a network, and the unskilled worker interacts with the outside world. Each of these two cases—namely, the robot or the person handling the on-site operation—has its own advantages and disadvantages as explained below.

1.(a) Remote-controlled-robot type: Robot operation (e.g., in terms of power and information-processing capability) can surpass that of a human operator, but the present level of autonomy of current robots is low and cannot match the operation skill of the remote skilled worker.

1.(b) Remote-supported-human type: Generally decision capability of a person in response to site conditions is much better than that of a robot, but under the present state of communication between a on-site work's side and a supporter's side, it is difficult to sufficiently convey the intentions of the remote supporter (skilled operator) without putting undue stress on the unskilled worker. For example, due to the time-delay of a network, the supporter's intention often cannot be transmitted rapidly and smoothly.

With the drawbacks of the above two approaches in mind, and aiming at extending the skill and ideas of a remote supporter to cover work sites, where specialized robot functions such as high-level information processing are particularly applicable, we are proposing a new form of collaboration between a robot and an on-site worker (who has a high decision capability). Since we have extended communication by means of a robot's functions, we call this collaboration set-up "robot augmented communication" hereafter. As shown in Fig. 1(c), by actively utilizing interaction between an on-site worker and robot functions that cannot be imitated by humans, robot-augmented communication provides effective support by emphasizing the intentions of the remote supporter through the robot.



(a) Remote-controlled-robot type

(b) Remote-supported-human type

(c) Robot-Augmented Communication

Fig. 1 Set ups for remote maintenance.

In the case of a remote support for on-site worker, two examples utilizing robots are GestureMan [5] developed by Kuzuoka et al. and C-term [6] developed by Mikawa et al. These systems, in which robots with mechanisms of some kind or other mediate between remote supporters and on-site workers, aim to smooth communication between these parties, and share the same fundamental research goals. However, the main point of these systems is to get the robot to re-create the behavior of the remote supporter; they have not been developed from the viewpoint of actively utilizing the functions of robots that humans cannot imitate.

Furthermore, as regards applications in fields apart from remote maintenance, such as InterRobot [7] developed by Watanabe et al. and Alter Ego Interface [8] developed by Hiraiwa et al., although experiments are being performed on attaining smooth communication through robots in distant places, the main thrust of these researches—namely, as in [7] and [8] directly recreating the behavior of humans—is different from our principle aim.

III. SCOPE: A System For Supporting A Shared Field Of View In Real Space

A. *Functions required by robots*

As robot functions that seek to surpass the ability of humans, mechanical support by power assistance and intellectual support by high-level information processing are two good examples. These functions must be selected in response to the target operation. As regards the current work, we are aiming at remote maintenance work as the target operation, and with realizing our goal of "robot-augmented communication" in mind, we are focusing on precise transmission of the intentions of a remote supporter to an on-site worker. In our previous work, we developed a remote-supported-human-type system called Field-AID [3]—which has the collaboration function utilizing multi-point video and voice communication. According to the experimental results on remote collaboration operations using Field-AID, the following key issues must be addressed in order to make remote collaboration more effective.

(A) Whether the object indicated by the remote supporter is within the field of view of the on-site worker or what is in the field of view are unclear.

(B) The relationship between the information presented by the remote supporter and physical objects at the on-site worker's side is undefined.

(C) Devices worn by the on-site worker (i.e., a head-mounted display and a wearable PC) exert a heavy load.

As regards tackling issues (A) and (B), we set up a particularly effective hypothesis called a "real-space

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information presentation function," as explained in the following key points and shown schematically in Fig. 2.

(1) Shared-field-of-view function: Share a target object perceived in the field of view of an on-site worker with a remote supporter.

(2) Indexing function: From a remote place, affix information to objects in on-site real space or in specified locations.

(3) Superimposed-information function: Information is presented directly in real space, where it can be selected and manipulated.

As regards the solution to issue (C) stated above, by fitting a projector and a camera to a mobile robot, and turning over the function of presenting information in real space to the robot itself, we are able to realize the functions stated above. That is to say, the functions that a person cannot perform themselves—such as presenting information in real space—are given to the robot. In addition, as for operations in the real world, since the working space is not always spatially fixed, so a projector fixed in one place is inadequate. By having the robot move in real space, we can expect that the on-site worker will not have to wear information devices and spatial limitations in the working space will be eliminated.

With realizing the above-mentioned functions in mind, we considered a method using a head-mounted display (HMD)—often used in the fields of mixed reality (MR) and augmented reality (AR)—for superimposing meta-information onto a target object. However, in the case of using a current HMD, issue (C) remains unsolved; therefore, we consider that the method proposed here—namely, utilizing a projector—is more effective.

B. System for hypothesis testing

1) System configurations

To test the hypothesis outlines in the previous section, we developed a remote-support system called SCOPE (sight collaboration by projection effect) for providing a shared field of view in real space. Fig. 3 shows the configuration of this system schematically.

Under this configuration, a multi-point video/voice transmission server is connected via an IP network with client PCs set up respectively on the supporter's side and the on-site worker's side. The server can also function as a database server for managing attribute information (mentioned hereafter). The video/voice transmission unit utilizes NTT-IT's teleconferencing service called Meeting Plaza.

On the on-site worker's side, a camera and a projector are integrated as one, and an incorporated stepping motor enables the camera's viewing field and the projected images to rotate around the vertical axis. To attain the capability of a "shared viewing field" as explained later, the domains of the viewing fields of the camera and the projector are adjusted so that they line up as one. Furthermore, in this study, major emphasis is placed on verifying the function of presenting information in real space, and it is assumed that the number of degrees of freedom of the robot is only one.

Since the on-site worker is not wearing a "wearable" PC, operating the client PC while working is difficult. Accordingly, a laser pointer is set up as an input interface. By means of image-recognition processing on the position of the laser pointer, we experimentally implemented a manipulation function equivalent to the mouse on the client PC.

2) Shared-field-of-view function

During remote collaborative operations, one scene that often occurs is the remote supporter giving instructions to the on-site worker verbally. As long as the remote supporter and on-site worker share common information about the targeted object, specifying the targeted object and giving manipulation instructions are relatively easy. However, if that is not the case, indicating relative directions like "on the right" is frequently used. At such times, the remote supporter's viewing field becomes essential information from the viewpoint of the on-site worker.

In the SCOPE system, by unifying the camera's viewing field and projector's projection area and displaying a frame on the projected images, it is possible to present the remote supporter's viewing field to the on-site worker.

3) Indexing function

Information needed for carrying out operations (referred to as "attribute information" hereafter), is affixed to the target object in terms of position coordinates in the working space, controlled, and displayed as occasion demands. In the developed system, five kinds of fool-proof information are conveyed: text, still images, video, sound, and program administration. Programs are looked upon as attributed

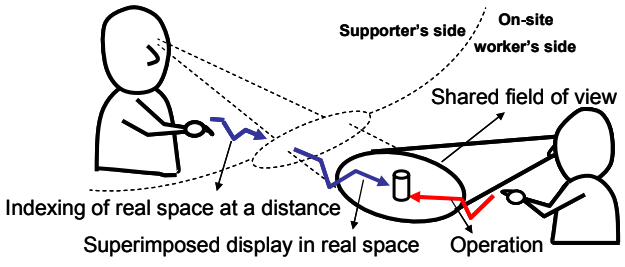


Fig. 2 Image of remote support to provide a shared field of view in real space.

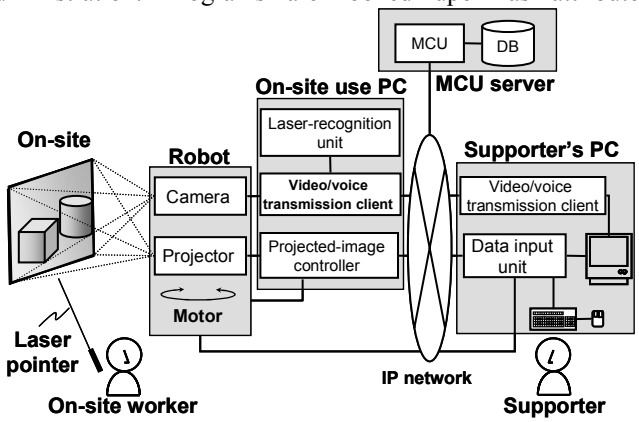


Fig. 3 Schematic configuration of SCOPE system.

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information and foolproof, so they can be executed and terminated on the on-site worker's side. The location of related attributed information affixed to the target object is marked as a graphical image with a circular form (known as a "projected object"). For example, in a scene in which a chemical solution is selected from a shelf of items, attribute information is recorded as its characteristic properties and appropriate handling procedures, and a projected object is displayed at the location of the bottle containing that chemical. By manipulating the projected object, the display status of attribute information can also be manipulated. On the on-site worker's side, the laser pointer is used to manipulate the projected object; on the supporter's side, the projected object is shown on a communication screen displaying images transmitted from the on-site worker's side and manipulated by PC mouse (see Fig. 4). Records of the attribute information can then be processed and analyzed by various GUIs on the supporter's side communication display.

4) Superimposed-information function

As regards the SCOPE system, the camera and projector on the on-site worker's side can be manipulated from the supporter's side, and the domains of the viewing field and the information presentation can be changed. In this case, the movement of the motor and the projected image plane of the connected projector are compensated, and the projected object and the attribute information can be presented in real space in a stationary manner. This function enables the on-site worker to intuitively recognize the relationship between a stationary object in real space and its attribute information.

5) Other functions

By projection of images to the on-site work's side by moving the mouse of the remote supporter's client PC, an action referred to as "pseudo-finger pointing" is performed. The mouse-cursor mode can be selected to show or hide the track of the cursor. Accordingly, by choosing to show the cursor tracks, it is possible to write simple text and draw signs in real space. Moving the operation target object in this way is exploited when the operation instructions involve directions.

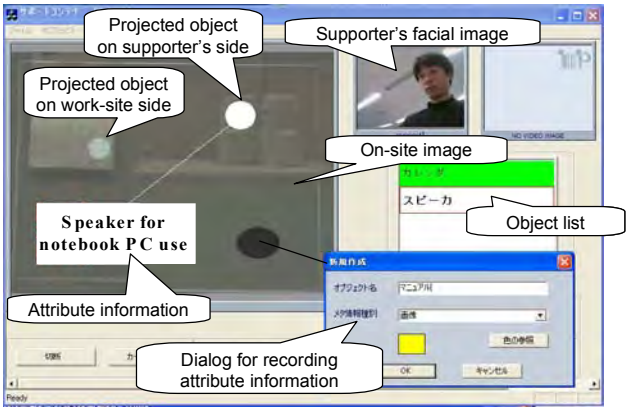


Fig. 4 View of a support screen.

IV. Verification Experiments

A. Verification of shared-field-of-view function

1) Experimental aims

In the most cases of receiving instructions regarding equipment maintenance work from a skilled worker at a remote support center, first, "comprehending the target object"—namely, mutually recognizing the place to be the target of instructions—is carried out. After that, "transmission of instruction details" is performed. In this section, taking up the "comprehending the target object" phase just mentioned, we aimed at verifying the effectiveness of the shared-viewing-field function experimentally. Accordingly, by means of remote indication utilizing the shared-field-of-view function of SCOPE, we measured the time taken for the on-site worker to comprehend the indicated target object and, thus, estimated the worker's efficiency.

2) Experimental method

The experiments consist of one person as the on-site worker and another person as the remote supporter. The task of the worker is to pick out a target object stuck to a wall by following instructions from the remote supporter, and then stick that object in a different place. As target objects, 20 cards painted with various graphical forms were stuck to a wall on the worker's side; the same cards were also laid out on the supporter's side. The supporter arbitrarily chose five cards from the 20 and then instructed the worker to pick out these cards in sequence. The graphics on the cards were framed by random free-form curves. A scene from one of the experiments is shown in Fig. 5.

Table I lists the four sets of conditions set up for the experiments. Under conditions 1 and 2, the shared-field-of-view function of SCOPE is used to indicate the target object. Under condition 1, by displaying the PC mouse cursor, specified points within the shared viewing field can be pointed out. Under condition 3, only conventional video and voice communication is used to give instructions. And under condition 4, instructions are given by voice—via telephone—



Fig. 5 Scenes of verification experiments.

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TABLE I
EXPERIMENTAL CONDITIONS FOR VERIFYING SHARED VIEWING FIELD

	Voice	Image	Viewing field display	Cursor display
Condition 1	Yes	Yes	Yes	Yes
Condition 2	Yes	Yes	Yes	No
Condition 3	Yes	Yes	No	No
Condition 4	Yes	No	No	No

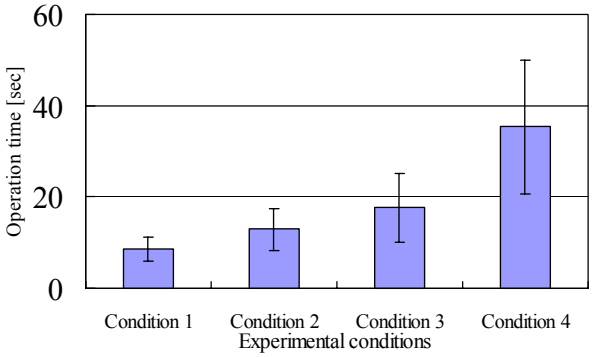


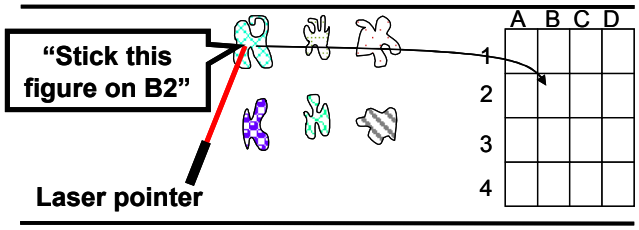
Fig. 6 Experimental results on shared viewing field.

only. A group of four people were used as subjects in experiments under all four conditions.

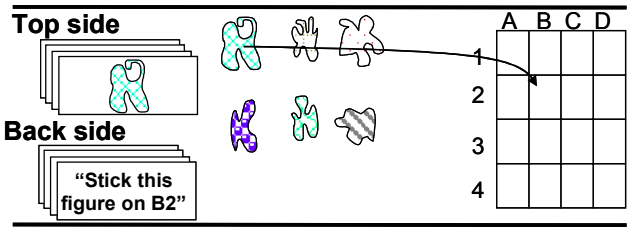
3) Experimental results and discussion

The time taken from the beginning of the supporter's explanation about the target object until the worker sticks that object at the specified point is taken as the "operation time." The mean values and standard deviations of the measured operation times under the four test conditions are plotted as bar graphs in Fig. 6. It is clear that compared to the operation time for the voice-only condition 4, the times get shorter and variation gets lower as more functions are added (i.e., conditions 3 to 1). Moreover, the results confirm that utilizing the shared-field-of-view function of SCOPE (i.e., conditions 1 and 2) shortens the time required to identify the target object.

Furthermore, as for the result under condition 4—which shows a large variation—even with voice instructions only, some short operation times are shown. This is because in some cases the graphic symbols framed by random curved lines remind both the worker and the supporter of familiar shapes (e.g., the shape of a prefecture boundary or an animal). That is to say, it is sometimes the case that an operation can be sufficiently carried out by listening to voice instructions alone. This means that, as regards remote collaboration operations, in the case that both the worker and supporter are skilled workers, they both understand common technical jargon, and voice communication only is sufficient. On the other hand, under the noise of a factory environment, it is difficult to hear voice instructions, and language barriers can sometimes arise during interactions with overseas locations. In these problematic cases, we consider that the shared-field-of-view function will demonstrate its effectiveness.



(a) Superimposed display of instruction details



(b) Look up instruction details in booklet of cards

Fig. 7 Method used for Test 1.

B. Verification experiments for indexing and superimposed-information functions

1) Experimental aims

The aim of these experiments was to verify the effectiveness of the indexing and superimposed-information functions under the assumptions described in section 3. Accordingly, taking up the phase "transmission of instruction details" mentioned previously, we set out two tasks for testing. In experiment 1, the "ease of transmission" of the instruction details within the time taken to understand them was evaluated. In experiment 2, the "memory retainability" of the instruction details (i.e., how easily they are retained) within the time required to perform the operation was evaluated.

2) Experiment 1: Ease of transmission of instruction details

As target objects, 16 cards each drawn with a different graphic figure are stuck to a wall, and each card is fixed with corresponding instructions. The worker thus performs operations according to these 16 sets of instructions. As shown in Fig. 7, the worker transfers each card to a specified position on a four-by-four matrix, and by following the two different instruction methods only, the worker correlates the cards on the matrix. In method (a), the indexing function of SCOPE is used beforehand to record the instructions on the cards in text. When the card is pointed out by laser pointer, the recorded instructions are superimposed onto the card. In method (b), a booklet (or "manual") of cards, each drawn with the same graphic figures as the cards stuck to the wall, is used, and the instructions for each card are written on it's back face. By looking though the manual, the worker can search for the instructions corresponding to a certain figure. In the experiments, three subjects performed the tasks using method (a) and method (b).

3) Experiment 1 results and discussion

In the two cases—either (a) superimposing the instructions on the cards or (b) looking up the instructions in

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TABLE II
RESULTS OF EXPERIMENT 1

Test subject	(a) Superimposition display method (operation time in sec)	(b) Card booklet (manual) look-up method (operation time in sec)
1	157	380
2	175	295
3	159	290

the booklet—the time taken to lay out all 16 correctly is taken as the "operation time," and the measured operation times for the three subjects using each method are listed in Table II. For all subjects, it is clear that the operation time is shorter when they use method (a). Moreover, the time required to record the instructions by using the SCOPE indexing function is 640 seconds (i.e., an average of 40 seconds per card). In regards to the instruction recording, although the time required to record the instructions can be reduced by improving the user interface, the time that goes with an increased number of recordings is thought to be considerable. From the viewpoint of the worker, it is necessary to take into account not only the operation time but also the time required for preparation. Nevertheless, in the case that instructions recorded once are used any number of times or in the case that the operation time should be shortened even a little under a poor factory environment, the indexing function is effective.

4) Experiment 2: Memory remnants of instruction details

In this experiment 2, 48 cards are stuck to a wall, and a memory game is played. One of the 24 letters of the alphabet is stuck to each card, creating 24 pairs of cards with the same letter. The worker chooses two cards at a time, and using either method (c) or (d) below, verifies the details associated with each card, and performs operations created by the pairs.

(c) Cards are selected by laser pointer, and their descriptions (letters of the alphabet) are superimposed on them. In the case that the selected cards are not a matching pair, the description of those cards are not displayed.

(d) Cards are selected by laser pointer, and their descriptions (letters of the alphabet) are given by voice.

Each of three subjects performed the task once using method (c) and once by (d).

5) Experiment 2 results and discussion

The time to complete matching of all the cards is taken as the operation time, and the measurement times are listed in Table III. In the case of all the subjects, the operation times are shorter when they perform the task using the superimposition method (see (c) above). According to the post-experiment impressions of the subjects, using the voice-only method (see (d) above) was often stressful. In the case of a memory game like this, if a card flipped over once does not form a pair, that card has to be kept in mind. The experimental results suggest that the superimposition method makes it easier for the subject to memorize the cards. In the case that support is given from a skilled worker at a distant location, if a problem can be handled only once, it is sufficient

TABLE III
RESULTS OF EXPERIMENT 2

	Subject	Operation time
Superimposed display (method (c))	1	10 min 41 sec
	2	24 min 38 sec
	3	13 min 01 sec
Voice presentation (method (d))	1	15 min 36 sec
	2	30 min 31 sec
	3	17 min 35 sec

to give instructions and guidance by voice. However, in the case that an on-site worker has to repeat the same operation at a later date, if the superimposition method was used, the on-site worker gets a deeper understanding of the operation details and will find it easier to remember them for future operations. This intriguing result thus shows the advantage of the superimposition method.

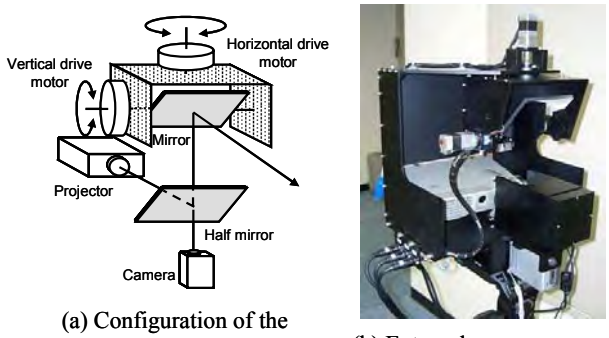
C. Discussion on multiplying the number of degrees of freedom of the robot and related future work

In the current study, we took up the function of displaying information in real space as a robot function for extending communication, and we verified the effectiveness of this method in the previous sections. As for the robot's motion mechanism, only one degree of freedom (i.e., rotation about the vertical axis) was dealt with. However, as mentioned in section 3, if we assume operations in the real world, to achieve unrestricted operation in free space, it is necessary to increase the robot's number of degrees of freedom, especially concerning it's mobility. Accordingly, in the following discussion, we examine the challenges concerning equipping a mobile robot with the capability of displaying information in real space.

As regards our SCOPE system, to achieve the capability of a shared field of view, as shown previously in Figure 3, a camera and projector are unified as one in order to bring together the camera's viewing field and the projector's projection field. In the case of this method, the distance to the projected image is assumed to be constant. However, in the case of a mobile robot, this distance is variable. This means that, in accordance with the degree of this variation, calibration must be performed to match up the camera's viewing field and the projector's projection field. By skillfully aligning the optical axes of the camera and projector mechanically, as shown in the set up in Fig. 8(a), even if the distance to the target object varies, the viewing field and projection field are kept together. An external view of our prototype camera/projector with a combined optical axis is shown in Fig. 8(b). In our future work, we plan to mount this camera/projector on a mobile robot and investigate its effectiveness.

In regards to SCOPE, by realizing the functions for information indexing and superimposition, and correcting the projected image plane in accordance with the variation of the camera's orientation, projected objects and attribute information can be presented as still images in real space. With this method, it is assumed that the camera's orientation is

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(a) Configuration of the projector and camera

(b) External appearance

Fig. 8 Projector and camera with unified optical axis.

known. In the case of mounting the camera on a mobile robot, the location of the robot itself must be obtained, and the projected image plane must be corrected according to that location. In the system targeted in the current study, since it is expected that a human worker can do corrections (for example, adjustments by a remotely located skilled worker on the position of the projected object), there is a good chance that the accurate position of the robot itself cannot be acquired. From now onwards, firstly, we plan to establish the capability of correcting the projected image by utilizing existing identification methods for acquiring a robot's own location, and then verify these methods experimentally.

V. CONCLUSIONS

The concept of "robot-augmented communication" was introduced in this study. Involving cooperation between an unskilled worker and a robot on-site, this concept aims at a collaboration set up in which a skilled worker remotely located from a work site supports an on-site worker by communicating his intentions through a robot. Incorporating three essential functions that a robot must be fitted with, namely, shared field of view, information indexing, and superimposed presentation, the constructed SCOPE (sight collaboration by projection effect) system demonstrated that these functions shorten the on-site operation time. Furthermore, we discussed problems in regard to equipping a mobile robot with the function for presenting information in real-space. From now on, we plan to mount such a real-space-information-presentation function—which combines the optical axes of a camera and projector—on a mobile robot, and while verifying this function, we will examine ways of handling the challenge of identifying the robot's own location.

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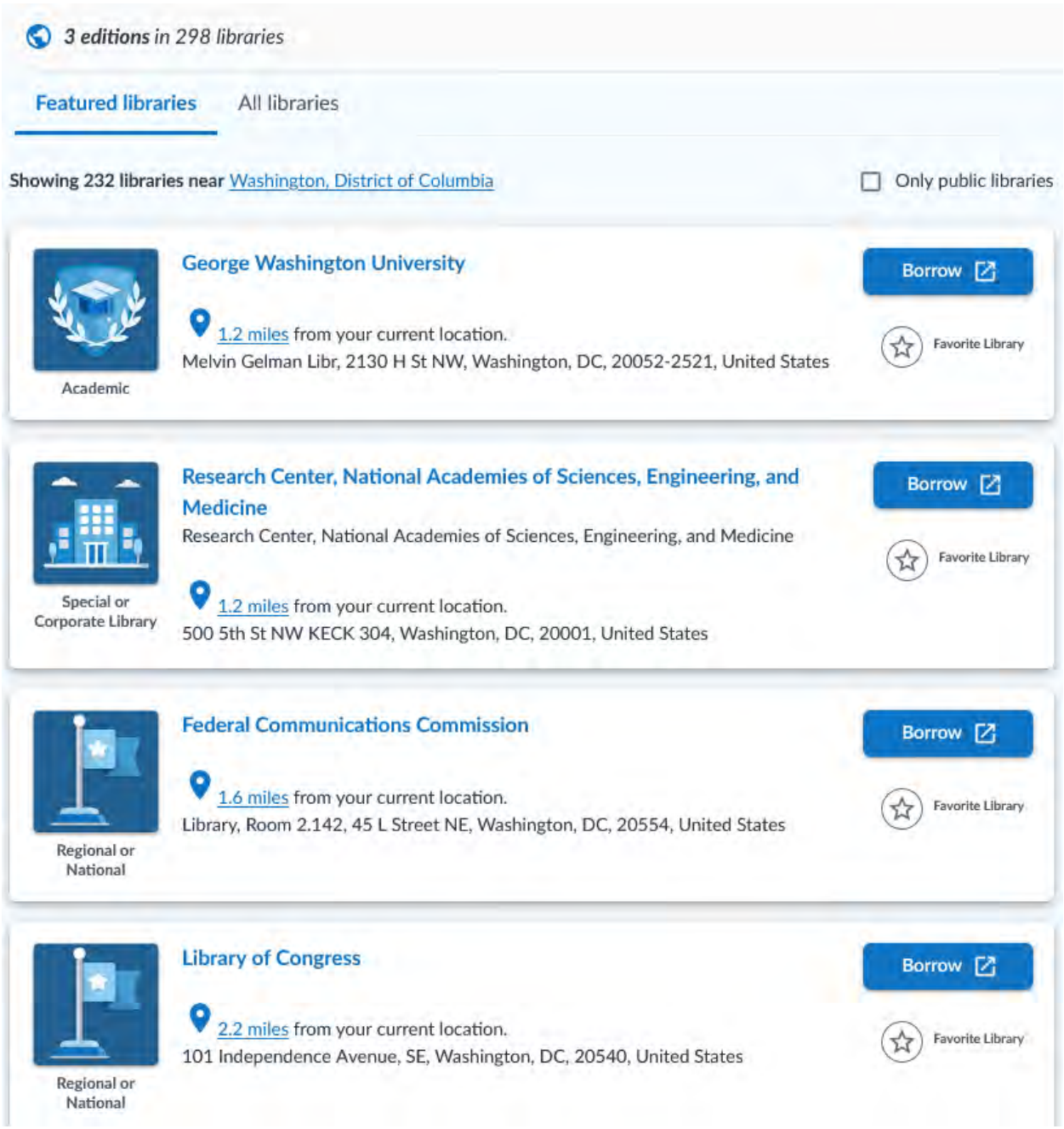
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Appendix E-7

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Step-On Interface on Mobile Robot to Operate by Stepping on Projected Button

Takafumi Matsumaru* and Kosuke Akai

Bio-Robotics and Human-Mechatronics Laboratory, Shizuoka University, Johoku, Naka, Hamamatsu 432-8561, Japan

Abstract: This paper proposes the step-on interface (SOI) to operate a mobile robot in which a projector projects and displays a direction screen on a floor and a user specifies a button showing the selected movement by stepping or pointing. The HFAMRO-1 mobile robot has been developed to demonstrate the SOI's potential (HFAMRO: "human-friendly amusing" mobile robot). The SOI of HFAMRO-1 consists of a projector and a range scanner on an omni-directional mobile platform. From operational comparison with other input interfaces, it is confirmed that we can direct the robot movement using our own foot. We had some students who does not specialize robotic systems try to operate HFAMRO-1 with their shoes, and all trial students could specify the button to operate the robot satisfactorily and everyone mastered the SOI immediately.

Keywords: Step-On Interface (SOI), Human-Friendly Amusing Mobile Robot (HFAMRO), Projector, Range scanner, Direction screen.

1. INTRODUCTION

This paper proposes the step-on interface (SOI) to operate a mobile robot in which a projector projects and displays a direction screen on a floor and a user specifies a button showing the selected movement by stepping or pointing. The HFAMRO-1 mobile robot has been developed to demonstrate the SOI's potential (HFAMRO: "human-friendly amusing" mobile robot) [1-4]. The SOI of HFAMRO-1 consists of a projector and a range scanner on an omni-directional mobile platform.

This paper is organized as follows: Section 2 explains the feature of the SOI comparing with related studies and conventional methods. Section 3 introduces the HFAMRO-1 mobile robot. Section 4 and 5 explain the measurement method and the direction procedure when the robot is idle and when it is operating respectively. Section 6 shows setup movements of HFAMRO-1. Section 7 discusses experiments. Section 8 presents conclusions.

2. STEP-ON INTERFACE

2.1. Conventional Interface Using Projector

Human interface (HI) means, in a narrow meaning, a connection part between a person and a machine or a computer, and is an equipment to make user easy to operate a machine [5]. Interface usually informs multimedia information and a display presents information visually via a screen such as CRT (cathode-ray tube), LCD (liquid crystal display) and projector (projection equipment).

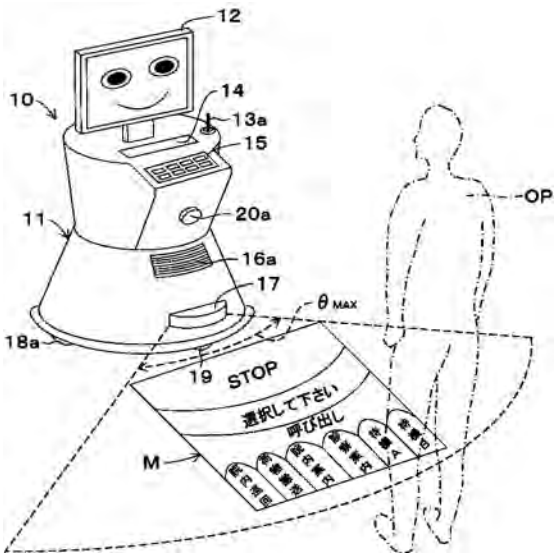
Digital Desk [6] proposed by Wellner in 1991 has changed previous indirect relationship between a user and a computer using a screen and a computer mouse. On Digital Desk, three functions are considered: visually representation function (a visual desktop is projected on a desk), control function (user's own fingertip is utilized to direct operation), and registration function (objects such as documents and figures are input electronically in the desktop environment as information resources using, for example, a camera). These three functions are studied as Enhanced Desk [7], Sensetable [8], Illuminating Clay [9], SmartSkin [10], Lumisight Table [11], and Attentive Workbench [12] and some prototype projects vertically on a wall [13, 14]. These three functions are visual interaction, however, a reaction function is studied so that a reaction force against operation is fed back to a user such as PSyBench (physically synchronized bench) [15], Visual Haptic Workbench [16], Actuated Workbench [17], and Proactive Desk [18]. However all these interactions are only between a user and a virtual environment.

Projector is sometimes used to support handling a real object, for example, it displays information from a remote supporter to an on-site worker to support and prescribe tasks or operations [19, 20]. RFIG (radio frequency identification and geometry) lamp (local-aware mobile projector) [21] is interesting as an informational interaction in real workspace which uses an active RFID tag with photo electronic sensor and a handheld projector with camera. ID information and location of tags in readable area are recognized using a gray code light pattern from the projector, and the information is projected on each object. As an interface between a user and a robot, projector is usually used for teaching [22-24], but it is mainly off-line and the operation and direction of working robot are seldom examined. The information sharing function on manipulator [25] and the preliminary-announcement and indication function of upcoming operation on mobile robot [26] are studied to present user a robot's movement information via projector, however, it transmits information only from robot to user.

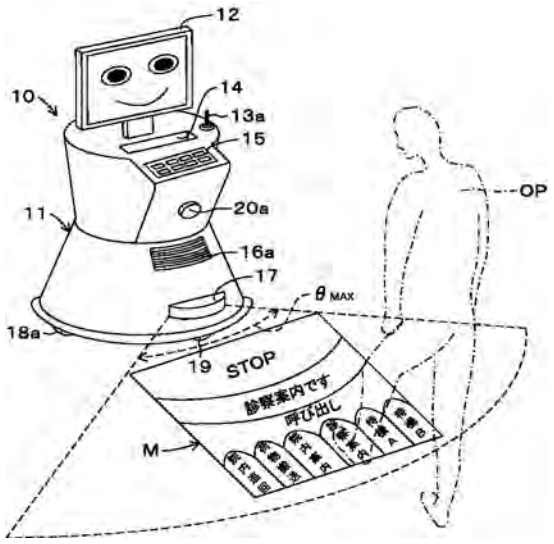
*Address correspondence to this author at the Bio-Robotics and Human-Mechatronics Lab., Shizuoka Univ., Johoku, Naka, Hamamatsu 432-8561, Japan; E-mail: ttmatum@ipc.shizuoka.ac.jp

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(a) Projection



(b) Stepping-on

Fig. (1). SOI on In-Hospital Service Robot.

2.2. Step-On Interface

The SOI is a new interface to direct robotic or mechartonic tasks or operations. A projector displays a direction screen on a floor or other surface, and a user specifies a button showing the selected movement by stepping or pointing. The SOI is considered, for example, to be equipped on a support robot in hospital or nursing facility (Fig. **1**) [27]. In many cases still more supports with one more pair of hands are needed to assist those whose busy hands are already full – nurses, doctors, and care workers in the quickly aging society. Accordingly a human coexisting type robot which performs, for example, delivery or conveyance of medical appliances, patient's records and meals is desired.

The SOI has a special feature that the projected screen is used as a bilateral interface. It not only presents information from equipment to user but also delivers instructions from user to equipment. The SOI has the following features:

(1) The SOI can be used hands-free, unlike keyboard and computer mouse, touch panels, and joysticks. Therefore the elderly, the physically challenged, and users whose hands are full can use it.

(2) Because the SOI does not need voice input, it can be used anywhere without disturbing others and in noisy environments.

(3) No special devices are needed, and the user can use his own foot or stick (walking case) usually used, although the eye control requires special devices to detect eye movement and has constraints such as user's position and orientation to be recognized.

(4) A user only moves his foot or stick roughly to direct, instead of hands and fingers movement with high accuracy.

(5) Direction screen projection means that the SOI requires little preliminary preparation or special setup.

(6) Because the SOI can use figures and pictures in addition to letters, it is no specifically language dependent, making it possible for beginners and non-native speakers to use it.

(7) Screen functions are easy to design, setup and change because they are included in software.

2.3. Comparison with Conventional Method

Conventional input by users may be manual operation, voice input and eye control (Table **1**). Manual operation uses push-pull button, joystick, keyboard and computer mouse, touch panel (touch screen) [28, 29], which are not always possible for the elderly or physically challenged. Voice input

Table 1. Comparison Among Various Input Devices

	Manual	Voice	Eye control	SOI
Capability of mounting	AA	AA	AA	AA
Instrumentation	AA	AA	AA	AA
Hands-free	-	AA	AA	AA
Skill to use	AA	A	-	AAA
Range of use	A (front)	AA (away)	- (limited)	A (front)
Environmental condition	AA	- (noisy)	A (lighting)	A (lighting)
Operating efficiency	AAA	-	-	AAA

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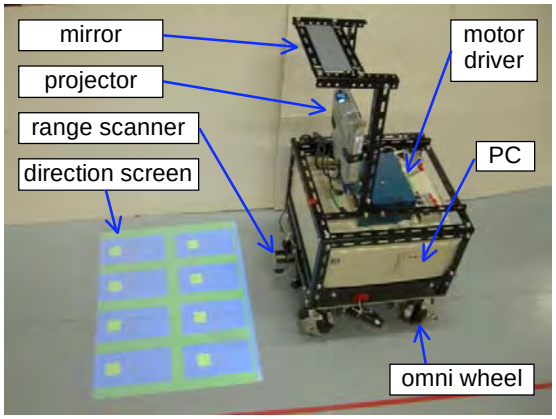


Fig. (2). HFAMRO-1.

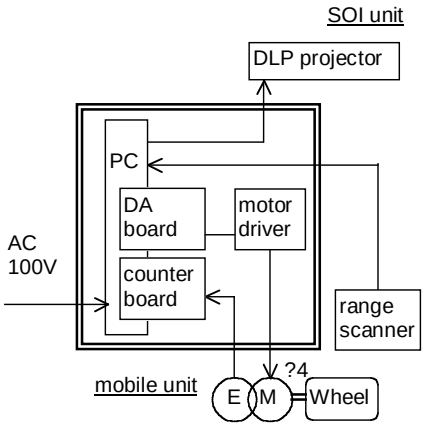


Fig. (3). HFAMRO-1 system configuration.

Table 2. HFAMRO-1 Specifications

Item	Specification
Size	D450 × W450 × H960 mm
Weight	46.7 kg
Max. speed	220 mm/s, 0.87 rad/s

[30, 31] has difficulties in recognition, sometimes due to direction, noise, speech peculiarities, and language translation. Also it occurs "noise" to disturb quietness and give unpleasant to others, and it cannot keep communicated content from being understood by others. Eye control [32, 33] requires neither special instruments nor the hands for users to input command but does require practice, mastering, and familiarity. Limitations may exist such as lighting conditions or user's position and orientation to be recognized.

"Small Fish" [34] is a representative example of media artwork featuring user-equipment interaction using projector. The symbols (the translucence or real objects with round or rectangle shape, the cushions of a doughnut form, a log form, an asteroid form, etc.) handled by users on a projected screen are detected by an infrared camera and a motion-tracking software, and the system provides sound and changes contents based on object conditions and user operations. "Tap Talk" [35], a commercialized example of user-equipment interaction acts as an interactive floor screen on which an image reacts and changes when people walk over an image projected on the floor. The motion of people and other materials is detected by an infrared camera. The system limitation lies in the fact that the camera and projector are assumed to be fixed to the ceiling, the floor image location is fixed beforehand, and the object handled is not actual object but is multimedia information. It also does not consider the application as an interface for artificial mechatronic systems. A virtual keyboard (projection keyboard) [36], similar to the SOI and marketed as computer peripheral equipment, projects an outline of a keyboard on a desk using a red semiconductor laser. A built-in infrared sensor detects the keys "touched". This equipment assumes a precise professional-typist key touch, so the elderly or physically challenged may not use it easily.

3. MOBILE ROBOT EQUIPPED WITH SOI

3.1. HFAMRO-1 Mobile Robot

The HFAMRO-1 mobile robot, developed to demonstrate the SOI's potential, uses a SOI consisting of a projector and a range scanner on an omni-directional mobile platform. The projector displays a direction screen on a travel surface and the two-dimensional (2D) range scanner which scans on a plane and measures the distance to an object detects and measures the user's stepping to specify the selected button on the direction screen. HFAMRO is intended represent the concept based on which robots interact with users with its mobility, for example, the ability to play tag – in this case playing tag with "light", similar to "shadow" tag. This assumes a scenario in which a child runs after a mobile robot and, when a button on the projected screen is stepped on, the robot responds, for example, by playing a game like rock-paper-scissors or a riddle, giving the time or weather report, and moving in some way to indicate an emotion.

3.2. System Configuration

Outward appearance, system configuration and principal specifications of HFAMRO-1 are shown in Figs. (**2**, **3**), and Table **2** respectively. The omni-directional mobile platform consists of four sets of omni-wheels driven by a DC motor, reduction gears, and an encoder. It can move in any direction keeping its orientation and also rotate centering on an arbitrary point on a travel surface.

The SOI consists of the display in the form of a projector and the detector in the form of a range scanner. A commercial product, V3-131 by Plus Vision Co., used as the projector, faces upward and the screen is reflected in the mirror above it and projected on a travel surface. This keeps the robot height under 1 m while minimizing projection distance to 1.2 m. The mirror is installed so as to be inside the robot's main body (450 mm square) to reduce the risk to contact with users or objects around. The mirror is installed with inclination angle of 5 deg so that the robot's main body does not interfere with screen projected. The trapezoid compensation makes the projected screen a rectangle (730 mm wide and 550 mm long) on a travel surface. A commercial product, URG-X002S by Hokuyo Automatic Co. [37], used as the range scanner, scans 682 steps across 240 deg (step number: 1 to 682; step angle: 0.35 deg), determining the dis-

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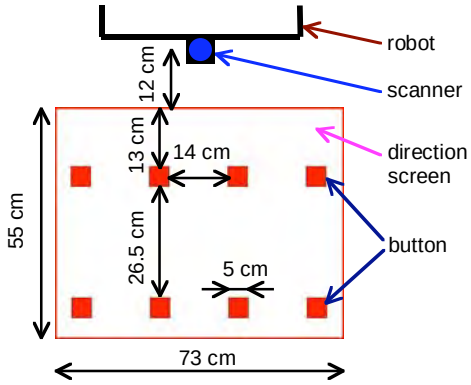


Fig. (4). Placement of buttons in direction screen.

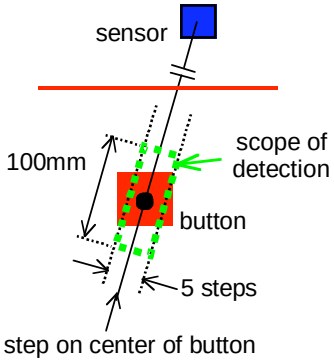


Fig. (5). Scope of detection when robot is idle.

tance from 20 to 4095 mm to an obstacle via RS-232C or USB. Located on lower front center of the robot, the range scanner is roughly 20 mm above the travel surface keeping from touch with the surface unevenness.

3.3. Button Arrangement in Direction Screen

The 50-mm-square buttons are placed in two lines by four sequences on the direction screen (730 mm wide and 550 mm long) (Fig. **4**). It is based on the range scanner performance in experiments [38] and the investigation reports on foot length (21.1 cm to 28.7 cm) and footwear size (25EE) of common male adults (18 to 60 years old) in Japan [39].

4. SOI OPERATION WHEN ROBOT IS IDLE

The direction screen when the robot is idle is designed considering that we can select and direct as many operations as possible from a screen in which buttons are placed in two lines by four sequences.

4.1. Recognition Method and Judgment of Stepping

The robot can acquire the step number (direction angle) and the distance value to an object as position data from the range scanner, and the existence of foot or footwear on a operation button is judged using the distance values at adjacent five steps (equivalent to 1.4 deg and, for example, 16 mm wide at the distance of 65 cm from the scanner) including each two steps right and left with the center step passing through the button center. It is because a misjudgment due to measurement error of range scanner may occur if checking the distance only at the step corresponding to the button center. We consider the operation button size (50-mm-square), the maximum measurement error of range scanner (about 20 mm), and the individual difference by users on the button-foot relative position from a pilot study [38]. Consequently the scope of detection is set at the distance from the scanner to the button center plus or minus 50 mm (Fig. **5**). When the distance at all five steps is in the scope of detection, it is judged that a user steps on the button to direct the operation indicated.

4.2. Hierarchy

The hierarchical structure is introduced since the number of button which can be placed on a direction screen is limited to eight, two lines by four sequences, and the number of operation directed from a screen is restricted to eight. The operations selected are detailed from robot side to user side on the screen. That is, when one of four classification buttons placed in the upper line is stepped (Fig. **6**(**a**)), four individual buttons which show lower-rank operations detailed under the classification are displayed in the lower line (Fig. **6**(**b**)). By this hierarchy, sixteen kinds of operation, four classifications by four individuals, can be selected and directed when the robot is idle.

4.3. Direction Procedure

The direction procedure from button selection to robot movement is as follows (Fig. **7**):

(1) The projector projects the direction screen on a floor (Fig. **8**(**a**)).

(2) The range scanner scans on the screen and it acquires the position data (angle and distance).

(3) When all the distances checked at five steps are in the scope of detection, it is judged that the button is



(a) 1st stage (2) 2nd stage

Fig. (6). Hierarchical structure for direction screen.

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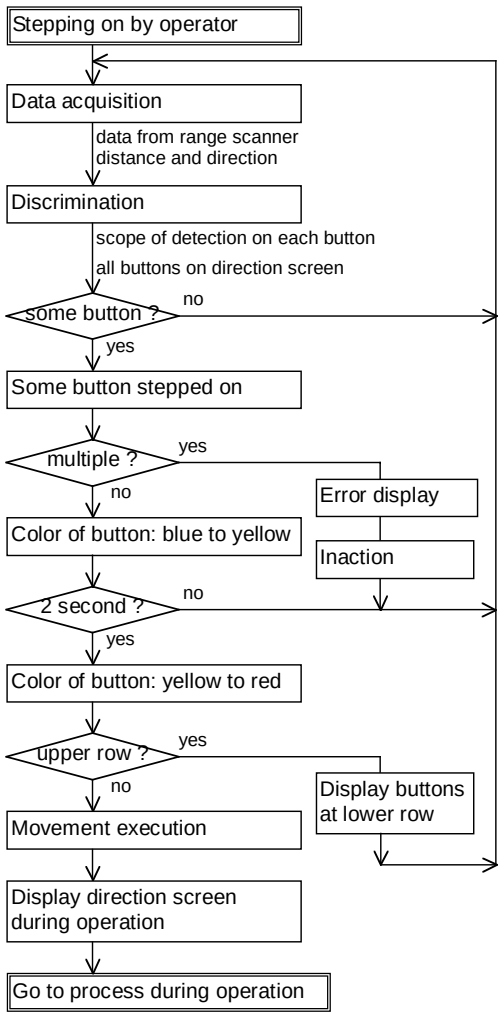


Fig. (7). Direction procedure when robot is idle.

stepped. The system doesn't have any sensory feedback corresponding to keyboard typing feeling, so the color inside the frame around the button (i.e. button frame) is changed from usual blue to yellow to inform the user that the system recognizes the button stepped (Fig. **8**(**b**)).

(4) The system doesn't immediately perform the operation considering that the user makes a mistake in stepping or the system fails to recognize. When the system recognizes the button stepped for two seconds (the period can be easily changed in software), the color inside the button frame is changed from yellow to red and the operation is performed (Fig. **8**(**c**)).

(5) While two or more buttons stepped are recognized simultaneously, any direction is ignored and the error indication is displayed on the screen (Fig. **8**(**d**)). When the error is resolved, the direction screen goes back to the previous state.

5. SOI OPERATION WHEN ROBOT IS OPERATING

When the robot comes into operation responding to the user's direction, the direction screen is transformed. The judgment of stepping is designed considering that operations can be performed without interruption.

5.1. Recognition Method

When the robot is operating, the direction screen moves from the user with the robot movement, conversely from the range scanner, the user's stepping location moves. So we have to make the scope of detection for each button wider, and we made the scope of detection for each button all areas inside the button frame.

As stated, when the robot is idle, a part of ring centering on the range scanner is set as the scope of detection to judge the button directed by user, so the position data (step number and distance) acquired from range scanner can be used directly. However, when the robot is operating, if applying this, we have to make the part of ring wider than the button frame. This makes it difficult to correctly detect the button stepped because the scope contains other button frames and overlaps each other (Fig. **9**).

Accordingly the position data acquired from range scanner is converted to X-Y Cartesian coordinates, and it is investigated whether the X-Y value is in the scope of detection corresponding to the button frame. When there are five or more X-Y values in the scope of detection, it is judged that a user directs the operation indicated on the button (Fig. **10**).

5.2. Judgment of Stepping

A new operation is performed immediately when the system recognizes a button stepped when the robot is operating. Even though the scope of detection is set widely as all inside the button frame, the same state is not necessarily kept for a period because the robot is moving. For example, if the user's foot stepped on a button stays in the same place, the button judged as directed changes one after another with the robot movement. Therefore, when the robot is operating, next direction is ignored for one second (the period can be easily changed in software). Nevertheless the 'stop' button is always given top priority to make the robot stop immediately. In addition each operation has a time limit so that after some predefined period the robot stops and the direction screen goes back to select individual buttons. Even if two or more buttons stepped are recognized simultaneously, the robot continues the current operation because the interruption reduces the robot maneuverability for users.

On the direction screen, in principle, the large 'stop' button is set in the upper line and other operation buttons are placed in the lower line (Fig. **11**). The operation buttons should be placed in a line because, if the operation buttons are arranged in two lines, the operation button in lower line could incorrectly react in response to the user's foot returning from stepping an operation button in the upper line. It is also possible when a user returns his foot after stepping the 'stop' button in the upper line, the operation button in the lower line is misrecognized as stepped and the robot executes the next operation. So, when the stop button is recognized, the recognition of other buttons is ignored for two seconds (the period can be easily changed in software).

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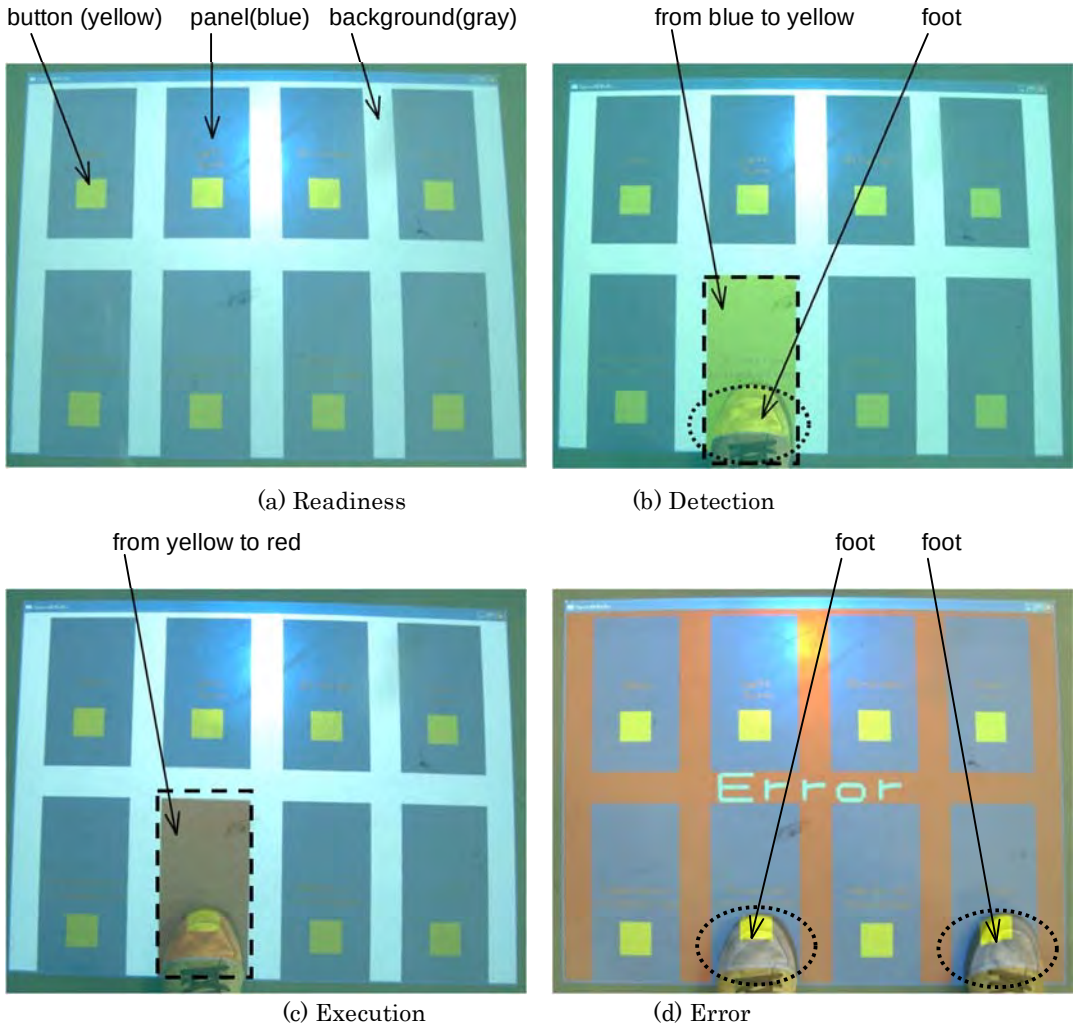


Fig. (8). Direction screen when robot is idle.

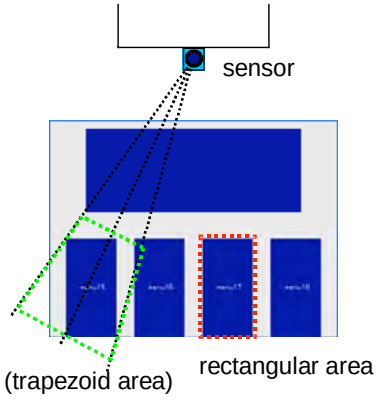


Fig. (9). Scope of detection when robot is operating.

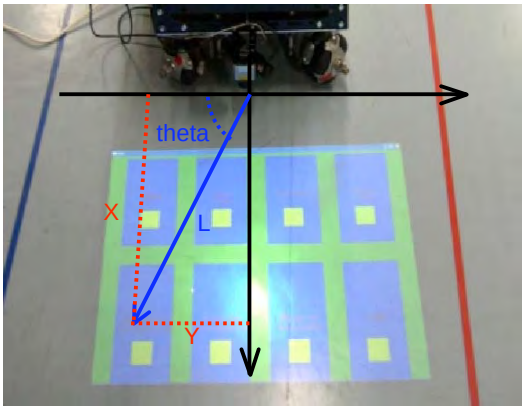


Fig. (10). Coordinate conversion.

5.3. Direction Procedure

The direction procedure from button selection to robot movement is as follows (Fig. **12**):

(1) The projector projects the direction screen on a floor.

(2) The range scanner scans on the screen and it acquires the position data (angle and distance).

(3) The acquired position data is converted to X-Y Cartesian coordinates.

(4) When five or more X-Y values are there inside the button frame, it is judged that the button is stepped.

(5) When the system recognizes a button stepped, it informs the user by changing the color inside the button

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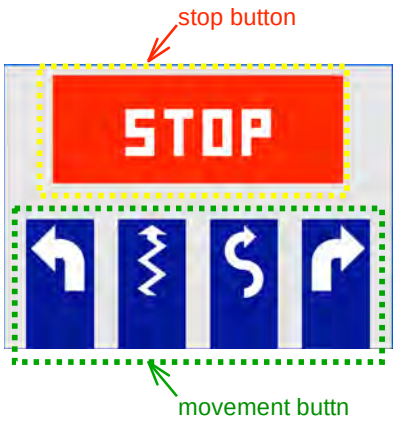


Fig. (11). Direction screen when robot is operating.

frame from usual blue to red and the robot performs the operation immediately.

(6) While two or more buttons stepped are recognized simultaneously, the robot continues the current operation.

(7) After some predefined period the robot stops and the direction screen goes back to select individual buttons.

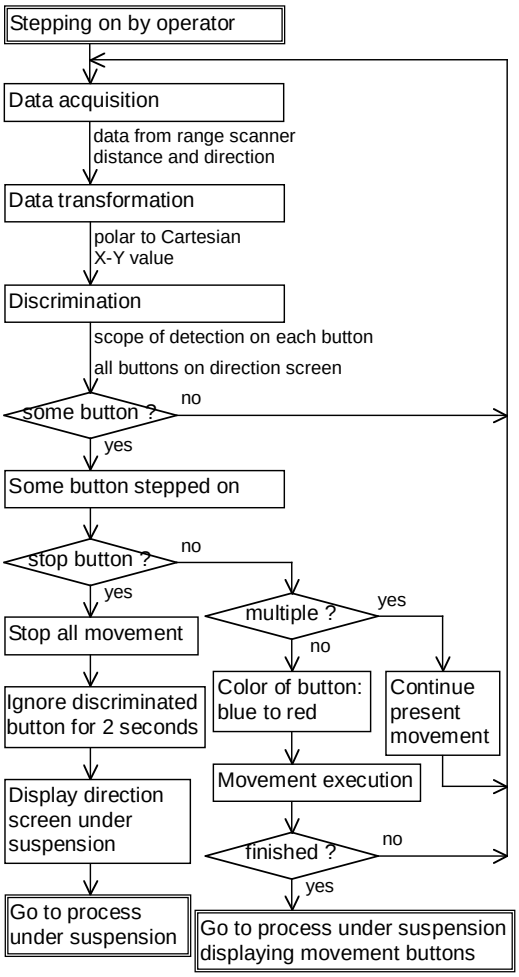
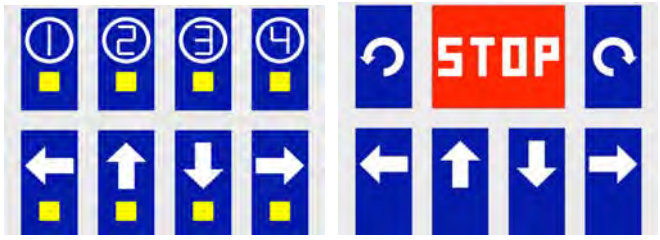
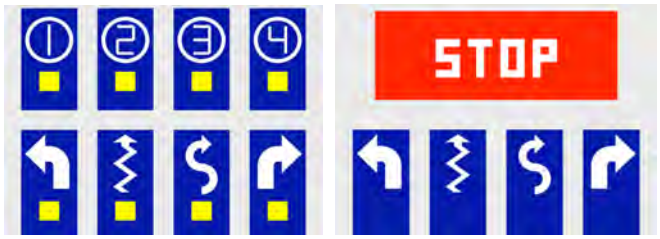


Fig. (12). Direction procedure when robot is operating.



(a) When robot is idle (b) When robot is operating

Fig. (13). Direction screen for basic movement.



(a) When robot is idle (b) When robot is operating

Fig. (14). Direction screen for elemental movement (1st half).

6. SETUP MOVEMENT OF HFAMRO-1

In HFAMRO-1 eighteen kinds of movement are prepared: six kinds of basic movement, eight kinds of elemental movement, and four kinds of emotional movement.

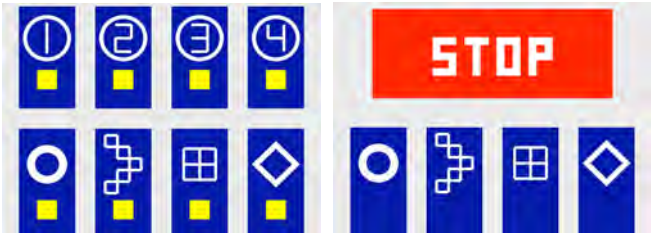
6.1. Basic Movement

Basic movement means a fundamental motion. Six kinds of movement can be considered in a omni-directional mobile platform: back-and-forth translations, right-and-left translations, and clockwise-and-counterclockwise rotations. On the direction screen when the robot is idle, only four kinds of translation are displayed as individual button (Fig. **13**(**a**)). On the direction screen when the robot is operating, the operation buttons are set not only in the lower line but also at right and left in the upper line (Fig. **13**(**b**)) since we want to select all the six basic movements on the direction screen. Even if a user keeps his foot stepped on the upper right or left buttons, the system may not operate incorrectly because these two buttons are assigned to rotation and the direction screen leaves from the user when the robot starts operations. The 'stop' button is placed at the upper center so the operator's stepping never contact with robot's body. Basic movements can be selected on the direction screen from the classification button-1 when the robot is idle.

6.2. Elemental Movement

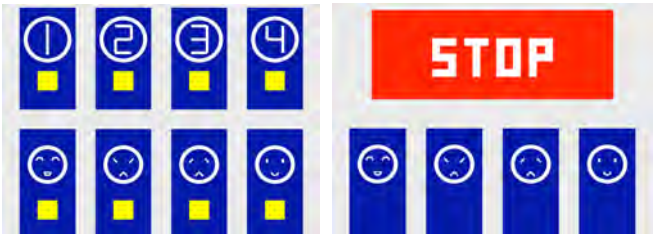
Elemental movement is a complicated motion combining basic movements and other movements based on trigonometric functions, etc. Operations called 'left turn', 'zigzag', 'slalom', and 'right turn' can be selected on the first direction screen displayed from the classification button-2 (Fig. **14**), and operations called 'circle', 'step turn', 'box', and 'diagram' can be selected on the second screen from the classification button-3 (Fig. **15**). Buttons for elemental movements are shown with icons indicating robot's trajectory.

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(a) When robot is idle (b) When robot is operating

Fig. (15). Direction screen for elemental movement (2nd half).



(a) When robot is idle (b) When robot is operating

Fig. (16). Direction screen for emotional movement.

6.3. Emotional Movement

Emotional movement is designed aiming to express robot's 'emotion' only with its movement. Four kinds of movement – 'joy (pleasure)', 'anger (spoiled child)', 'sadness (depression)', and 'happiness (grace)' – are set on trial (Fig. **16**). It can be selected on the direction screen from the classification button-4 when the robot is idle (detailed explanation about movements is omitted because of space limitation). Buttons for emotional movements are presented with moonfaced icons with eyes and mouth.

7. EXPERIMENTAL EVALUATION

7.1. Operational Comparison with Other Input Interfaces

The feature of SOI is studied based on the HFAMRO-1 operations with keyboard, voice, and SOI.

We asked a subject, undergraduate student who is not expert at robotic system, to move the robot along a trajectory drawn on the floor with straight lines 1 m long and the rotation angle of 45 deg (Fig. **17**). The robot is set to move at a speed of 120 mm/s (translation) and 0.34 rad/s (rotation),

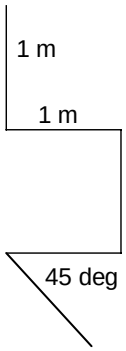


Fig. (17). Desired trajectory.

and the subject directs only the movement direction and the temporary stopping. Reverse run is prohibited even if the robot overruns. A 10-key part of 106-keyboard [40] as a keyboard, the Julius for SAPI (speech application program interface) [41] as a speech recognition system for voice input, the direction screen for basic movements for the SOI (Fig. **13**) are used respectively. Setup is shown in Table **3**.

The movement loci are shown in (Fig. **18**). By keyboard (required time: 48 s, rotation angle: 45.2 deg), the difference between the target and the result is the smallest. It shows if a user can use his hands and fingers satisfactorily he can operate the robot precisely. By voice (required time: 49 s, rotation angle: 49.7 deg), the difference is the largest – more than 10 cm at the maximum. The movement changeover at aimed direction in rotation is especially difficult due to the time lag in the speech recognition system. By SOI (required time: 47 s, rotation angle: 48.5 deg), the difference is not so large, but the movement changeover is comparatively difficult because the direction screen moves with the robot movement. Nevertheless it is confirmed that we can operate the robot with our own foot using SOI if the task dose not require high accuracy.

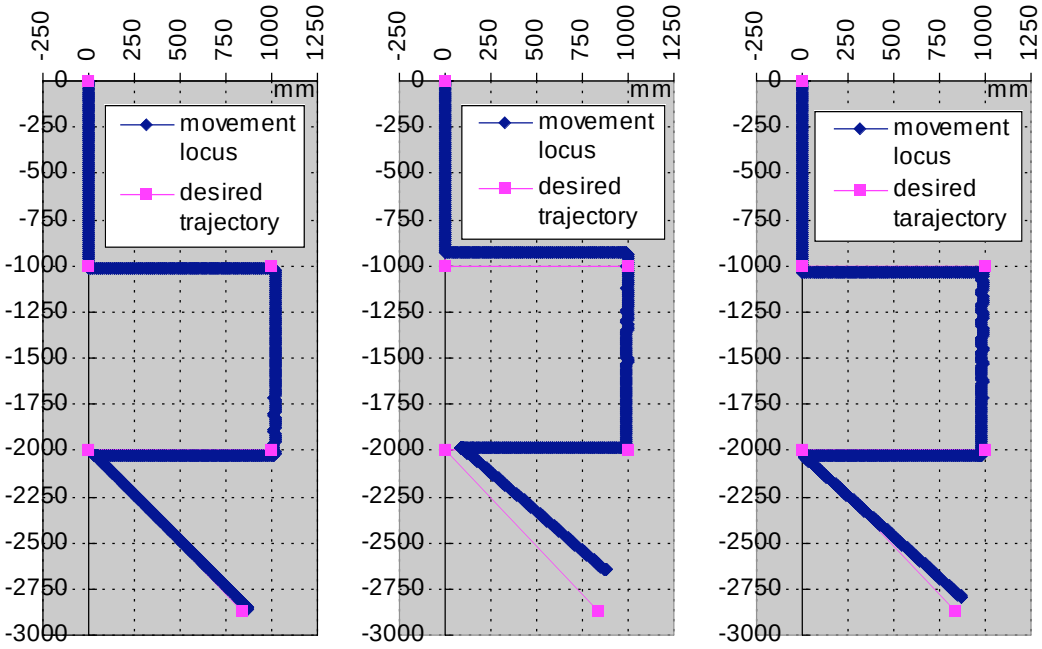
7.2. Trial Operation of HFAMRO-1

We brought the HFAMRO-1 to a campus cafeteria and had some students, who do not specialize robotic systems, try to operate HFAMRO-1 with their shoes (Fig. **19**). Fifteen students replied to the questionnaire after the trial.

Table 3. Setup of Input Interface

Robot Movement	Input Device		
	Keyboard	Voice	SOI
Going forward	'8' key	"mae" = fore	button with symbolic icon
Going backward	'2' key	"ushiro" = back	button with symbolic icon
Going leftward	'4' key	"hidari" = left	button with symbolic icon
Going rightward	'6' key	"migi" = right	button with symbolic icon
Left rotation	'7' key	"kaiten" = rotate	button with symbolic icon
Stop	'5' key	"teishi" = stop	button with characters

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(a) Keyboard (b) Voice (c) SOI

Fig. (18). Movement locus of HFAMRO-1.

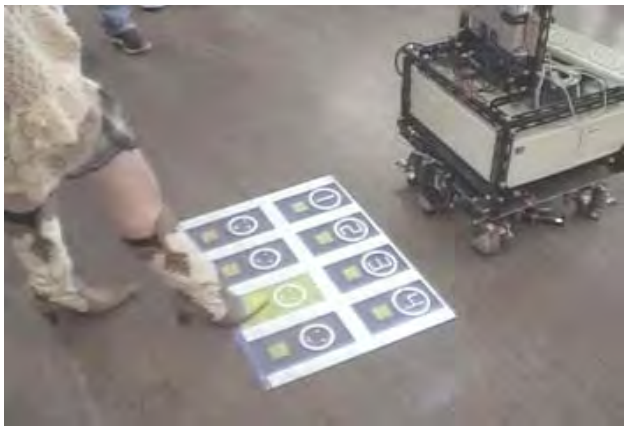


Fig. (19). Trail operation of HFAMRO-1.

Table 4. Robot Maneuverability

Maneuverability	Number of People
Easy to operate	10
Reasonable to operate	3
Difficult to operate	0
(No opinion)	2
Total	15

7.2.1. Questionnaire Result

The subjects noted the kind of shoes they worn and answered the threefold choice about robot maneuverability – easy to operate, reasonable to operate, and difficult to operate (Table **4**). No one answered difficult to operate.

- Shoes of ten students answered easy to operate: white sneaker (3), black sneaker (3), silver sneaker (1), dark blue with gray sneaker (1), black mesh material (1), black leather shoes (1).
- Shoes of three students answered reasonable to operate: brown sneaker (2), beige leather boots (1).

All trial students including those who did not reply to the questionnaire could specify the button to operate the robot satisfactorily and everyone mastered the SOI immediately beyond our expectation. Many students looked for the location at which the SOI responds moving around their toe at first because the portion of shoes which the range scanner detects is depending on shoes color, size, and shape. A student who worn black shoes presented tips as raising heel and tiptoeing. The SOI seems to be less responsive to the upper right and left buttons on the direction screen because the shoes facing to the robot at the upper corner on the direction screen have some inclination angle to the scanner and the amount of reflected light to the scanner may be reduced. Accordingly we should examine the recognition and judgment of shoes with various materials and shapes, and exercise the ingenuity on shoes orientation such as the design and placement of buttons to let the user turn his shoes facing to the scanner.

7.2.2. Comments and Opinions

Comments and opinions filled in the free entry are considered as follows:

ADVANTAGE AND DISADVANTAGE

Many students understand the advantage of SOI mentioning that, for example, anyone can operate the robot without

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his hands even if he carries some loads or baggage. Disadvantage is also pointed out such that the direction screen moves with the robot movement and a user has to run after the robot to direct it sequentially. This might be a serious problem depending on its application and situation. Some student requests the function to display the direction screen around the user continuously as in remote operation. The interruption function after it leaves somewhat away from the user is a simple and immediate countermeasure.

USAGE ENVIRONMENT

It is also pointed out that a user is difficult to recognize buttons when a floor has some unevenness or clear pattern, and that it is dangerous if others step on undesired buttons, e.g., in a crowd. The system is assumed to be used indoors at first. As for the detection and measurement of user's stepping, we have to examine, for example, the recognition and judgment of shoes processing shape data acquired from range scanner or usage of other sensors to distinguish the user from others and obstacles. We plan to use the SOI on various applications examining its implementations.

EMOTIONAL MOVEMENT

Many positive comments are there on emotional movement, especially on the anger expression – swaying its body like a child throwing a tantrum. However, there are also negative opinions such that it is difficult to understand without explanation and there is not much difference among four emotional movements. We would like to examine more on various expressions with improving robot mobility. We would like to apply the SOI not only to assist people but also to entertain.

8. CONCLUSION

This paper proposed the step-on interface (SOI) to operate a mobile robot in which a projector projects and displays a direction screen on a floor and a user specifies a button showing the selected movement by stepping or pointing. The HFAMRO-1 mobile robot has been developed to demonstrate the SOI's potential (HFAMRO: "human-friendly amusing" mobile robot). The SOI of HFAMRO-1 consists of a projector and a range scanner on an omni-directional mobile platform. From operational comparison with other input interfaces, it is confirmed that we can direct the robot movement using our own foot. We had some students who does not specialize robotic systems try to operate HFAMRO-1 with their shoes, and all trial students could specify the button to operate the robot satisfactorily and everyone mastered the SOI immediately.

In order to make the SOI and HFAMRO practical, it is necessary to solve various problems. The first problem is the detection of foot or shoes. Since the range scanner only detects the existence of object on a button, it reacts also to the wall and obstacles. We should examine the method to detect the shape of foot or shoes from the range data for the system to react it exclusively. Image processing using camera should also be considered. We would like to address the method to discriminate user's foot or shoes with various shapes and sizes, for example, by putting some mark on a tip of shoes to indicate a specified user. The second problem is downsizing and lightweight for robot mobility. Speeding up is necessary to interact with users, e.g. play tag, and downsizing and lightweight is required not to harm users. The third problem is multiple screens projected on the floor. We plan to develop the robot which projects screens all around it and examine creative usage and coupling control.

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Appendix E-8

Paper:

Functions of Mobile-Robot Step-On Interface

Takafumi Matsumaru and Kosuke Akai

Graduate School of Engineering, Shizuoka University,
3-5-1 Johoku, Naka, Hamamatsu, 432-8561 Japan
E-mail: {ttmatum, f0730052 }@ipc.shizuoka.ac.jp
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To improve HFAMRO-1 mobile robot maneuverability and safety, we added a step-on interface (SOI) to direct robotic or mechatronic tasks and operations (HFAMRO: "human-friendly amusing" mobile robot). To do so, a projector displays a direction screen on a floor or other surface, and an operator specifies a button showing the selected movement by stepping or pointing. We modified the direction screen so that among buttons displayed on two lines, stepped-on buttons directing movement are displayed only on the lower line. We also shortened retention time and had selected movement executed only when the foot was removed from the stepped-on button. The robot has 2 SOIs and multiple projection screens, and can be controlled from either direction for the same function. We synchronized direction and preliminary-announcement screens to inform passers-by which way the robot would move. Using range scanner data, the robot distinguishes feet from other objects based on size and autonomous movement fusion control to avoid obstacles is implemented.

Keywords: step-on interface, mobile robot, projector, range sensor, human interaction

1. Introduction

To improve mobile robot maneuverability and safety, we added a step-on interface (SOI) to direct robotic or mechatronic tasks and operations. To do so, a projector displays a direction screen on a floor or other surface, and an operator specifies a button showing the selected action by stepping or pointing [1, 2].

Robots are gradually expanding from their original task of improving productivity in a manufacturing setting into applications such as "service" robots, e.g., RS1 [3] and SuiPPi [4], that have automated the cleaning of large areas such as railway stations, airports, department stores, and factories. Robots such as MMDR [5] and HOSPI [6] deliver meals, medicines, and medical records in medical and welfare institutions. Unlike many cleaning robots, which operate automatically and autonomously, delivery robots often have interactive displays with touch panels for users, as do service robots conducting guidance and instructions or patrolling and guarding public facilities, e.g., Guard Robo i [7] and enon [8]. Robots developed to support nonmanufacturing operations, e.g., EMIEW [9] and Smart Pal 5 [10], communicate with users via speech recognition and voice synthesis. Wakamaru [11], developed as a home service robot, provides support through speech interaction. Input/output interfaces are used less in specialized work robots, e.g., ApriAttenda [12] and ASKA [13], a hide-and-seek (tag-playing) robot.

We are working to broaden robot interface options and to increase the types of interface used simultaneously by creating an interface other than displays with touch panels or voice interaction.

This paper is organized as follows: Section 2 discusses the SOI in terms of conventional approaches and related works. Section 3 introduces the "human-friendly amusing" mobile robot (HFAMRO-1) developed to confirm SOI performance. Section 4 details screen improvements and recognition changes. Section 5 demonstrates multiple projected screen applications. Section 6 explains range data applications – the discrimination of feet from other objects, and fusion control of autonomous movement to avoid obstacles. Section 7 presents conclusions.

2. Step-On Interface

The SOI uses a screen projected as a bilateral interface, presenting information from equipment to the user and delivers user instructions to equipment.

2.1. Background

Conventional input by users may be manual or vocal and involve eye control (**Table 1**). Manual uses buttons, joysticks, keyboards and mice, and touch panels (touchscreens) [14, 15] – approaches not always possible for the elderly or physically challenged. Vocal input [16, 17] raises difficulties in recognition, sometimes due to direction, noise, speech peculiarities, or language in transmission or due to its occurrence as "noise," disturbance, or the need to keep communicated content from being understood by others. Eye control [18, 19] requires neither special instruments nor the hands to input commands but does require practice, mastery, and familiarity. Limitations may exist in the form of lighting conditions or space such as positioning or the user's orientation.

In "Small Fish," a representative example of media

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Table 1. Comparison of Input Types.

Input	Mounting	Instrumentation	Hands-free	Practice	Range of use	Environment	Efficiency
Manual	AA:	AA:	-:	AA:	A:(front)	AA:	AAA:
Voice	AA:	AA:	AA:	A:	AA:(away)	-:(noisy)	-:
Eye	AA:	AA:	AA:	-:	-:(limited)	A:(lighting)	-:
SOI	**A:**	**AA:**	**AA:**	**AAA:**	**A:(front)**	**A:(lighting)**	**AAA:**

art [20] featuring user-equipment interaction, users handling symbols of different shapes and forms on a projected screen are detected by an infrared camera and motion-tracking software. The system provides sound and changes contents based on object conditions and user actions. A commercialized example of user-equipment interaction, Tap Talk [21], acts as an interactive floor screen on which an image reacts and changes when people walk over an image projected on the floor. The system's limitations lie in the fact that the floor image location is fixed beforehand, the camera and projector are assumed to be fixed to the ceiling, and the object "handled" are not actual objects but are multimedia information. It also does not consider the application as an interface for artificial mechatronic systems. A virtual "projection" keyboard [22] similar to the SOI and marketed as an information equipment input device projects an outline of a keyboard on a desk using a red semiconductor laser. Keys that are "touched" are detected by a built-in infrared sensor. Because the system assumes a precise "professional typist" touch, however, it cannot be used easily by the elderly or the physically challenged.

The projector may be used to support the handling of real objects, e.g., in presenting information from a remote site to an on-site user [23, 24]. The radio-frequency identification and geometry (RFIG) lamp [25] is an interesting example of information interaction in a real workspace using an active RFID tag with a photoelectronic sensor and a handheld projector with a camera. ID information and tag locations in a limited readable area are recognized using gray code light patterns from a projector, then information is projected on an object. In research on user-equipment interfacing, a projector is used to teach operations to a robot [26–28], but teaching is mainly offline and operation and instructions to working robots are seldom considered. In other information-sharing applications, equipment presents information to the user, but not vice versa [29, 30].

2.2. SOI Features

The SOI has the following features:

- The SOI can be used hands-free, unlike keyboards and mice, touch panels, and joysticks, enabling the elderly, the physically challenged, and users whose hands are full to use it.
- Because the SOI does not need voice input, it can be used anywhere without disturbing others and in noisy environments.
- No special devices are needed, and the user can use his own foot or stick (walking cane) usually used.
- The SOI does not require delicate or precise hand and finger movement, and rough foot or stick use is sufficient.
- Direct screen projection means that the SOI requires little preliminary preparation or special setup.
- Because the SOI can use figures and pictures in addition to letters, it is not specifically language-dependent, making it possible for beginners and non-native speakers to use it.
- Screen functions are easy to setup and change because they are included in software.

In the world's most quickly aging country with its mushrooming need for careworkers, innovations such as the SOI could provide all sectors of society with one more pair of needed hands by assisting those whose busy hands are already too full – nurses, doctors, and caretakers in hospitals and nursing facilities – by, for example, carrying meals to patients, transferring medical records, and providing medical appliances.

The SOI also provides those unfamiliar with robots, or not wanting to interact with them, with needed distance, since users need not directly contact the SOI to use it.

3. HFAMRO-1 Mobile Robot

The HFAMRO-1 mobile robot, developed to demonstrate the SOI's potential, uses a SOI consisting of a projector and a range scanner on an omnidirectional mobile platform (**Fig. 1** and **Table 2**). The projector displays a direction screen on a travel surface and the range scanner detects and measures the movement of a user. A range sensor measures the distance to an object, and a two-dimensional (2D) range scanner rotates to scan and measure distances on a plane.

HFAMRO is intended to represent the concept based on which robots interact with users. It assumes, for example, the ability to play "tag" – in this case, playing tag with light, similar to "shadow" tag. This, in turn, assumes a scenario in which a child runs after a mobile robot and, when a button on the projected screen is stepped on, the robot responds, e.g., by playing a game with child, giving the time, or moving in some way to indicate an "emotion."

HFAMRO-1's omni-directional mobile platform consists of four omniwheels driven independently by a DC

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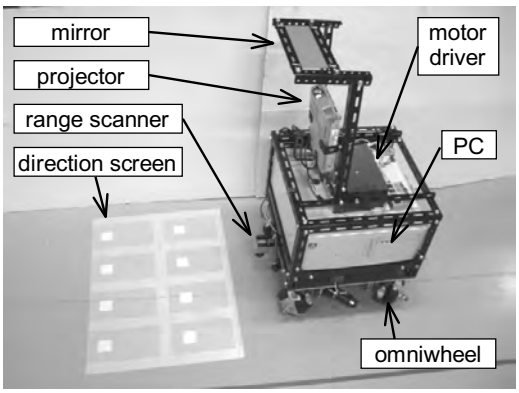


Fig. 1. HFAMRO-1.

Table 2. HFAMRO-1 specifications.

Features		Specification
Size	mm	L450×W450×H960
Weight	kg	46.7
Max. speed	mm/s	220
	rad/s	0.87

motor, reduction gears, and an encoder. It moves in any direction without changing its orientation and rotates as needed on the travel surface. The SOI itself consists of an indicator in the form of a projector (V3-131, Plus Vision Co., Ltd.) and a detector in the form of a range scanner (URG-X002S, Hokuyo Automatic Co., Ltd.). The projector and range scanner are both commercially available. The projector faces upward and the screen, reflected in a mirror above it, is projected on the travel surface. This keeps the robot height under 1 m while minimizing projection distance to 1.2 m. The mirror is installed so that the robot does not interfere with screen projection. The screen is arranged to project a 550×730 mm rectangle on the travel surface. The range scanner scans 682 steps across 240 deg(step number: 1 to 682; step angle: 0.35 deg), determining the distance from 20 to 4095 mm to objects via an RS-232C and USB. Located on the lower front of the robot, the range scanner is roughly 20 mm above the travel surface.

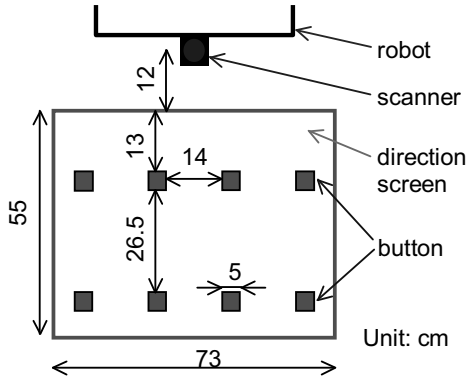
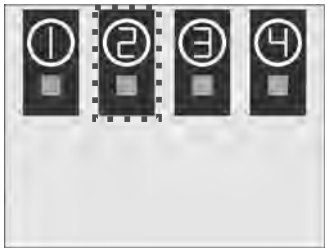
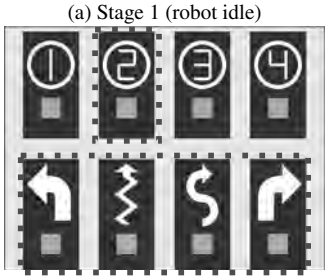


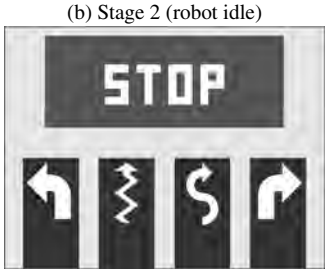
Fig. 2. Direction screen buttons.



(a) Stage 1 (robot idle)



(b) Stage 2 (robot idle)



(c) Robot operating

Fig. 3. Direction screen hierarchy.

4. Screen Improvements and Recognition Changes

4.1. Background

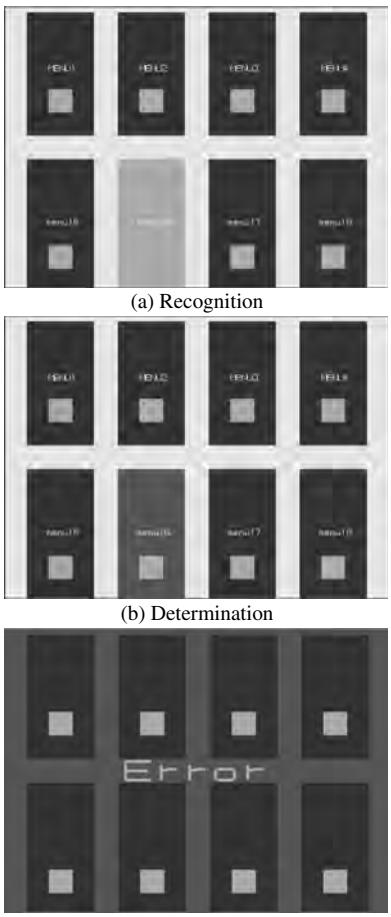
4.1.1. Hierarchy

Based on range scanner performance in experiments [31] and maximum common shoe length and width [32], we divided the projected screen into two rows of four buttons each (**Fig. 2**). With the number of movements instructed from one screen thus limited to eight, we arranged buttons hierarchically. This hierarchy enables 16 movements to be selected from among four classifications. When the robot is idle, the four classification buttons are in the upper line. When a classification button is stepped on (**Fig. 3 (a)**), four buttons showing available movements are displayed on the lower line (**Fig. 3 (b)**). When the robot is operating, the robot continues moving while changing movement by continuously displaying individual buttons on the lower line (**Fig. 3 (c)**). Using both upper and lower lines on the operating screen while the robot is idle, however, caused the robot to malfunction, for example, when a button on the lower line reacts to the foot on the way back from the stepping on a button on the upper line.

4.1.2. Prevention of Incorrect Operation Using Retention Time

Given the absence of haptic feedback with the SOI equivalent to pressing a button or keying in or typing on a

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(a) Recognition

(b) Determination

(c) Error

Fig. 4. Status.

keyboard, we decided to use visual feedback, i.e., changing the button frame color, to prevent accidental or incorrect operation. The color changes from blue (default) to yellow when the system senses that the button is stepped on (**Fig. 4 (a)**). If recognition continues for one second, i.e., the designated retention time, the direction is set and the color changes from yellow to red, then the designated operation is executed (**Fig. 4 (b)**). When the system senses that more than one buttons has been stepped on at the same time, an error is displayed (**Fig. 4 (c)**). We found, however, that retention time varied greatly among individuals when we let visitors experiment using HFAMRO-1. Some users removed their foot immediately after stepping on the button – an occurrence more frequent than we had expected. Others became confused when the robot did not act immediately in response to a step, so we had to explain that they must step on the display for at least one second for the robot to sense it.

4.1.3. Button Detection Setting

Easy setup and simple modification thanks to software implementation are special features of the SOI. The scope of detection is the region in which the robot senses whether a button has been stepped on, and it was complex and troublesome to deal with because we set the scope of detection manually for each button.

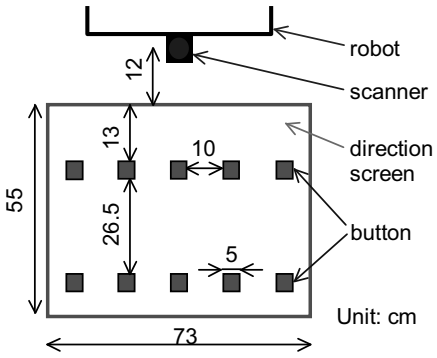
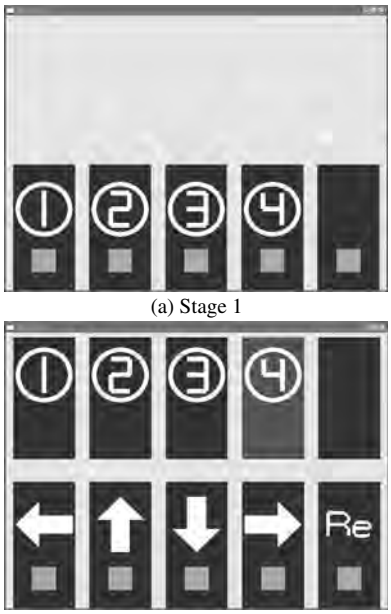


Fig. 5. Direction screen buttons.



(a) Stage 1

(b) Stage 2

Fig. 6. Bottom-line button use (robot suspended).

4.2. Screen Improvements

To solve these problems, we improved screen organization.

4.2.1. Button Increase

We increased the number of buttons to display on the direction screen from four to five columns during the robot's idle time (**Fig. 5**). Arranging buttons with five in a line is roughly the common shoe width, and leaves a 10 cm lateral interval between buttons. We figured this would be sufficient to prevent accidental operation while the robot is idle.

4.2.2. Lower-line Button Operation

We reconfigured the screen while maintaining two-line hierarchy. This enabled an operator to step at any time on buttons on the lower line. The operator first steps on a classification button located on the lower line (**Fig. 6 (a)**). The classification buttons then move to the upper line and individual movement button under the classification are displayed on the lower line (**Fig. 6 (b)**). The operator

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steps either on one of the individual buttons nearby to direct a movement or task. The fifth button was used to return to the previous state, where classification buttons are displayed on the lower line and the operator chooses an operation from among them (**Fig. 6 (a)**). This screen configuration enables the use of 20 movements from one operation screen based on five classifications.

4.2.3. Retention Time Shortening

As stated, we found that many users immediately removed their foot after stepping on a button, so we decided to shorten retention time from one second to 0.2 sec. "Active attention" conducted intentionally or positively for a purpose is said to involve 0.4 sec. for motivation or curiosity, and "passive attention" triggered involuntarily by external action or stimulation to take about 0.1 sec. [33]. We set retention time to slightly longer than that for passive attention. This is easily changed in software program and should be adjusted based on the application, user, etc.

4.2.4. Execution After Foot Removed

By shortening retention time and with buttons operated on only the lower line, when an operator withdraws a foot slowly after stepping on a button, the foot may cross or overlap other buttons because the direction screen moves when the robot moves, in which case the robot may conceivably execute a movement the operator does not intend. We thus decided that an individual button instruction would not be executed immediately, but instead would be executed after the system senses that the foot has been removed from the button.

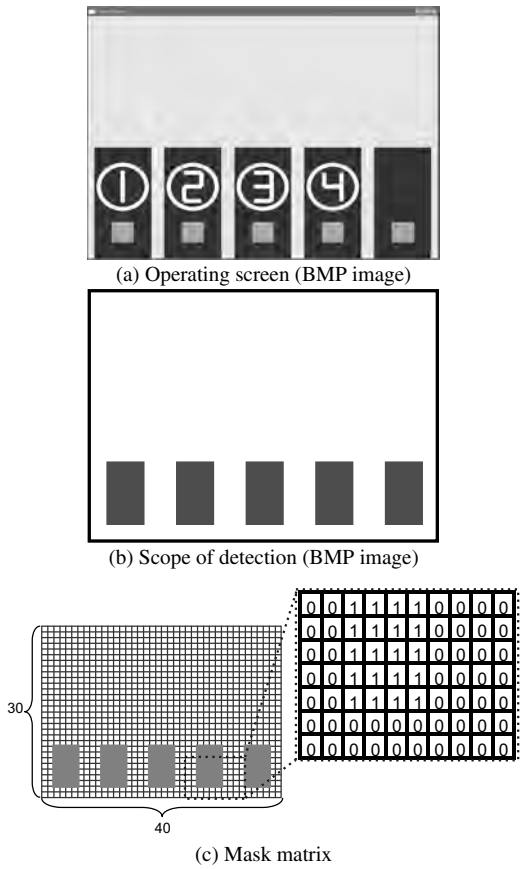
4.3. Recognition Change

4.3.1. Screen Design Change

The direction screen was drawn and displayed by OpenGL whenever the display changed. To speed up display, we decided that the BMP image made beforehand would be displayed on the screen using painting software and designing button placement and color as needed.

4.3.2. Simple Detection Scope Setup

To make it easier to set the scope of detection for individual buttons, we had painting software read the direction screen BMP image (**Fig. 7 (a)**), then set the scope of detection with a specific color around the button (**Fig. 7 (b)**). We then introduced a "mask matrix" which has 18.3 mm cell squares arranged into 30 lines and 40 columns for the 550×730 mm direction screen. We developed software to automatically generate the mask matrix (**Fig. 7 (c)**), i.e., "1" is set for cells including the specific color and "0" for other cells. We then used this mask matrix in stepping recognition.



(a) Operating screen (BMP image)

(b) Scope of detection (BMP image)

(c) Mask matrix

Fig. 7. Simple detection scope setup.

4.3.3. Stepping Recognition Using the Mask Matrix

In stepping recognition, all position data (step number and distance to the obstacle) acquired from range scanner scanning is converted to X-Y Cartesian coordinates (**Fig. 8 (a)**). The "obstacle matrix" has 18.3 mm cell squares arranged in 30 lines and 40 columns for the 550×730 mm direction screen. We determined which obstacle matrix cells each direction screen location data would be in and if the number of data included in a cell exceeded a preset threshold, the cell was changed from "0" to "1", enabling an obstacle matrix to be generated in one range scanner scan (**Fig. 8 (b)**). The obstacle matrix is superimposed on and compared to the mask matrix (**Fig. 8 (c)**) to determine the designated button from the number of cells in the obstacle matrix that indicates "1" in the scope of detection set for each button shown by the mask matrix.

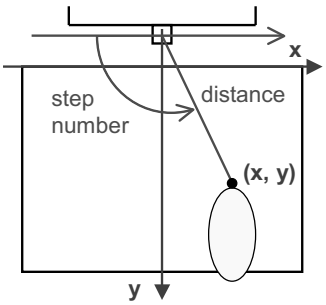
4.4. Postimprovement Direction and Operation

Based on the improvements just discussed, the user and robot interact as follows:

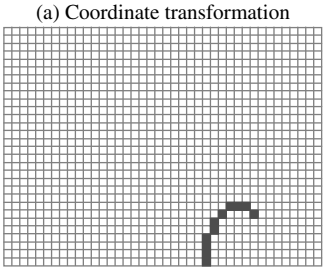
1. The range scanner repeatedly scans and acquires location data.

2. The user steps on a direction screen button projected and displayed on the travel surface.

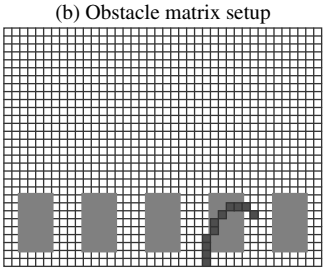
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(a) Coordinate transformation



(b) Obstacle matrix setup



(c) Obstacle matrix superimposed on the mask matrix

Fig. 8. Stepping recognition using the mask matrix.

3. If the number of location data exceeds the threshold in the scope of detection around a button, that button is recognized as having been selected.
4. If recognized buttons number one, the button indication-frame color changes from blue to yellow.
5. If recognition continues for 0.2 sec., it changes from yellow to red.
6. The robot remains idle until it recognizes that a foot has been removed from a button.
7. The robot begins the operation indicated by the button when it senses that the button in the red frame is no longer being stepped on.

5. Multiple Projected Screen Application

The area where the direction screen is projected is fixed if the robot has only one SOI, consisting of a projector and range scanner – meaning that the robot's nonholonomic omnidirectional mobility is not used effectively. We therefore equipped the robot with 2 SOIs to study use.

Using two screens having the same function, we controlled the robot from either direction screen. It is necessary to introduce the control for cooperation movement and competing evasion like multi-master single-slave system in telerobotics (details in, e.g., [34]). This enabled more than one person to simultaneously operate one robot (**Fig. 9**).

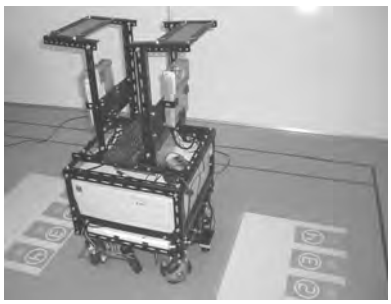


Fig. 9. SOI function with double-direction screens.

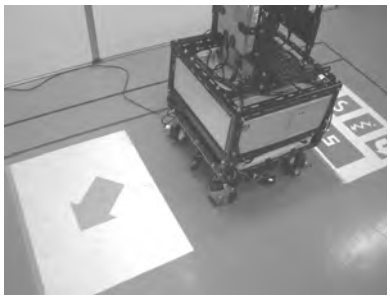


Fig. 10. SOI function plus preliminary-announcement.

Using two screens having different functions, we coordinated the direction and preliminary-announcement screens (**Fig. 10**). The purpose of the preliminary-announcement is to inform passers-by of robot movement beforehand. This may include upcoming direction and speed of movement or scheduled ongoing movement. Because scheduled omnidirectional routes cannot always be displayed on one screen projected on a specific area, we decided to display the upcoming movement (**Fig. 11**). This had the advantage of transmitting simple information such as the alternatives of right and left, useful when a passer-by must decide immediately which way to go to avoid colliding with the robot, displaying an arrow on the announcement screen whose direction, size, and color indicated robot direction and speed one second before actual movement [35, 36].

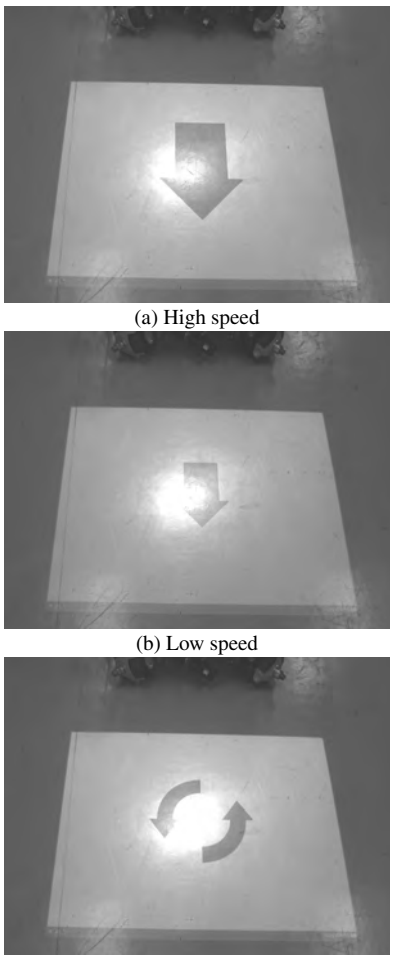
6. Range Data Application

Because the conventional HFAMRO-1 used only range scanner data to detect an object on a button, the robot could potentially move unintentionally in response to objects or walls on the travel surface. It also lacked sufficient obstacle avoidance. Even a potential user could be judged to be obstacle, preventing SOI use. We therefore implemented a simple function to discriminate feet from obstacles, then function control for obstacle avoidance to slow autonomous robot movement.

6.1. Discriminating Feet from Obstacles

SOI data is differentiated from obstacle avoidance data based on object size. The range scanner acquires dis-

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(a) High speed

(b) Low speed

(c) Turning

Fig. 11. Speed and direction of next movement.

tance to an object every 0.35 deg and calculated 2D obstacle locations as Cartesian coordinates from the distance and step number. If the distance between an object at one step and at the next step is less than 100 mm, objects in two different directions are determined to be the same object. Data considered to be from the same object based on object location is calculated from the distance and step number. The distance between leftmost (at the step with the minimum number) and the rightmost (at the step with the maximum number) position is then calculated for the same object, i.e., for a distance more than 300 mm away, the data for the object is used for obstacle avoidance and when less, it is used for the SOI (**Fig. 12**). Using the algorithm, object (a square box) (circled at right in **Fig. 12**) is used for obstacle avoidance, and objects (a pair of feet) (circled at left in **Fig. 12**) are used for the SOI.

When objects are put on the direction screen (**Fig. 13**), even a cardboard box put down (lower left, **Fig. 13 (a)**) does not cause buttons to react. An operator stepping on a button (lower center, **Fig. 13 (b)**), causes the indication frame color of the stepped-on button to change, i.e., the system reacts to a footstep – but not to the cardboard box – enabling the operator to direct the robot to execute a movement or task.

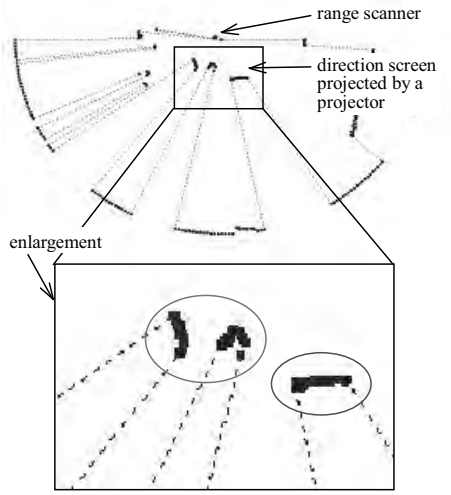
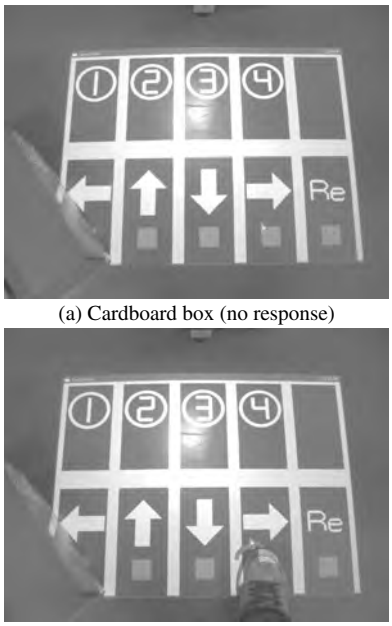


Fig. 12. Discriminating feet from obstacles.



(a) Cardboard box (no response)

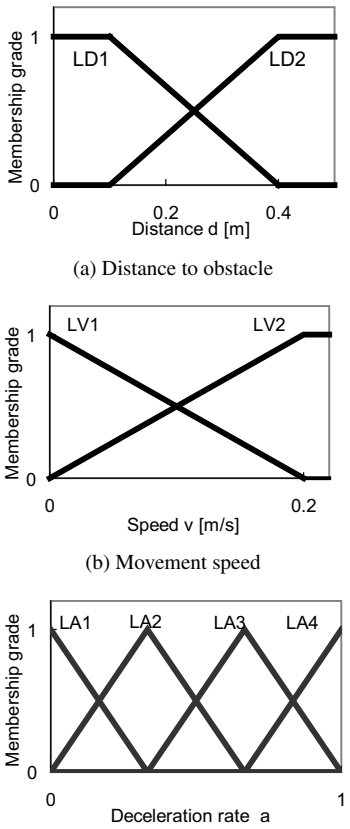
(b) Cardboard box and foot (response only to foot)

Fig. 13. Cardboard box and foot on direction screen.

6.2. Autonomous Movement Fusion Control

We implemented three autonomous movements – slowing, turning, and following – to operate the mobile robot safely using obstacle avoidance data [37], with slowing explained here as an example of limiting the robot's maximum speed based on the distance to the obstacle and robot speed. Maximum speed is decided using fuzzy reasoning calculating the shortest distance to the obstacle and current robot speed and outputting the degree of deceleration. Specifically, two membership functions concerning the shortest distance to an obstacle (**Fig. 14 (a)**) and two membership functions concerning robot speed (**Fig. 14 (b)**) are set, and four membership functions concerning the degree of deceleration (**Fig. 14 (c)**) are prepared for four rules combining these two inputs (**Table 3**). The output for the degree of deceleration is calculated using the center of gravity law

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(a) Distance to obstacle

(b) Movement speed

(c) Deceleration degree

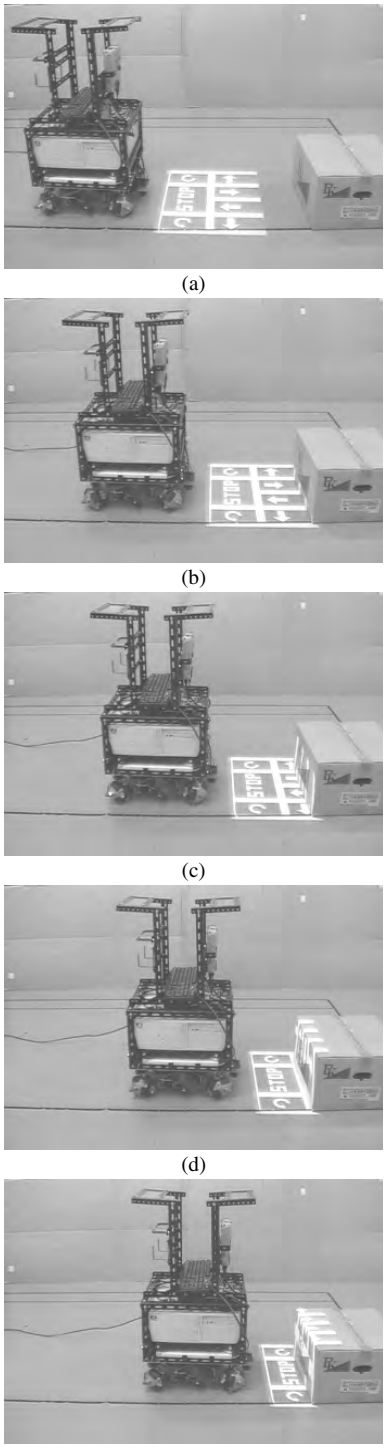
Fig. 14. Autonomous deceleration membership functions.

Table 3. Fuzzy autonomous deceleration rules.

Rules	Distance d (in)	Speed v (in)	Deceleration a (out)
R1	LD1	LV1	LA2
R2	LD1	LV2	LA1
R3	LD2	LV1	LA4
R4	LD2	LV2	LA3

for numeric conversion and used to autonomously limit the speed of movement.

The robot approaches a cardboard box (**Fig. 15**, pictures at 2.8 sec. intervals). Slowing is set to operate 40 cm from the range scanner, and the robot stops 10 cm from the object. The robot approaches the box (**Fig. 15 (a)**), but the button does not react even if the direction screen overlaps the box (**Fig. 15 (b)**). As it nears the box, the robot slows (**Fig. 15 (c)-(d)**). The robot finally stops without touching the box (**Fig. 15 (e)**).



(a)

(b)

(c)

(d)

(e)

Fig. 15. Experimental results of autonomous deceleration.

7. Conclusions

We have discussed the functions developed to improve HFAMRO-1 mobile robot maneuverability and safety for a step-on interface (SOI). The SOI, an innovative interface for directing robotic or mechatronic tasks and operations, uses a projector that displays a direction screen on a floor or other surface. An operator specifies buttons showing selected movement by stepping or pointing. Buttons displayed on two lines on the direction screen were reconfigured so that buttons stepped on to select movement were displayed on the lower of two lines. We also shortened retention time and had tasks executed after a foot was removed from the stepped-on button. Two SOIs used on the robot had multiple projected screens. After controlling the robot from either screen for the same function, we coordinated direction and preliminary-announcement screens to inform passers-by of anticipated robot movement. Using range scanner data, we distinguished feet

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from objects based on object size and autonomous movement fusion control for obstacle avoidance was implemented. We are continuing to improve functions such as environment recognition by the robot based on range data and autonomous movement fusion control using environmental data.

Visitors to our exhibits at Innovation JAPAN 2007 (Tokyo International Forum, Sep. 12–14), which had 44,495 visitors, and at 2007 International Robot Exhibition (Tokyo Big Sight, Nov. 28–Dec. 01), which had 104,211 visitors, were able to operate HFAMRO-1 satisfactorily. This demonstrated SOI reliability and robustness. We must now study the usability of instructions both by stepping and pointing.

We have proposed a SOI, explaining its functions, but it may not be the best interface for replacing manual operation, voice input, eye control, etc. The SOI may be an alternative, depending on the condition and situation, and the SOI could be used with other complementary interfaces.

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Name:
Takafumi Matsumaru

Affiliation:
Associate Professor, Faculty of Engineering and Graduate School of Engineering, Shizuoka University

Address:
3-5-1 Johoku, Naka, Hamamatsu, Shizuoka 432-8561, Japan

Brief Biographical History:
1987-1999 Toshiba Corp. R&D Center
1999- Shizuoka University
2002 Invited Researcher, Shizuoka Industrial Research Institute
2003 Invited Professor, LSC (Laboratoire Systemes Complexe) – CNRS, France

Main Works:
• "Study on Design of Physique and Motion for Humanoid Robot," Trans. of the Virtual Reality Society of Japan, Vol.11, No.2, pp. 283-292, 2006.
• "Development of four kinds of mobile robot with preliminary-announcement and display function of its forthcoming operation," J. of Robotics and Mechatronics, Vol.19, No.2, pp. 148-159, 2007.
• "Evaluation Experiment in Simulated Interactive Situation between People and Mobile Robot with Preliminary-Announcement and Indication Function of Upcoming Operation," Trans. of Human Interface Society, Vol.10, No.1, pp. 11-20, 2008.

Membership in Academic Societies:
• Society of Biomechanisms Japan (SOBIM)
• The Robotic Society of Japan (RSJ)
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Name:
Kosuka Akai

Affiliation:
Master's Course Student, Graduate School of Engineering, Shizuoka University

Address:
3-5-1 Johoku, Naka, Hamamatsu, Shizuoka 432-8561, Japan

Brief Biographical History:
2007- Graduate School of Engineering, Shizuoka University

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Appendix F-2

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Remote-Collaboration System Using Mobile Robot with Camera and Projector

Tamotsu Machino, Satoshi Iwaki, Hiroaki Kawata, Yoshimasa Yanagihara,
Yoshito Nanjo, and Ken-ichiro Shimokura
Human Interaction Project, NTT Cyber Solutions Laboratories
3-9-11 Midori-Cho, Musashino-shi, Tokyo 180-8585, Japan
E-mail: {machino.tamotsu, kawata.hiroaki, iwaki.satoshi, yanagihara.yoshimasa, nanjo.yoshito, k.shimokura}@lab.ntt.co.jp

***Abstract* - We have been studying a remote-collaboration system called SCOPE (sight collaboration by projection effect) featuring image projecting and capturing capabilities as implemented in a maintenance robot. With the help of SCOPE and a remote support person, an on-site worker can perform maintenance very efficiently. We propose a mobile SCOPE that can significantly expand the area of activity of the conventional SCOPE. To enable an on-site worker to share the field of view of a remote support person, we developed a technique for aligning the optical axes of a camera and a projector. We present experimental data that demonstrates the validity of our optomechanical design. Finally, we show that the mobile SCOPE enables workers to continuously share their field of view, no matter where the mobile SCOPE moves.**

Index Terms* - *Remote collaboration, Shared field of view, Mobile robot, Camera and projector, Tele-operation.

I. Introduction

To create a more efficient environment in which to perform remote maintenance over a network, we have been studying a new collaboration concept, called "robot-augmented communication" (RAC) [11]. In RAC, a maintenance robot and an on-site human worker, who may not be skilled in maintaining the target object, are assisted by a veteran operator of the object at a remote support center. RAC provides effective support for on-site workers by augmenting the communication ability of the remote support person with robotic functions that people do not have.

A prototype remote-collaboration system called SCOPE (sight collaboration by projection effect) was developed as a maintenance robot that was the first instance of RAC, which featured image projecting and capturing capability. This SCOPE system, equipped with a projector and a camera, enables a target object perceived in the field of view of a remote support person to be shared with an on-site worker. This function should dramatically shorten the time taken to perform maintenance operations.

However, this SCOPE system cannot move about in an on-site maintenance area. Generally, on-site maintenance areas include very large plant sites or huge industrial facilities, so mobility is indispensable. Therefore, we present a mobile SCOPE and discuss its key technological issues. A future scene of remote support using the mobile SCOPE is shown in Fig. 1. As far as we know, such a robotic system has never been reported before.

Numerous papers on real-space projection technology utilizing a camera and projector set have been published, mainly in the fields of augmented reality (AR), Computer Supported Cooperative Work (CSCW), and ubiquitous computing [1]-[5]. Almost all of these studies focused on applications inside a room in an office or home, so the equipment was spatially fixed to the room structure such as to a desk, ceiling, wall, or floor. Utilizing a head-mounted display [6] or hand-held projector [7] enables us to move about in an on-site maintenance area; however, the current size and weight of such devices make them too troublesome to wear and carry around. In that respect, mobile SCOPE can relieve the on-site worker from having to wear such heavy, bulky devices.

On the other hand, the addition of mobility to the SCOPE system will cause an inherent, serious problem with sharing the field of view in an actual space because the spatial relationship between the image frame of the camera and that of the projector will change depending on the distance between SCOPE and the target to be captured and projected. Therefore, one of the most important problems for a mobile SCOPE is to maintain a shared field of view, no matter where the SCOPE system moves. To overcome this problem, we describe a method, based on the use of an ingenious optomechanical structure, that enables the optical axis of the camera and that of the projector to be aligned.

After a brief introduction of our RAC concept and the

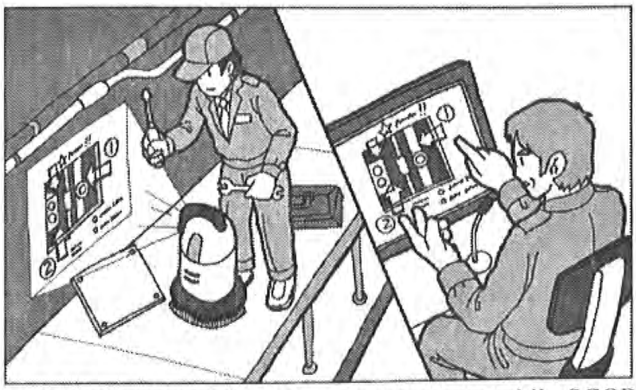


Fig. 1 Future scene of remote support using mobile SCOPE

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conventional SCOPE, we discuss requirements for the mobile SCOPE and its key technology for optical-axis alignment of the camera and the projector. Next, we provide experimental data on the evaluation of the optomechanical design of the mobile SCOPE. Finally, we describe implementing the mobile SCOPE with an optomechanical design that enables an on-site worker to share the field of view of a remote support person, no matter where the SCOPE moves.

II. Concept for New Collaboration between Robot and Human over Network

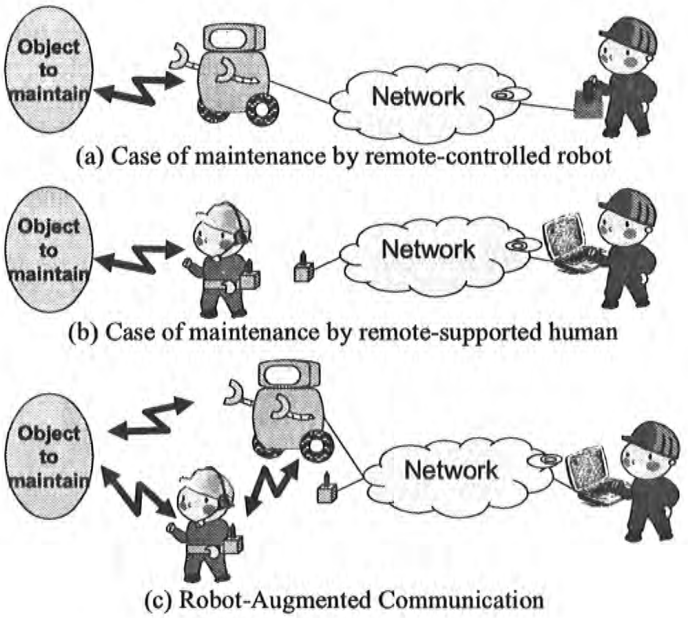
A. Robot-Augmented Communication

When no skilled workers are present at a work site, there are two ways of handling maintenance: either remotely operate a robot and devices at the site [8] [9] (see Fig. 2(a) below) or dispatch an unskilled worker to the site and remotely instruct him/her to perform maintenance operations from a distance [6] [10] (see Fig. 2(b)). In Fig. 2(a), a robot that interacts with a maintenance object cooperates with and is controlled by a remote, skilled operator through a network. In Fig. 2(b), an unskilled worker and a skilled operator cooperate through a network, and the unskilled worker interacts with the maintenance object. Each of these two cases – namely, the robot or the person handling the on-site operation – has its advantages and disadvantages, as explained below.

(a) Remote-controlled robot: Robot function, e.g., in terms of power and information-processing capability, can surpass that of a human operator, but the current level of robot autonomy is low and cannot match the operation skill of a remote skilled worker.

(b) Remote-supported human: Generally, the decision-making capability of a person in response to site conditions is much better than that of a robot. However, sufficiently conveying the intentions of the remote support person, i.e., skilled operators, without putting undue stress on the unskilled worker is difficult under the present state of communication between unskilled on-site workers and skilled remote support workers. For example, due to the time delay of a network, the supporter's intention often cannot be transmitted rapidly and easily.

With the drawbacks of the above two approaches in mind and aiming at extending the skill and ideas of a remote support person to cover work sites, where specialized robotic functions such as high-level information processing are particularly applicable, we propose a new form of collaboration between robots and on-site workers who have high decision-making capability. We have extended communication by means of a robot's functions, so this collaboration setup is called "robot-augmented communication" (RAC). As shown in Fig. 2(c), RAC provides effective support by emphasizing the intentions of the remote support person through the robot. This is achieved by actively utilizing the interaction between an on-site worker and robot functions that cannot be performed by humans.



(a) Case of maintenance by remote-controlled robot

(b) Case of maintenance by remote-supported human

(c) Robot-Augmented Communication

Fig. 2 Setups for remote maintenance.

B. SCOPE: System for supporting a shared field of view in an actual space

We selected the function of projecting information in an actual space as a robot function that is intended to surpass the ability of humans. In this section, we introduce a remote-support system called SCOPE as the first instance of an RAC concept.

1) System overview

A schematic of the configuration of this system is shown in Fig. 3. At the on-site worker's location, a camera and a projector are integrated in one piece, and an incorporated stepping motor enables the camera's viewing field and projected images to rotate around the vertical axis of a camera and projector unit. To attain the capability of a "shared viewing field" as explained later, domains of the viewing field of the camera and that of the projector are adjusted so that they are aligned. An on-site worker can use a laser pointer as an input interface. We implemented a manipulation function

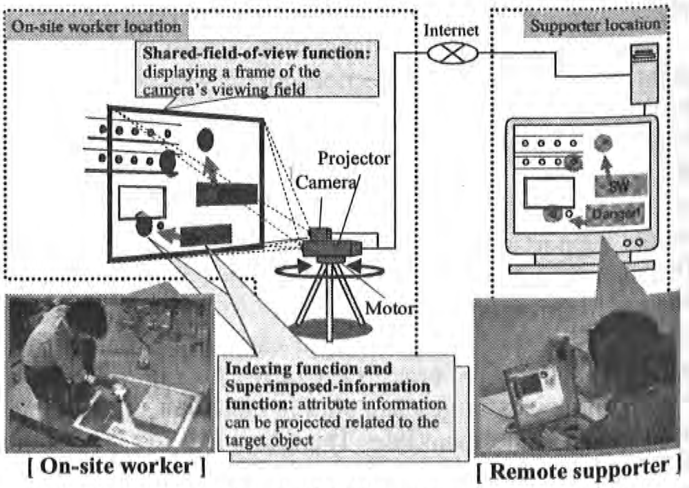


Fig. 3 SCOPE system.

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equivalent to the mouse on the client PC by applying image-recognition processing at the position of the laser pointer's spot.

2) Shared-field-of-view function

During collaborative operations at remote locations, a situation that often occurs is a remote support person verbally indicating relative directions like "on the right" to give instructions to an on-site worker. At such times, the remote support person's viewing field becomes essential information from the viewpoint of the on-site worker. In the SCOPE system, presenting the remote support person's viewing field to the on-site worker is possible by unifying the camera's viewing field and projector's projection area and displaying a frame of the camera's viewing field on the projected images.

3) Indexing function

Information needed for carrying out operations, "attribute information," is projected onto the target object as the occasion demands. This is like affixing notes on the target object with light. In the developed system, five kinds of information are conveyed: text, still images, video, sound, and program administration. The location of attributed information is indicated as a graphical image with a circular form. We call this mark a "projected image". By manipulating a projected image, one can also manipulate the display status of attribute information. At the on-site worker's location, the laser pointer is used to manipulate the projected image. At the supporter's location, the projected image is shown on a communication screen, which displays images transmitted from the on-site worker's location, and manipulated using the PC's mouse.

4) Superimposed-information function

In the SCOPE system, the camera/projector unit at the on-site worker's location can be manipulated from the supporter's location. The projected image and the attribute information are positioned on the target object by correcting the position of a projected image according to the movement of the camera and projector unit. This function enables the on-site worker to intuitively recognize the relationship between a stationary object in space and its attribute information.

5) Effectiveness of SCOPE for maintenance

The effectiveness of SCOPE was evaluated by experiments on two types of fundamental tasks, "comprehending the target object" and "transmitting instructions", involved in a typical maintenance operation. The experimental results indicate that shared-field-of-view, indexing, and superimposed-information functions are effective in shortening the time taken to perform the maintenance operation.

III. Hardware Design For a Mobile-type SCOPE

In this section, we discuss the hardware design of the mobile SCOPE in terms of user requirements and the conventional SCOPE technology. We use a planar mobile robot on which a camera-projector pair is mounted.

A. Requirements for utilizing SCOPE in an actual space

First, we assumed a very wide area with a flat floor in a huge indoor plant as the working environment of the mobile SCOPE. Therefore, we used a robot that has wheels with two degrees of freedom (DOF) of planar mobility. These DOF should be necessary for traveling in a wide working area and for avoiding projections, which are occluded by the on-site worker's body, between the robot and the object to be maintained.

B. Setup of projector and camera

We considered a projection plane approximately 4 × 4 m, about 1 – 3 m away from the mobile robot. A single small fixed projector cannot cover such a wide area, so pan-and-tilt rotational DOF are indispensable to broaden the projection coverage. On the other hand, rotation with respect to the optical axis is not needed because an on-site worker mainly works in a vertical standing position. We do not have to actively control the three translational DOF of the projector (one vertical and two horizontal) because we can relatively easily modify a projection image that has trapezoidal distortion caused by slanted projection on a flat plane. Based on the above discussion, we eventually designed a two-rotational-DOF projector on a 2-DOF planar mobile robot on wheels.

Many research studies have been performed on the autonomy of a mobile robot. For example, autonomous navigation technology such as path planning or SLAM (Simultaneous Localisation and Mapping) is a crucial issue that needs to be resolved for mobile robots. However, in the RAC concept, the present low level of mobile robot capabilities can be supplemented by human capabilities. On the other hand, the shared-field-of-view function of the mobile SCOPE has a fatal problem, as discussed in detail in the next section.

IV. Optomechanical Design

In this section, we discuss the layout for mounting a projector and camera on the mobile robot. First, we explain why aligning the optical axis of the projector and that of the camera is important, and we describe the optomechanical design for achieving this.

A. Issues in sharing field-of-view function of the mobile SCOPE

The basic functions of our mobile SCOPE include the following.

(1) Showing the remote support person's field of view by projecting the image frame of the camera

(2) Projecting various information on the viewing field as a shared area

(3) Enabling functions (1) and (2) in any place

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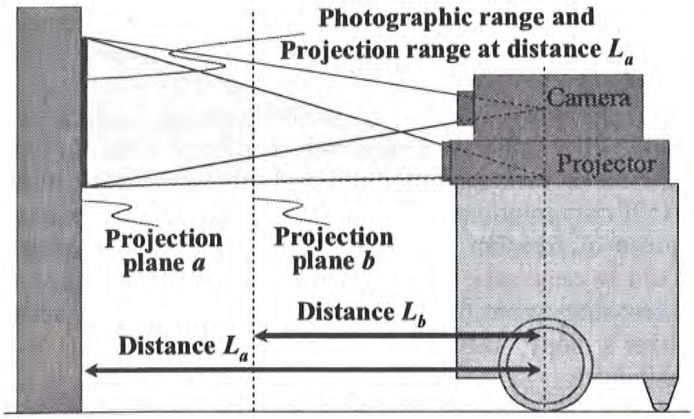


Fig. 4 Relationship between distance to projection plane, and photographic and projection ranges.

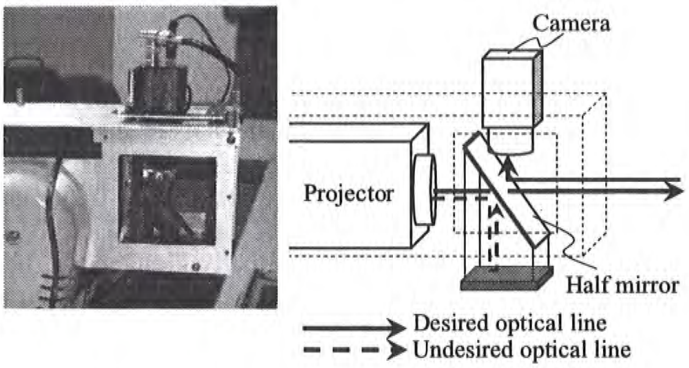


Fig. 5 Setup for aligning optical axes with half mirror.

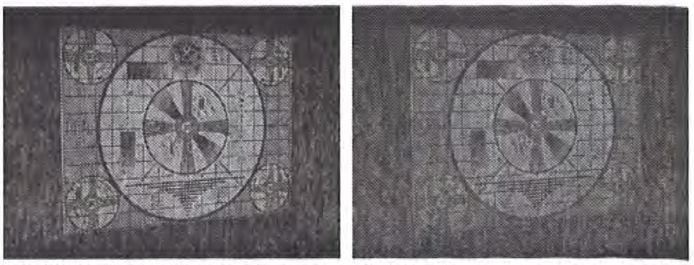
For the conventional SCOPE, we confirmed (1) and (2) by simply assembling the camera and projector so that their frames correctly overlapped on the projection plane. In this configuration, if the distance to the photographic plane (or the projection plane) is fixed, adjusting the orientations of the camera and projector only once is sufficient, which makes installation relatively easy. In the mobile SCOPE case, however, the distance is not fixed.

As shown in Fig. 4, if the camera's photographic range and the projector's projection range are the same at a projection plane located at distance L_a, then the photographic and projection ranges are not the same in projection plane b for distance L_b. To deal with this problem, one might normally have to develop one of the following.

(i) A hardware mechanism for automatically correcting the orientations of the camera and projector

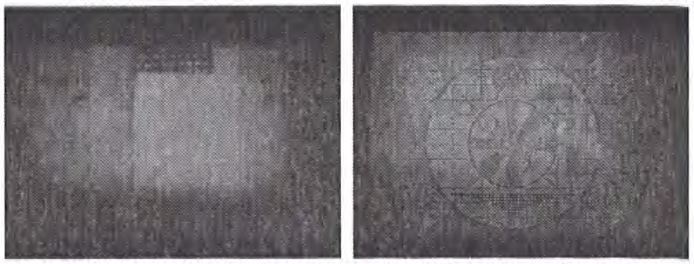
(ii) A real-time image-data-processing method that maintains the projected content within the visual field of the camera.

These are both very difficult and laborious to implement. Therefore, we propose another novel approach utilizing a half mirror.



(a) Directly projected image (b) Projected image through half-mirror

Fig. 6 Projected images on projection plane.



(a) Without black flock paper (b) With black flock paper

Fig. 7 Images captured by camera on SCOPE.

B. Aligning optical axes with a half mirror

To match the photographic range of the camera and the projection range of the projector independently of the distance to the subject, the ideal situation is for the focal point of the camera and the light source of the projector to be the same. However, this is impossible due to hardware restrictions. Therefore, we chose to achieve the same function by using a half mirror. First, as a preliminary investigation, we conducted an experiment using the equipment illustrated in Fig. 5.

Projected images on a projection plane without and with a half mirror, where the rate of reflection with respect to the rate of transmission, R:T, is 3:7, are shown in Figs. 6(a) and 6(b), respectively. The luminance of the projector is 1,500 lumens. These photographs were taken by another camera; they are images of what the on-site worker can see with the naked eye. Naturally, Fig. 6(b) is darker than Fig. 6(a).

Images captured by a camera on the mobile SCOPE are shown in Figs. 7(a) and (b). These are images of what the remote support person can see through the mobile SCOPE. If these images are completely the same as those in Fig. 6(b), the remote support person can see exactly what the on-site worker sees. However, they are clearly different, as is seen by comparing Figs. 6 and 7. In particular, Fig. 7(a) is extremely poor. An image of the black chassis passing through the half mirror is shown instead of the desired image. We call this phenomenon 'ghosting'. Ghosting occurs when the projector light that is reflected in the direction of the chassis is too bright. To delete the ghost image, we tried placing black flock paper on the chassis, and an image of that is shown in Fig. 7(b). The black flock paper reduces the ghosting. However, excess light still appeared in the camera image. The next section describes a method to eliminate this excess light.

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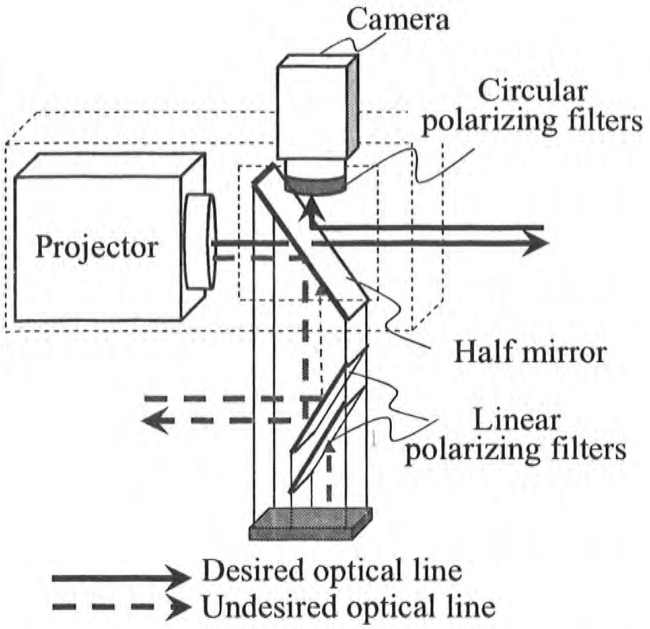
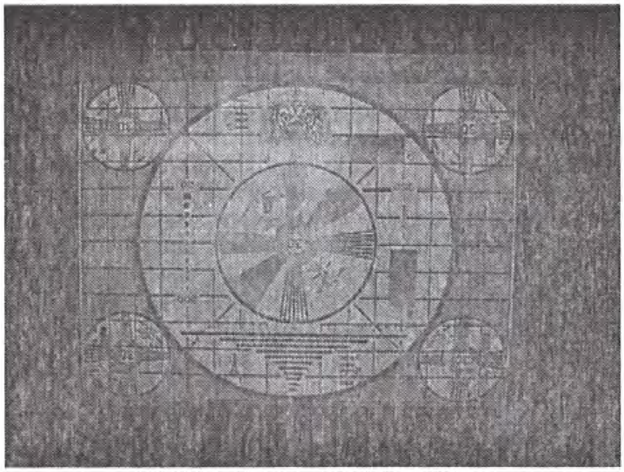
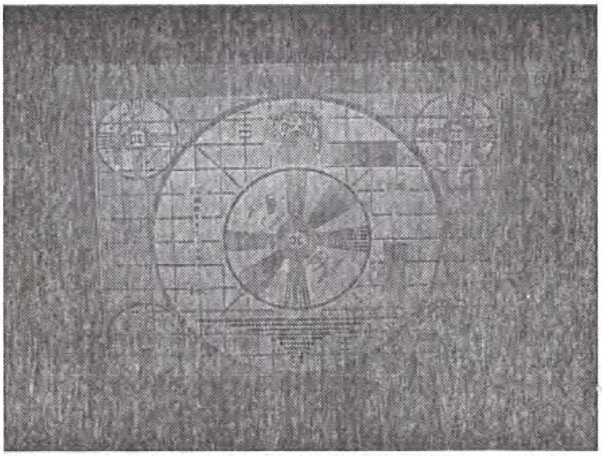


Fig. 8 Construction to eliminate ghost image.



(a) With linear polarizing filters



(b) With linear and circular filters

Fig. 9 Images captured by camera on SCOPE with polarizing filters.

C. Polarizing filters to eliminate the ghost image

We investigated ways to eliminate the excess light that passes through the half mirror and appears in the camera image. Utilizing polarizing filters is the key to solving this problem. The most effective configuration for eliminating the excess light is shown in Fig. 8. In this configuration, two linear polarizing filters reflect ambient light in the direction of the half mirror, and the circular polarizing filter blocks the light that has passed through the half mirror.

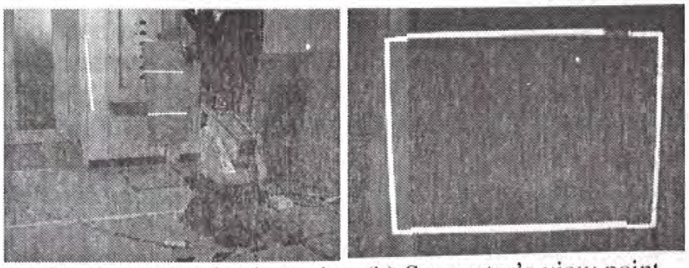
Images captured by the camera mounted on the SCOPE are shown in Fig. 9. They demonstrate the effectiveness of using polarizing filters. The result obtained when two linear polarizing filters were used is shown in Fig. 9(a). As the figure indicates, background image noise was cut by the linear polarization filters, compared with that of Fig. 7(b). However, the excess light that was reflected at the linear polarization filter and passed through the half mirror still appeared. The result obtained when two linear polarizing filters and a circular filter were used is shown in Fig. 9(b). The excess light from outside, which was present in Fig. 9(a), is reduced. This camera image can convey sufficient information about the on-site worker's site to a remote support person.

Photographs taken from the on-site worker's viewpoint and from the supporter's viewpoint, are shown in Figs. 10(a) and (b), respectively. Although the on-site worker's rectangular frame is extremely deformed by nonflat planes that consist of a cardboard and the background, the supporter's rectangular frame is almost the same as the rectangular frame of the projected image. This is evidence of the alignment of the optical axes of the camera and the projector.

From these experimental results, we confirmed the validity of our idea of using a half mirror and polarizing filters.

D. Implementation of mobile SCOPE

We unified a projector and a camera in the manner shown in Fig. 8 and mounted them on a mobile robot, Pioneer 3 manufactured by Active Media. A scene of remote support using the mobile SCOPE is shown in Figs. 11 and 12. Clearly, the viewing field of the remote supporter can be displayed in the on-site space. Aligning the optical axes enables sharing the field of view no matter where the mobile SCOPE moves. In this case, the position and orientation of the mobile SCOPE is controlled by the remote support person to find a target object or to avoid obstacles. Furthermore, the indexing and superimposed-information functions of the conventional



(a) On-site worker's viewpoint (b) Supporter's view point

Fig. 10 Result of aligning optical axes.

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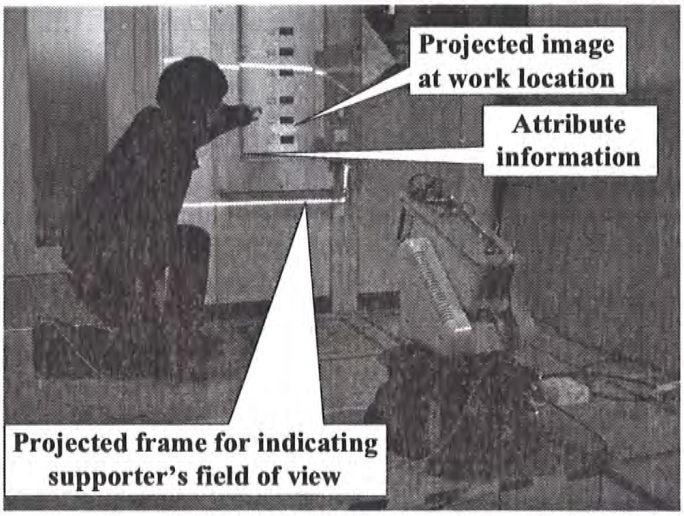


Fig. 11 Mobile SCOPE (on-site location).

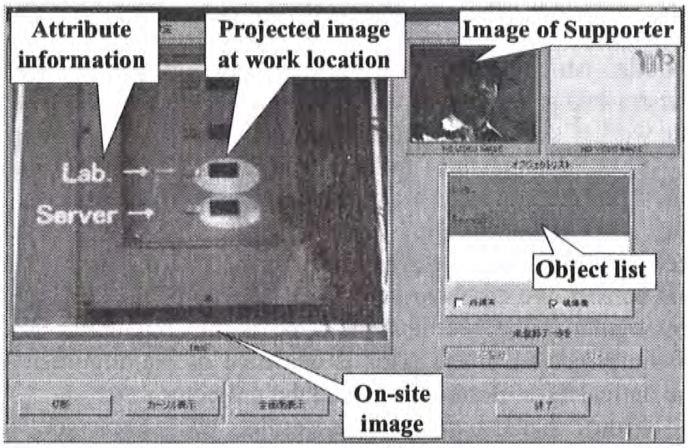


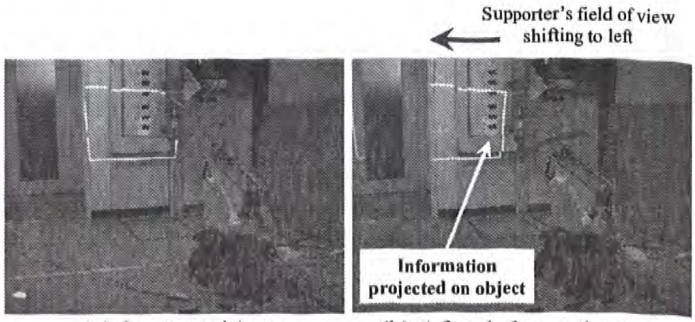
Fig. 12 Screen shot (supporter's location).

SCOPE were also implemented. Two photos indicate the result of automatic correction of the position of projected attribute information, as shown in Figs. 13(a) and (b).

V. Conclusion

To create a more efficient environment in which to perform remote maintenance over a network, we proposed a mobile SCOPE to significantly expand the field of activity. We developed a technique for aligning the optical axes of the camera and the projector to share the field of view between an on-site worker and a remote support person. Experimental data regarding the optomechanical design demonstrated the validity of our idea.

A conventional technique of many optomechanical systems uses a half mirror, such as that in a see-through head-mounted display. However, those systems are not relevant to the problems discussed in this paper such as "ghosting" because they do not use a bright light source like a projector.



(a) Start position (b) After left rotation

Fig. 13 Result of automatic correction of projected attribute information.

Therefore, a major contribution of this paper is the new finding of a new interdisciplinary research field covering AR and robotics. We plan to extend the autonomy functions of the mobile SCOPE to include obstacle avoidance or tracking target objects.

Acknowledgement

The authors gratefully acknowledge Takasuke Sonoyama for providing the illustration expressing a future scene of remote support using our mobile SCOPE.

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Remote-Collaboration System Using Mobile Robot with Camera and Projector

Tamotsu Machino, Satoshi Iwaki, Hiroaki Kawata, Yoshimasa Yanagihara,
Yoshito Nanjo, and Ken-ichiro Shimokura
Human Interaction Project, NTT Cyber Solutions Laboratories
3-9-11 Midori-Cho, Musashino-shi, Tokyo 180-8585, Japan
E-mail: {machino.tamotsu, kawata.hiroaki, iwaki.satoshi, yanagihara.yoshimasa, nanjo.yoshito, k.shimokura}@lab.ntt.co.jp

***Abstract* - We have been studying a remote-collaboration system called SCOPE (sight collaboration by projection effect) featuring image projecting and capturing capabilities as implemented in a maintenance robot. With the help of SCOPE and a remote support person, an on-site worker can perform maintenance very efficiently. We propose a mobile SCOPE that can significantly expand the area of activity of the conventional SCOPE. To enable an on-site worker to share the field of view of a remote support person, we developed a technique for aligning the optical axes of a camera and a projector. We present experimental data that demonstrates the validity of our optomechanical design. Finally, we show that the mobile SCOPE enables workers to continuously share their field of view, no matter where the mobile SCOPE moves.**

Index Terms* - *Remote collaboration, Shared field of view, Mobile robot, Camera and projector, Tele-operation.

I. INTRODUCTION

To create a more efficient environment in which to perform remote maintenance over a network, we have been studying a new collaboration concept, called "robot-augmented communication" (RAC) [11]. In RAC, a maintenance robot and an on-site human worker, who may not be skilled in maintaining the target object, are assisted by a veteran operator of the object at a remote support center. RAC provides effective support for on-site workers by augmenting the communication ability of the remote support person with robotic functions that people do not have.

A prototype remote-collaboration system called SCOPE (sight collaboration by projection effect) was developed as a maintenance robot that was the first instance of RAC, which featured image projecting and capturing capability. This SCOPE system, equipped with a projector and a camera, enables a target object perceived in the field of view of a remote support person to be shared with an on-site worker. This function should dramatically shorten the time taken to perform maintenance operations.

However, this SCOPE system cannot move about in an on-site maintenance area. Generally, on-site maintenance areas include very large plant sites or huge industrial facilities, so mobility is indispensable. Therefore, we present a mobile SCOPE and discuss its key technological issues. A future scene of remote support using the mobile SCOPE is shown in Fig. 1. As far as we know, such a robotic system has never been reported before.

Numerous papers on real-space projection technology utilizing a camera and projector set have been published, mainly in the fields of augmented reality (AR), Computer Supported Cooperative Work (CSCW), and ubiquitous computing [1]-[5]. Almost all of these studies focused on applications inside a room in an office or home, so the equipment was spatially fixed to the room structure such as to a desk, ceiling, wall, or floor. Utilizing a head-mounted display [6] or hand-held projector [7] enables us to move about in an on-site maintenance area; however, the current size and weight of such devices make them too troublesome to wear and carry around. In that respect, mobile SCOPE can relieve the on-site worker from having to wear such heavy, bulky devices.

On the other hand, the addition of mobility to the SCOPE system will cause an inherent, serious problem with sharing the field of view in an actual space because the spatial relationship between the image frame of the camera and that of the projector will change depending on the distance between SCOPE and the target to be captured and projected. Therefore, one of the most important problems for a mobile SCOPE is to maintain a shared field of view, no matter where the SCOPE system moves. To overcome this problem, we describe a method, based on the use of an ingenious optomechanical structure, that enables the optical axis of the camera and that of the projector to be aligned.

After a brief introduction of our RAC concept and the



Fig. 1 Future scene of remote support using mobile SCOPE

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conventional SCOPE, we discuss requirements for the mobile SCOPE and its key technology for optical-axis alignment of the camera and the projector. Next, we provide experimental data on the evaluation of the optomechanical design of the mobile SCOPE. Finally, we describe implementing the mobile SCOPE with an optomechanical design that enables an on-site worker to share the field of view of a remote support person, no matter where the SCOPE moves.

II. Concept for New Collaboration between Robot and Human over Network

A. Robot-Augmented Communication

When no skilled workers are present at a work site, there are two ways of handling maintenance: either remotely operate a robot and devices at the site [8] [9] (see Fig. 2(a) below) or dispatch an unskilled worker to the site and remotely instruct him/her to perform maintenance operations from a distance [6] [10] (see Fig. 2(b)). In Fig. 2(a), a robot that interacts with a maintenance object cooperates with and is controlled by a remote, skilled operator through a network. In Fig. 2(b), an unskilled worker and a skilled operator cooperate through a network, and the unskilled worker interacts with the maintenance object. Each of these two cases – namely, the robot or the person handling the on-site operation – has its advantages and disadvantages, as explained below.

(a) Remote-controlled robot: Robot function, e.g., in terms of power and information-processing capability, can surpass that of a human operator, but the current level of robot autonomy is low and cannot match the operation skill of a remote skilled worker.

(b) Remote-supported human: Generally, the decision-making capability of a person in response to site conditions is much better than that of a robot. However, sufficiently conveying the intentions of the remote support person, i.e., skilled operators, without putting undue stress on the unskilled worker is difficult under the present state of communication between unskilled on-site workers and skilled remote support workers. For example, due to the time delay of a network, the supporter's intention often cannot be transmitted rapidly and easily.

With the drawbacks of the above two approaches in mind and aiming at extending the skill and ideas of a remote support person to cover work sites, where specialized robotic functions such as high-level information processing are particularly applicable, we propose a new form of collaboration between robots and on-site workers who have high decision-making capability. We have extended communication by means of a robot's functions, so this collaboration setup is called "robot-augmented communication" (RAC). As shown in Fig. 2(c), RAC provides effective support by emphasizing the intentions of the remote support person through the robot. This is achieved by actively utilizing the interaction between an on-site worker and robot functions that cannot be performed by humans.

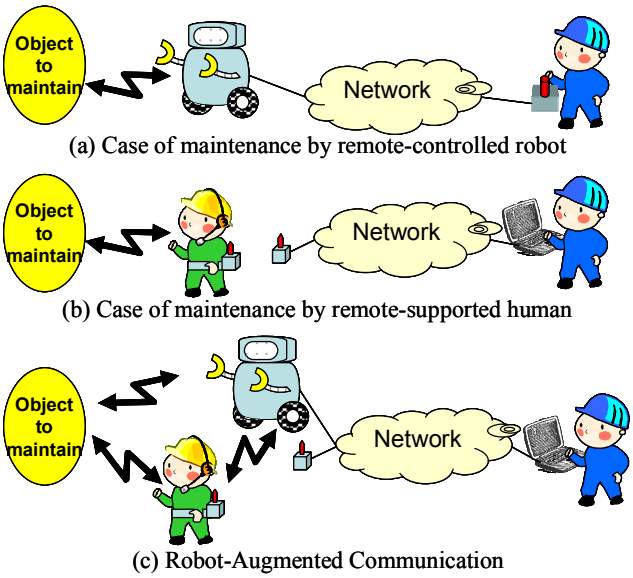


Fig. 2 Setups for remote maintenance.

B. SCOPE: System for supporting a shared field of view in an actual space

We selected the function of projecting information in an actual space as a robot function that is intended to surpass the ability of humans. In this section, we introduce a remote-support system called SCOPE as the first instance of an RAC concept.

1) System overview

A schematic of the configuration of this system is shown in Fig. 3. At the on-site worker's location, a camera and a projector are integrated in one piece, and an incorporated stepping motor enables the camera's viewing field and projected images to rotate around the vertical axis of a camera and projector unit. To attain the capability of a "shared viewing field" as explained later, domains of the viewing field of the camera and that of the projector are adjusted so that they are aligned. An on-site worker can use a laser pointer as an input interface. We implemented a manipulation function

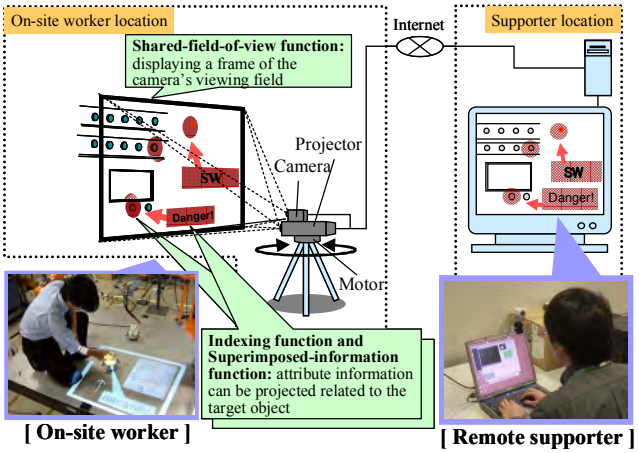


Fig. 3 SCOPE system.

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equivalent to the mouse on the client PC by applying image-recognition processing at the position of the laser pointer's spot.

2) Shared-field-of-view function

During collaborative operations at remote locations, a situation that often occurs is a remote support person verbally indicating relative directions like "on the right" to give instructions to an on-site worker. At such times, the remote support person's viewing field becomes essential information from the viewpoint of the on-site worker. In the SCOPE system, presenting the remote support person's viewing field to the on-site worker is possible by unifying the camera's viewing field and projector's projection area and displaying a frame of the camera's viewing field on the projected images.

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First, we assumed a very wide area with a flat floor in a huge indoor plant as the working environment of the mobile SCOPE. Therefore, we used a robot that has wheels with two degrees of freedom (DOF) of planar mobility. These DOF should be necessary for traveling in a wide working area and for avoiding projections, which are occluded by the on-site worker's body, between the robot and the object to be maintained.

B. Setup of projector and camera

We considered a projection plane approximately 4 × 4 m, about 1 – 3 m away from the mobile robot. A single small fixed projector cannot cover such a wide area, so pan-and-tilt rotational DOF are indispensable to broaden the projection coverage. On the other hand, rotation with respect to the optical axis is not needed because an on-site worker mainly works in a vertical standing position. We do not have to actively control the three translational DOF of the projector (one vertical and two horizontal) because we can relatively easily modify a projection image that has trapezoidal distortion caused by slanted projection on a flat plane. Based on the above discussion, we eventually designed a two-rotational-DOF projector on a 2-DOF planar mobile robot on wheels.

Many research studies have been performed on the autonomy of a mobile robot. For example, autonomous navigation technology such as path planning or SLAM (Simultaneous Localisation and Mapping) is a crucial issue that needs to be resolved for mobile robots. However, in the RAC concept, the present low level of mobile robot capabilities can be supplemented by human capabilities. On the other hand, the shared-field-of-view function of the mobile SCOPE has a fatal problem, as discussed in detail in the next section.

IV. Optomechanical Design

In this section, we discuss the layout for mounting a projector and camera on the mobile robot. First, we explain why aligning the optical axis of the projector and that of the camera is important, and we describe the optomechanical design for achieving this.

A. Issues in sharing field-of-view function of the mobile SCOPE

The basic functions of our mobile SCOPE include the following.

(1) Showing the remote support person's field of view by projecting the image frame of the camera

(2) Projecting various information on the viewing field as a shared area

(3) Enabling functions (1) and (2) in any place

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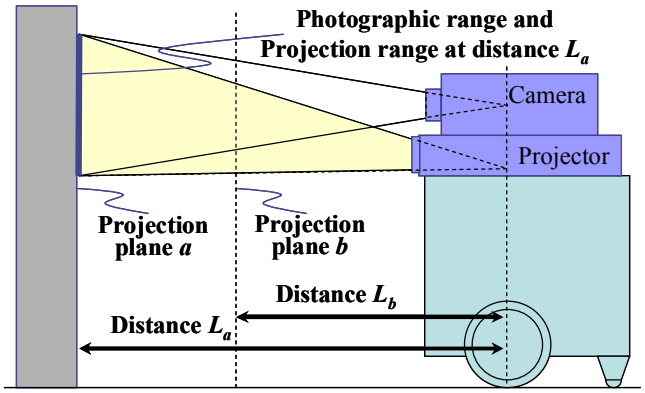


Fig. 4 Relationship between distance to projection plane, and photographic and projection ranges.

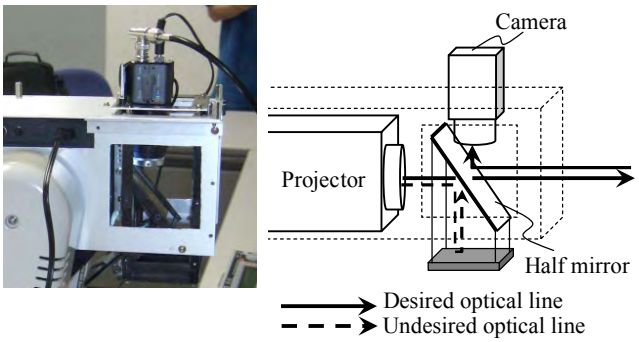


Fig. 5 Setup for aligning optical axes with half mirror.

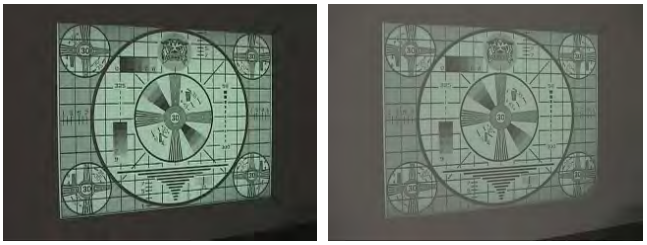
For the conventional SCOPE, we confirmed (1) and (2) by simply assembling the camera and projector so that their frames correctly overlapped on the projection plane. In this configuration, if the distance to the photographic plane (or the projection plane) is fixed, adjusting the orientations of the camera and projector only once is sufficient, which makes installation relatively easy. In the mobile SCOPE case, however, the distance is not fixed.

As shown in Fig. 4, if the camera's photographic range and the projector's projection range are the same at a projection plane located at distance L_a, then the photographic and projection ranges are not the same in projection plane *b* for distance L_b. To deal with this problem, one might normally have to develop one of the following.

(i) A hardware mechanism for automatically correcting the orientations of the camera and projector

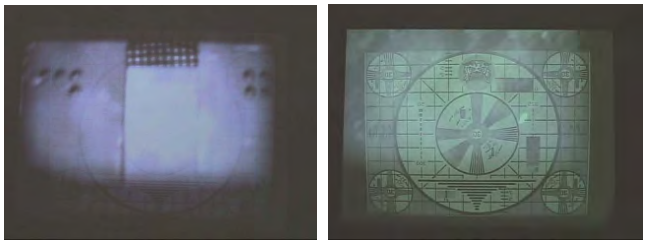
(ii) A real-time image-data-processing method that maintains the projected content within the visual field of the camera.

These are both very difficult and laborious to implement. Therefore, we propose another novel approach utilizing a half mirror.



(a) Directly projected image (b) Projected image through half-mirror

Fig. 6 Projected images on projection plane.



(a) Without black flock paper (b) With black flock paper

Fig. 7 Images captured by camera on SCOPE.

B. Aligning optical axes with a half mirror

To match the photographic range of the camera and the projection range of the projector independently of the distance to the subject, the ideal situation is for the focal point of the camera and the light source of the projector to be the same. However, this is impossible due to hardware restrictions. Therefore, we chose to achieve the same function by using a half mirror. First, as a preliminary investigation, we conducted an experiment using the equipment illustrated in Fig. 5.

Projected images on a projection plane without and with a half mirror, where the rate of reflection with respect to the rate of transmission, R:T, is 3:7, are shown in Figs. 6(a) and 6(b), respectively. The luminance of the projector is 1,500 lumens. These photographs were taken by another camera; they are images of what the on-site worker can see with the naked eye. Naturally, Fig. 6(b) is darker than Fig. 6(a).

Images captured by a camera on the mobile SCOPE are shown in Figs. 7(a) and (b). These are images of what the remote support person can see through the mobile SCOPE. If these images are completely the same as those in Fig. 6(b), the remote support person can see exactly what the on-site worker sees. However, they are clearly different, as is seen by comparing Figs. 6 and 7. In particular, Fig. 7(a) is extremely poor. An image of the black chassis passing through the half mirror is shown instead of the desired image. We call this phenomenon 'ghosting'. Ghosting occurs when the projector light that is reflected in the direction of the chassis is too bright. To delete the ghost image, we tried placing black flock paper on the chassis, and an image of that is shown in Fig. 7(b). The black flock paper reduces the ghosting. However, excess light still appeared in the camera image. The next section describes a method to eliminate this excess light.

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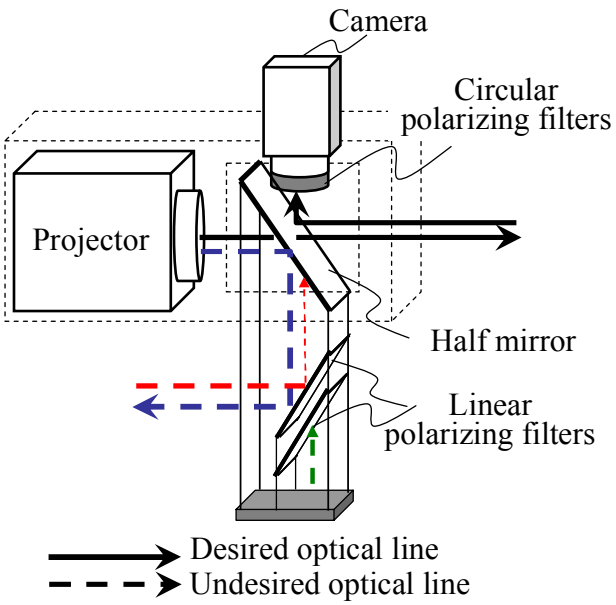
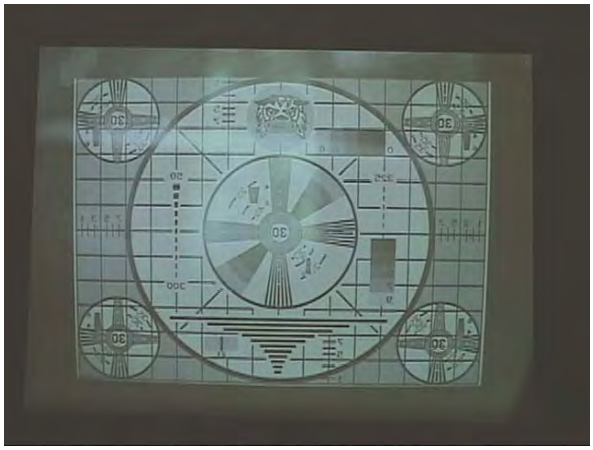
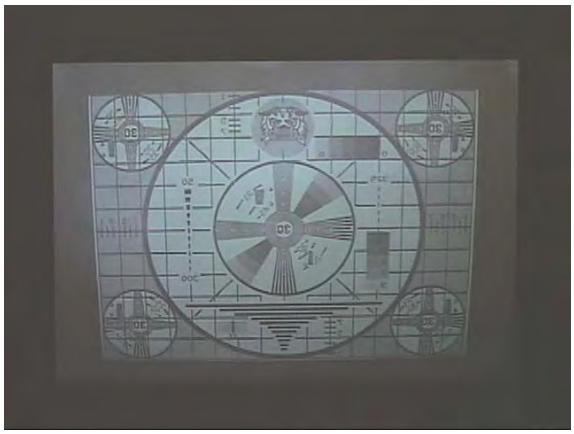


Fig. 8 Construction to eliminate ghost image.



(a) With linear polarizing filters



(b) With linear and circular filters

Fig. 9 Images captured by camera on SCOPE with polarizing filters.

C. Polarizing filters to eliminate the ghost image

We investigated ways to eliminate the excess light that passes through the half mirror and appears in the camera image. Utilizing polarizing filters is the key to solving this problem. The most effective configuration for eliminating the excess light is shown in Fig. 8. In this configuration, two linear polarizing filters reflect ambient light in the direction of the half mirror, and the circular polarizing filter blocks the light that has passed through the half mirror.

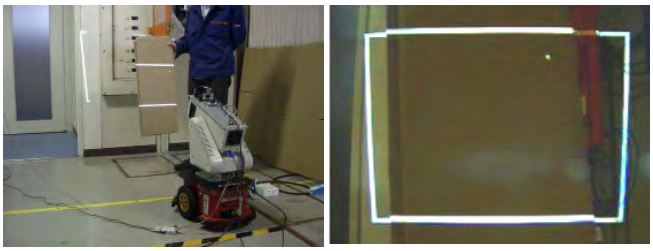
Images captured by the camera mounted on the SCOPE are shown in Fig. 9. They demonstrate the effectiveness of using polarizing filters. The result obtained when two linear polarizing filters were used is shown in Fig. 9(a). As the figure indicates, background image noise was cut by the linear polarization filters, compared with that of Fig. 7(b). However, the excess light that was reflected at the linear polarization filter and passed through the half mirror still appeared. The result obtained when two linear polarizing filters and a circular filter were used is shown in Fig. 9(b). The excess light from outside, which was present in Fig. 9(a), is reduced. This camera image can convey sufficient information about the on-site worker's site to a remote support person.

Photographs taken from the on-site worker's viewpoint and from the supporter's viewpoint, are shown in Figs. 10(a) and (b), respectively. Although the on-site worker's rectangular frame is extremely deformed by nonflat planes that consist of a cardboard and the background, the supporter's rectangular frame is almost the same as the rectangular frame of the projected image. This is evidence of the alignment of the optical axes of the camera and the projector.

From these experimental results, we confirmed the validity of our idea of using a half mirror and polarizing filters.

D. Implementation of mobile SCOPE

We unified a projector and a camera in the manner shown in Fig. 8 and mounted them on a mobile robot, Pioneer 3 manufactured by Active Media. A scene of remote support using the mobile SCOPE is shown in Figs. 11 and 12. Clearly, the viewing field of the remote supporter can be displayed in the on-site space. Aligning the optical axes enables sharing the field of view no matter where the mobile SCOPE moves. In this case, the position and orientation of the mobile SCOPE is controlled by the remote support person to find a target object or to avoid obstacles. Furthermore, the indexing and superimposed-information functions of the conventional



(a) On-site worker's viewpoint (b) Supporter's view point

Fig. 10 Result of aligning optical axes.

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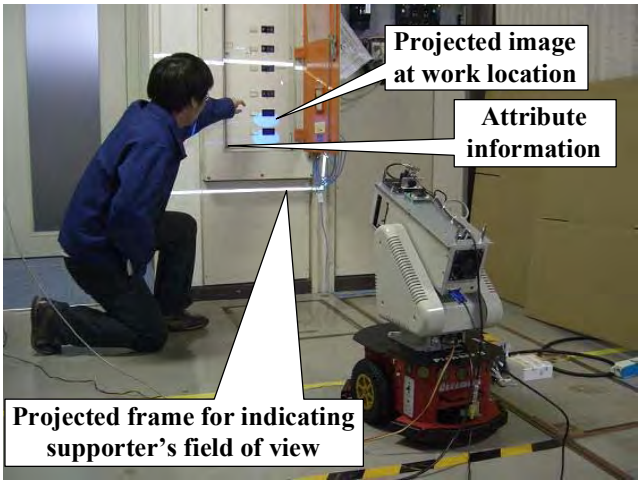


Fig. 11 Mobile SCOPE (on-site location).

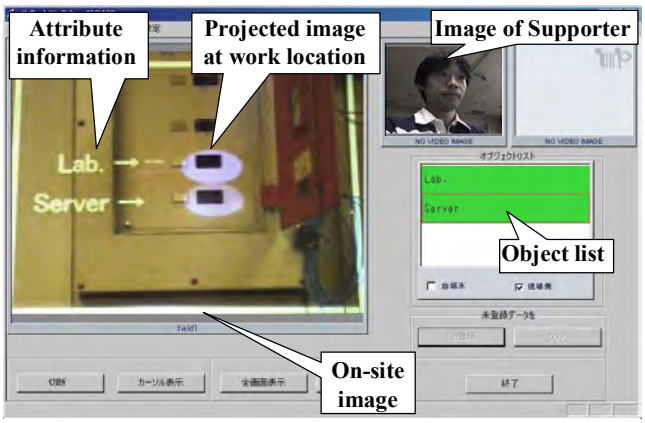


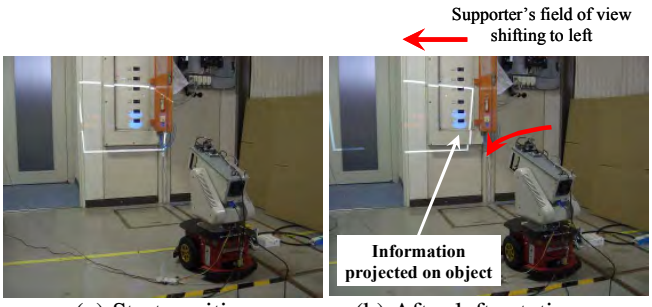
Fig. 12 Screen shot (supporter's location).

SCOPE were also implemented. Two photos indicate the result of automatic correction of the position of projected attribute information, as shown in Figs. 13(a) and (b).

V. Conclusion

To create a more efficient environment in which to perform remote maintenance over a network, we proposed a mobile SCOPE to significantly expand the field of activity. We developed a technique for aligning the optical axes of the camera and the projector to share the field of view between an on-site worker and a remote support person. Experimental data regarding the optomechanical design demonstrated the validity of our idea.

A conventional technique of many optomechanical systems uses a half mirror, such as that in a see-through head-mounted display. However, those systems are not relevant to the problems discussed in this paper such as "ghosting" because they do not use a bright light source like a projector.



(a) Start position (b) After left rotation

Fig. 13 Result of automatic correction of projected attribute information.

Therefore, a major contribution of this paper is the new finding of a new interdisciplinary research field covering AR and robotics. We plan to extend the autonomy functions of the mobile SCOPE to include obstacle avoidance or tracking target objects.

Acknowledgement

The authors gratefully acknowledge Takasuke Sonoyama for providing the illustration expressing a future scene of remote support using our mobile SCOPE.

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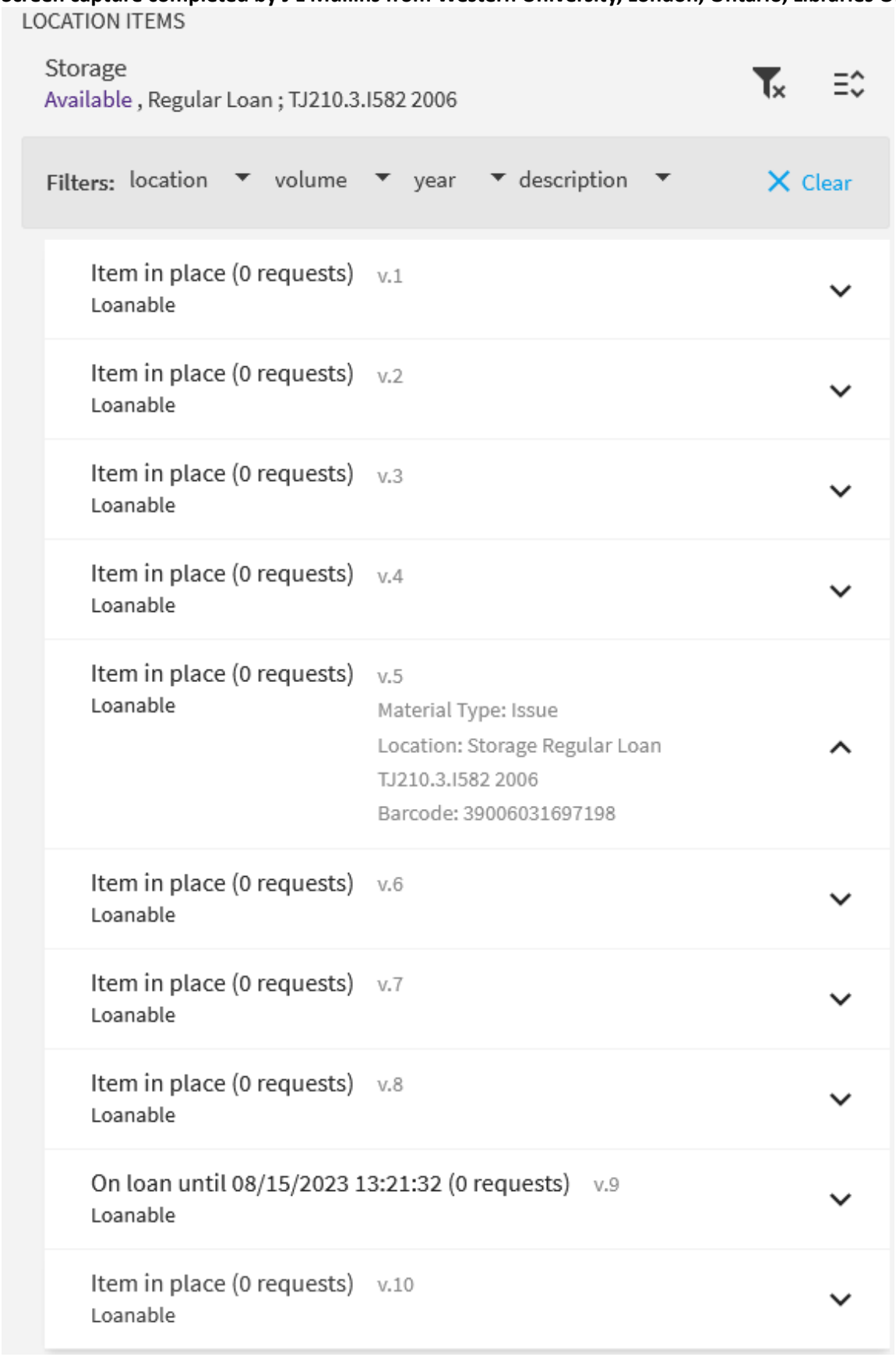
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Contents

I. Introduction

To create a more efficient environment in which to perform remote maintenance over a network, we have been studying a new collaboration concept, called "robot-augmented communication" (RAC) [11]. In RAC, a maintenance robot and an on-site human worker, who may not be skilled in

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maintaining the target object, are assisted by a veteran operator of the object at a remote support center. RAC provides effective support for on-site workers by augmenting the communication ability of the remote support person with robotic functions that people do not have.

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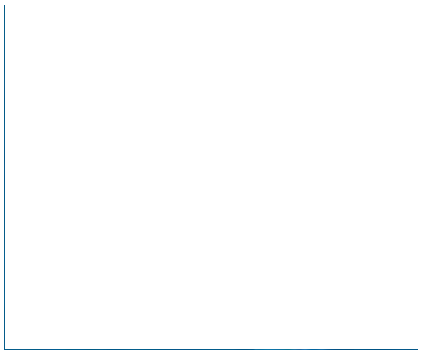
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parkjk@korea.ac.kr

ABSTRACT
Current forms of Human Robot Interaction (HRI) pursue mostly anthropomorphism and direct interaction. That is, the interaction paradigm is based on imitating how "people" interact with one another (e.g. using spoken language, gestures, facial expression, etc.). However, "direct" interaction/contact with the "robot," often causes significant inconvenience and usability problems. In this paper, we present an alternative to the anthropomorphic interface using a projected display and indirect, yet already familiar GUI based interaction. That is, the projector (on the moving robot) projects information on the nearby surface and provides a relatively large area through which indirect GUI based interaction can occur. As an instance of such an HRI paradigm, we present a moving robot kiosk that projects displays around itself and serve and interact with multiple people at once. We report our on-going development efforts and a pilot experimental study that compares it to the typical touch screen based direct HRI.

Categories and Subject Descriptors
H.5.2 [**HCI**]: User Interfaces –*Interaction Style, Input devices and strategies.*

General Terms
Design, Experimentation, Human Factors.

Keywords
Human robot interaction, Anthropomorphism, Indirect/direct interaction, Projector, Large display.

1. INTRODUCTION
Robots are finding their ways into our everyday environment [1] and as such their social aspect and interaction with humans have become a very important issue for their successful deployment and control. However, the conventional anthropomorphic and direct interaction with robots has not been so successful mainly because (1) most robots are not (or perhaps cannot be) optimized human factor-wise for the diverse users (e.g. touch screen interface, see Figure 1) and (2) recognition technologies (for language, face, etc.) for typical anthropomorphic interfaces is still limited in many ways. In fact, the problem of anthropomorphic interfaces generating false expectations of human-like responses and behaviors, and becoming a source of disappointment and confusion to users, has been well known [2].

As an alternative, "indirect" interaction mediated through a large projected display system is proposed. Figure 2 shows one possible way to employ such a framework where, in this particular case, the projector on the robot projects onto the floor around the robot and the interaction is made possible by using the camera and detection of laser pointers or software markers. We claim that such an interaction framework can alleviate much of the human factors problem and enhance the overall experience by the "enlarged" communication channel and amplified presence of the robot. The proposed framework is flexible to accommodate different types of users and tasks, one-to-many interaction, and even mixing of real and virtual objects. When combined with a hand-held interaction device, it can be extended to support a variety of interaction techniques with the consideration of robot's mobility.

In this short paper presentation, we report our progress in realizing the proposed HRI framework and a comparative experimental study to the conventional touch screen based HRI for task efficiency, usability and user satisfaction.



Figure 1. Interacting "directly" with robots. Robots cannot be ergonomically designed for all types of users. This makes the popular touch screen interface very difficult to use.

2. RELATED WORK
Most current HRI paradigms are anthropomorphic employing physical or graphical faces and human like behavior and recognition capabilities [3][4][5][6][7].

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As an alternative to conventional HRI, the idea of "projector-on-robot" was partially inspired from the movie "Star Wars" (holographic display given by R2D2) [8]. Machino et al. [9] also presented a similar idea but concentrated mostly on how to offer augmented information on the interested object in the environment. As already indicated, our framework suggests to use the projection display (and GUI) as the major mediating element between the human user and the robot. Figure 3 illustrates the idea. Note that the conventional interfaces may still be employed but perhaps in a supporting fashion due to their limited reliability. For instance, the robot can give information and guidance as it moves through the hall and interact with people mostly through the display (using hand-held interaction devices) and also by voice/sound/gestures.

3. IMPLEMENTATION & EXPERIMENT

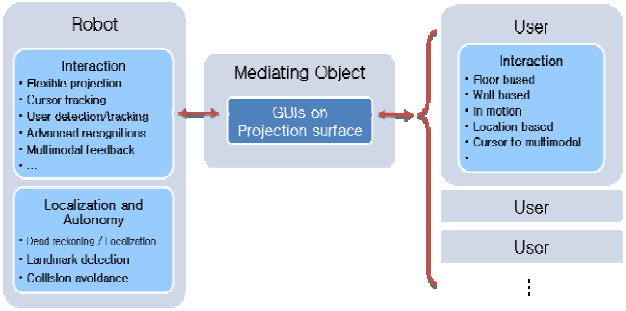


Figure 2. Major aspects of the indirect HRI framework.

Figure 2 shows several distinguishing aspects of the proposed HRI framework. On the part of the robot, aside from basic autonomy, tracking and recognition capabilities, it needs to have flexible projection capabilities (e.g. on the wall, floor, etc.), multiple user detection. In addition, a surface centered interaction framework needs to be employed for the large moving screen and to support remote interaction. Figure 3 shows our current implementation.

We conducted a pilot experimental study, comparing our HRI framework to a conventional touch screen based one. A group of subjects were tested for task completion efficiency and user experience for two different tasks, one requiring minimal amount of interaction (1~2) and another many (5~6). Contrast to our hypotheses, the proposed indirect HRI was not superior in terms of task efficiency due to the strong familiarity of the touch screen interfaces. However, it showed superiority in approachability and high satisfaction due to the large sized display. The post interviews and behavioral observation also indicated promising aspects of our framework with regards to ergonomics and ways for further improvements.

4. CONCLUSION

We have proposed a new indirect HRI framework based on the idea of mediating the interaction through projection from the robot. Our work is motivated by the lack of usability with the current mostly direct approach to interaction design for HRI. We have carried out a preliminary implementation and a comparative experiment to assess the feasibility of our approach. We are continuing to implement and complete other aspects of the proposed framework including basic robotic behaviors, middleware for multiple user and sensor/IO management, display surface selection, cursor tracking, and projection distortion correction. Based on our pilot experiment, a more formal and large scale experiment will be carried out as well.

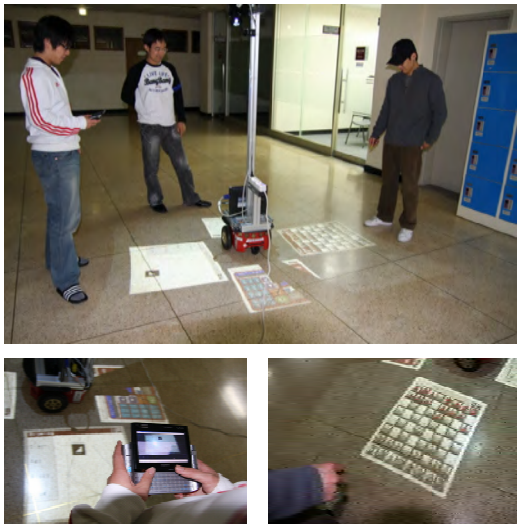


Figure 3. The proposed HRI platform with floor projection. Bottom pictures show marker based interaction using an UMPC (left) and laser pointer based interaction (right).

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Appendix F-8

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Field Trial of Asynchronous Communication Using Network-Based Interactive Child Watch System for the Participation of Parents in Day-Care Activities

Hiroaki Kawata*1, Yosuke Takano*2, Yoshiyuki Iwata*1,
Naoyoshi Kanamaru*1, Ken-ichiro Shimokura*3, Yoshihiro Fujita*2

*1 Network appliance and services project, NTT Cyber solutions laboratories,
*2 NEC Corporation,
*3 ATR Intelligent Robotics and Communication Laboratories

Abstract— **A recent trend in society is for young parents to ask for support in performing their childcare duties. Against this background and to promote the intermixing of parents and children and support information exchange between parents and nursery teachers, we developed the network-based interactive child-watch system called "Meru-robo Digital Log system". It is composed of the "Action Switch Platform (AcSP)" (developed by NTT Laboratories) for exchanging dialog with a "personal robot" (called "PaPeRo") (developed by NEC Corporation) by using cellular phone text messaging. A field trial showed that parents could send their intentions and receive information in a schedule-flexible manner via cellular phone text messaging. Since the robot in the nursery linked the parents to the teacher, their information exchanges did not interfere with the activities of the children. We report results of information exchanges using this system in two situations: parents are the same building (but not the same room as the children) and parents are in other locations going about their daily life. In the limited situation of children playing in a nursery, we found that parents in remote locations could get detailed information about their children's activities and expressions when desired via asynchronous communication.**

Index Terms - child-watch system, nursery facility, cellular phone, asynchronous communication

1. INTRODUCTION

More and more people are recently changing their lifestyle by having both parents working. Families now need to collaborate with the service providers taking care of their pre-school children and aged parents. To better support working parents, nursery facilities are offering extended opening hours. To encourage the elderly to lead a self-supporting life, more day service centers are offering home visit nursing. As implied, it will be more important to support collaboration between the family and the service providers.

The functionality offered by modern robots has advanced to the point that many of societies needs can be fulfilled by using these technologies. Several recent studies have targeted the effective support of the elderly and children through the use of robots. Experiments have been conducted on robots providing therapy services to elderly people and child-care in nurseries[1][2][3][4]. Several studies have been made on robotic systems and the remote control of robots for remote collaboration[5][6][7]. As mentioned above, several studies have been made on the use of robots to provide effective support for elderly people and children. However, no study has examined using robots to allow the parents to collaborate with service providers as well as their aged parents and children.

Higher levels of "safety" and "security" are being demanded, and expectations for services that allow parents to watch over children from a remote location and services that activate communication between parents and children are growing. We introduce here our concept of a robot system that establishes asynchronous communication between remote parents, teachers, and children.

We developed "Meru-robo Digital Log system", a network-based interactive child watch system for the participation of parents in day-care activities as a prototype of our concept. This system is composed of "Action Switch Platform (AcSP)" (developed by NTT Laboratory) for exchanging dialog with "PaPeRo", a personal robot developed by NEC Corporation. A key feature is that it is based on cellular-phone text messaging. The parent writes an e-mail message describing the parent's wishes and sends it to the system. PaPeRo receives the message which is passed to

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AcSP and converted into an action command acceptable to PaPeRo. The teacher, at the appropriate time, triggers PaPeRo to process the command. PaPeRo follows the parent's instructions and collects video images of the child's response to the parent's message. The collected video data is returned to the parent.

An experiment was conducted at two child care facilities to validate our concept; 12 families participated. We report trial results and interview data collected from the families and the teachers.

We describe our concept in the second chapter. Next, we describe the"Meru-robo Digital Log system," the prototype system used to validate our concept. We report the results of the experiment in the fourth chapter; our conclusions are given in the fifth chapter.

2. Robot System with Asynchronous Communication

2.1. *Problem of nursery facilities for parents*

Given the background of working parents utilizing child-care services, parents and teachers are sharing roles for child development. Parents can watch their child activities and can listen to the voice of their child at home. This is not possible while the parents are working. If the parents have a spare moment such as a coffee break, there is no direct way of getting detailed information about their child's activities. The parents are limited to second-hand information about their children provided by their child's teacher. Since working parents are very busy, their communication time is generally short. Therefore, parents cannot learn of their children's activities in any detail. Moreover, the parents and teachers have insufficient face time to be able to share the parent's policies and requests about day-care activities, as well as learning the teacher's advice about day-care activities.

Trials have been conducted in which parents could get information about their child's activities in Japanese nursery facilities[8][9]. Past trials set a Web-camera in the play room to deliver video of the children's activities to the remote parent's PC. This arrangement is effective in providing a parent with a general sense of reassurance about the day-care activities. Such Web-cameras, however, have a fixed position (usually on the ceiling) and are wide angle. The parent may have to wait for some time to see their child actually doing anything. This can be a serious problem since working parents have so little free time. Working parents are constrained and can only peruse web-cam feeds at particular periods such as a coffee break.

Our solution is to realize a system that permits the parent to establish an immediate link with their child whenever possible and interact with the child as needed.

2.2. *Our concept*

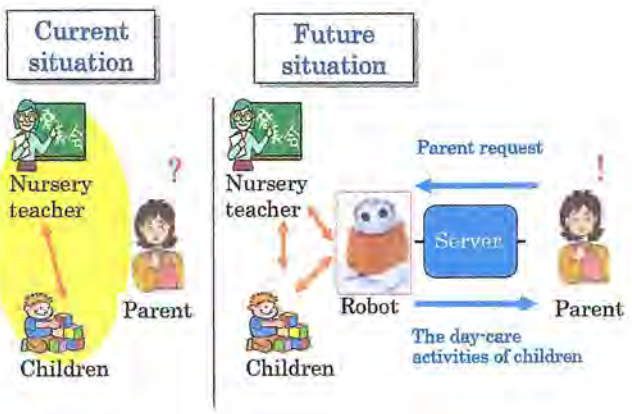


Fig. 1 Future situation in nursery facility.

Fig. 1 show the Future situation in nursery facility which we image. We think that the problems can be effectively resolved by using a robot system to link parents to the nursery teacher and child. In order to realize the proposed system, we first considered the robotic systems on remote collaboration model used to pass the information provided by a remote expert to an on-site worker and observe the results of the worker's actions.

The goal of these robotic systems are to realize an environment in which the remote expert can get feed back and so correct the worker's mistakes and the worker can get the information needed to finish the maintenance or repair actions scheduled. The remote expert and worker use video communication to share the condition of the work site in real time; a remote control robot is placed at the worker's site. The expert remotely controls the robot to assist the worker in understanding the operations needed. For example, the robot can highlight the part piece of equipment that must be tested next. This establishes intuitive communication between the remote parties.

To realize our proposed environment, a robot system is effective as the instruction medium to link remote parents with the teachers and children. But, as mentioned in the previous section, it is difficult for remote parents and nursery teacher, child in nursery facility to conduct synchronous communication. Because the parents, teacher, and child have different daily schedules.

A robot system using on asynchronous communication between parents and the teacher and child, allows us to develop new robot functionality to provide instruction channels that allow all parties to conduct comfortable communication. Our developed robot system needs to have the following capabilities.

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- Make it easy for parents and teachers to asynchronously input instructions to the robot system.
- Interact with child and collect information from the child in response to the asynchronous instructions from remote parents and teachers.
- Display the information collected to remote parents and teachers via asynchronous communication.

To validate our robot system, we developed Meru-robo Digital Log system, a network-based prototype system. It is composed of the "Action Switch Platform (AcSP)" (developed by NTT Laboratories) and the personal robot "PaPeRo" (developed by NEC Corporation).

3. Our Prototype System : Meru-robo Digital Log System

3.1. Overview of Meru-robo Digital Log system

We describe here our network-based interactive child watch system for the participation of parents in the day-care activities of their children : Meru-robo Digital Log system. Figure 2 shows overview of "Meru-robo Digital Log system". In this system, the remote parent uses his/her cellular phone as the interface device, because it is used on a routine basis and can be used anywhere at anytime. The teacher and children use the personal robot "PaPeRo" as the interface device, because it was designed to be perfectly safe for children and provides the interfaces needed. In this system, the "Action Switch Platform (AcSP)" on the network links PaPeRo to the cellular phone of the parent.

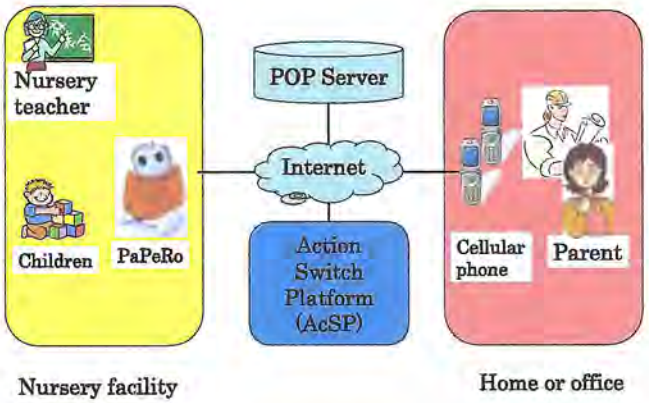


Fig. 2 Overview of "Meru-robo Digital Log system".

3.1.1Meru-robo Function

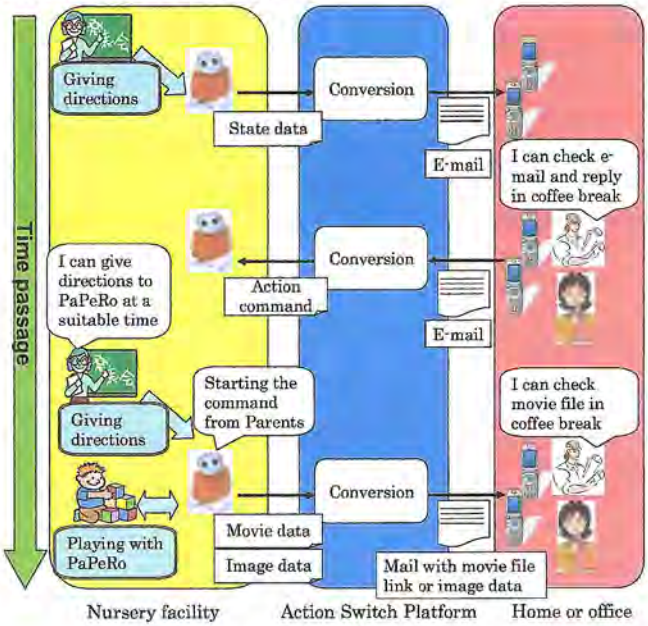


Fig.3 Overview of "Meru-robo Function".

This system has two functions but in this paper we explain only the "Meru-robo Function", an overview of which is given in Figure 3. The parent sends e-mail or reply to AcSP to access the Meru-robo Function. Using the Meru-robo function provided by this system, the parent can indicate to AcSP via cellular phone text messaging the action that their child should perform (play). The teacher gives directions to PaPeRo via touch control. When PaPeRo is triggered by the nursery teacher, PaPeRo starts the command received from AcSP and plays with the children. At the same time, PaPeRo take a movie of the child with its eye camera. The movie will include the child's facial expression, because PePeRo's eye camera is level with the child's eyes. The movie taken by PaPeRo is sent to the parent's cellular phone by Mail as a movie file link.

By using e-mail(cellular phone text messaging) as the communication tool, the parent can create and send messages when suitable for the parent and get, in return, the information desired. The parents have a direct way of getting detailed information about their child's activities. The response of the child is captured on video by PaPeRo and replayed asynchronously to the parent.

The teacher can decide what time is appropriate given the day-care schedule in the facility for starting robot activities or sending the information to remote parents.

In this way, through the robot, the parent can send a request and message to their child and the teacher, and the teacher can send details of the activities of the children to their parents at times suitable for each other.

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3.2. System constitution

Meru-robo Digital Log system is composed of AcSP, PaPeRo, Cellular Phone and POP server. We describe each part as below.

3.2.1Action Switch Platform (AcSP)

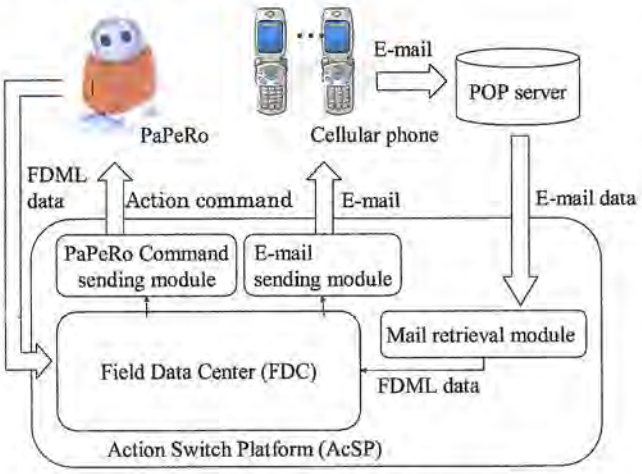


Fig.4 Outline of Action Switch Platform (AcSP).

AcSP is based on the information distribution platform "Field Data Center(FDC) " and some other modules. Figure 4 outlines AcSP. For realizing the asynchronous communication between FDC and the Personal robot, we developed a Mail retrieval module, a PaPeRo command sending module, and an E-mail sending module.

FDC was developed by other members of our laboratory[10]. The information distribution data format "Field Data markup Language(FDML) " , which is based on XML, is used to link the various devices across the network and pass information between them[11]. FDC stores and manages data in FDML format; it can check the conditions of events through the application of IF-THEN rules. FDC makes it easy to realize the functions needed for realizing link event processing with external applications. Therefore, desired events can be registered with FDC ahead of time and services and external applications can be triggered as desired by checking the conditions of events.

The Mail retrieval module converts the cellular phone text message into FDML data. It acquires e-mails from the mail server (POP server) at regular intervals. If a new e-mail is found, it extracts the body of the e-mail. This module holds pairs of keywords and FDML data. If a keyword registered in it is found in the message body, it sends the FDML data that matches the keyword to FDC.

The PaPeRo command sending module and E-mail sending module are external applications that are triggered as desired by checking the conditions of events on FDC. The PaPeRo command sending module can send an action command over HTTP protocol to PaPeRo to control its speaking function and actuators. The E-mail sending module can send one of several standard e-mails to parents.

3.2.2Personal robot "PaPeRo"

PaPeRo has several default scenarios written in a scripting language that describe basic behaviors and actions. PaPeRo's basic functions include a speaking function and an actuator control function. The software platform "robot virtual machine" in PaPeRo interprets these scenarios, and triggers the PaPeRo's functions as performance flow. This platform can switch these scenarios, received an action command over HTTP protocol, from other devices on the network. PaPeRo is able to run several scenarios in parallel such as one to interact with the child and another for receiving commands from the network. Therefore, while PaPeRo is playing with a child, PaPeRo's action and speech changed by the server. The child is unaware of any switching or activation of different scenarios.

3.2.3Processing of Meru-robo function in Meru-robo Digital Log system

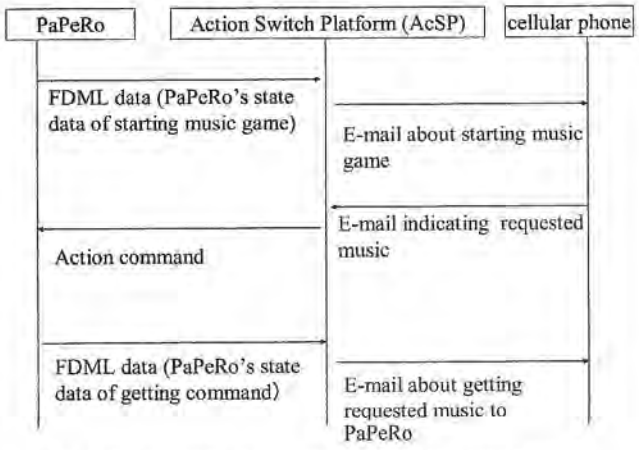


Fig.5 The example of processing flow of Meru-robo function.

We explain the key processing flow of the Meru-robo function on AcSP and PaPeRo, and the cellular phone below. Figure 5 shows an example of the processing flow of the Meru-robo function.

When the teacher triggers PaPeRo to start the music game via touch control, PaPeRo sends its FDML data to AcSP as state data corresponding to the touch command. Upon receiving the FDML data, AcSP checks the conditions of events associated with the FDML data received. If the conditions of events of "sending e-mail about starting music game to parents" are TRUE, AcSP initiates the action. After the parent's e-mail reply is received by AcSP, if the body of the e-mail contains keywords registered with AcSP, AcSP receives the FDML statements that match the keywords. Upon receiving the FDML data, AcSP checks the conditions of events associated with the FDML data received. If the

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conditions of events of "an action command over HTTP protocol to PaPeRo " are TRUE, AcSP does the actions.

Through this processing flow the system establishes asynchronous communication between remote parents, teachers, and children.

4. Experiment

The experiment was designed to encourage parents to communicate asynchronously with the teachers and the children by using the Meru-robo function, and to verify whether the parents could acquire useful information.

4.1. Outline of experiment

We conducted trials in two nursery facilities, Maito-project (infant education facility,Tokyo) and Makoto-aijien (day nursery, Yamanashi Prefecture). At the Maito-project site, we examined 6 infants from 5 to 9 years old and their parents while 6 infants from 5 to 6 years old and their parents in participated in the experiment at Makoto-aijien. Trials were executed for about 2 hours on selected days at each location. Each parent was assumed to have a different situation as regards the children in the facilities. At the Makoto-aijen site, parents stood around in a room apart from their children after they received an outline of the experiment; all parents shared a cellular phone provided by us. At the Maito-project site, on the other hand, parents left the site after receiving an outline of the experiment; each were given a cellular phone (same model as above). The actual experiment used the flow in which the parent's demands were collected over a certain period and presented to the children over a 2 hour period. The period when the child care was smoothly advanced to the nursery teachers was selected. The parents answered a questionnaire after the experiment. Moreover, we collected verbal comments from the parents and the teachers.

4.2. Flows of teachers and parents during the experiment

We now explain the flow of play actions observed during the trials. Figure 6 shows the example of paying attention to the behavior of the children and parents. In this experiment, we provide four pairs of keywords and FDML data as music type requests, and five pairs of keywords and FDML data to represent the types of impression from parents.

Each PaPeRo trial began with the children receiving some instruction from the teacher. When PaPeRo was turned on, it sent an FDML statement containing its state. Figure 7 shows children with PaPeRo. AcSP then sent e-mails to the parents asking them to nominate the tune to be played. The parent replied with an e-mail containing the name of the tune. Figure 8 shows a typical e-mail from a parent and display of a movie file on the cellular phone. When the parent's e-mail was received at AcSP, AcSP sent an action command over HTTP protocol to PaPeRo.

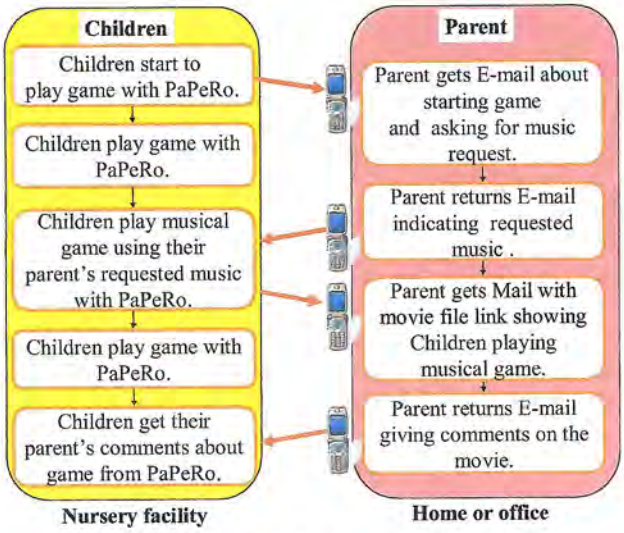


Fig.6 The example of user's flow chart.



Fig.7 Children playing with PaPeRo.

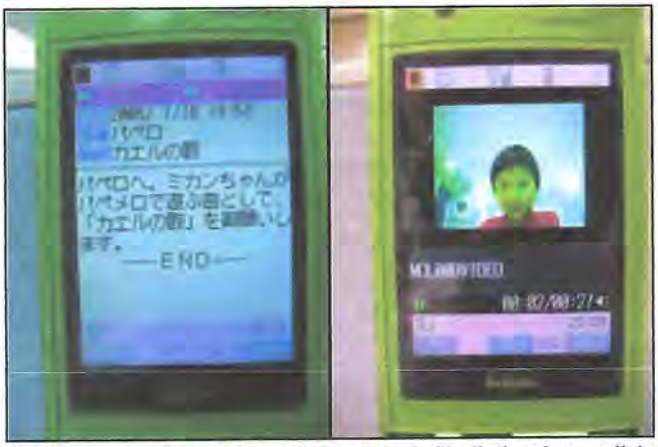


Fig. 8 Example of e-mail from parent and movie file displayed on a cellular phone. The e-mail states "To PaPeRo. my request is for the song of frogs to played in the musical game of the children with PaPeRo".

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Upon receiving this instruction, PaPeRo played the tune and invited the child to sing along. While PaPeRo sang to the child, PaPeRo took a movie of the child with its eye camera. The video captured at this time was transmitted to the parents as mail with a movie file link.

In each trial, the teacher let the children play with the robot for about 20 minutes. This gave the system enough time to send the requests and collect and process the parents' requests. Afterwards, after the impression from parents is sent via mail to AcSP, the impression from parents is presented to children by PaPeRo after the teacher's approval.

4.3. Trial results

TABLE 1
QUESTIONNIRE RESULTS FROM PARENTS

Questionnaire Items	Answer	total
Could you operate the cellular phone and make e-mail with keywords ?	YES	11
	NO	1
Could you understand the appearance of your child from the movie on e-mail link ?	YES	9
	NO	3

Of the twelve parents who used the Meru-robo function, eleven were able to acquire useful information about their child. One parent was unable to reply to a teacher's e-mail asking for the parent's request. Since this parent was in a subway train, the cellular phone connection was poor which lead to a failure to receive the e-mail.

Table 1 shows the questionnaire responses collected from the parents. From the responses, the following comments were obtained. Eleven of them could operate the cellular phone and make e-mail containing the desired keywords easily, because they often wrote e-mails of the same length. Nine of them were glad to be able to visually confirm their child's play and expression and the work performed in response to their requests by watching the movie accessed via the e-mail link. Most watched their child's appearance during spare moments such as a coffee break. Three parents indicated that they wanted to confirm not only their child's play and expression, but also their child's play with other children, an overall view. With regard to the impressions of the children, gathered from the parents, the children were very glad to receive their parents' requests and comments. In the limited situation of children playing in a nursery for this experiment, this system did not hinder the activities of the nursery teachers in terms of starting commands from parents in compliance with directions given from the teacher.

In future work, we need to improve the method of making the movie contents available to the parents and the method used by the teacher in giving directions to PaPeRo. We also need to extend the kinds of requests that the parents can issue for using this system.

5. CONCLUSON

In this paper, we proposed the concept of a robotic system that offers asynchronous communication between remote parents, nursery teachers, and the children themselves. To confirm our concept, we developed Meru-robo Digital Log system, a prototype network-based interactive child watch system that lets parents participate in day-care activities. We implemented this system in two childcare facilities and conducted a trial with the cooperation of 12 families. In the limited situation of children playing in a nursery, we found that parents in remote locations could get detailed information about their children's activities and expressions, when desired, via asynchronous communication.

ACKNOWLEDGMENT

We are grateful to two nursery facilities : Maito-project (Infant education facilities,Tokyo) and Makoto-aijien (day nursery, Yamanashi Prefecture) for cooperating with our research.

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Appendix F-9

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Spatial Memory for Collaboration Support System in Intelligent Space – User Identification Based on Spatial Memory –

Mihoko Niitsuma[1,2] and Hideki Hashimoto[1]

[1]Institute of Industrial Science, the University of Tokyo, Tokyo, Japan
(Tel : +81-3-5452-6258; E-mail: niitsuma@hlab.iis.u-tokyo.ac.jp)
[2]Research Fellow of the Japan Society for the Promotion of Science

Abstract: This paper presents an implementation of the spatial memory system for supporting collaboration activity in Intelligent Space. In this paper, a design of the new spatial memory system is described based on three requirements for a collaboration system: (1) sharing information for multi-users and multi-terminals, (2) access privileges for SKTs and (3) user identification. User identification method is one of the most important functions for sharing information systems. Therefore, this paper proposes a new user identification method by using the spatial memory system. More specifically, users create their own key-Spatial-Knowledge-Tags (SKTs) as passwords to use the spatial memory system. The new user identification method is evaluated through user experiments. Experimental results show high effectiveness of the method.

Keywords: Spatial memory, Intelligent Space, human interface, user identification, collaboration support system

1. INTRODUCTION

This paper presents an implementation of the spatial memory system for supporting collaboration activity in Intelligent Space [1]. The spatial memory system enables users to store computerized information into the real world by assigning a three-dimensional position to the information. The system also allows them to retrieve the information by directly indicating the points using their own hands [2]. In the spatial memory system, what associates computerized information with a three-dimensional position is called "Spatial- Knowledge-Tag (SKT)". The user actively creates SKTs based on his/her need. As a result, embedded SKTs in a working environment correspond to activity histories of the user [3].

When using the spatial memory for collaboration, history of activities will be useful to check the progress and facilitate it. In addition, the spatial memory can deliver useful information based on the spatial feature. The spatial feature means remarkable areas which are obtained by observation of users' activities [4]. When using the spatial memory for remote collaboration, the users, including remote users, can share information based on the real world. It is important and efficient for the users to share information and the view of a working area as noted in [5].

In order to realize the services supporting collaboration activity, the spatial memory system is re-designed based on three requirements: (1) Sharing information for multi-users and multi-terminals, (2) Access privileges for SKTs and (3) User identification. User identification method is one of the most important functions for sharing information systems. Therefore, this paper proposes a new user identification method by using the spatial memory system. More specifically, users create their own key-Spatial-Knowledge-Tags (SKTs) as a password required to use the spatial memory system.

The rest of the paper is organized as follows: Section 2 introduces the concept of the spatial memory system. Section 3 and 4 describe a design and an implementation of the new spatial memory. In Section 5, we propose a new user identification method by using the spatial memory system. The new user identification method is evaluated through user experiments. The last section concludes the paper.

2. SPATIAL MEMORY

The spatial memory enables humans to store computerized information such as digital files and commands into the real world by assigning three-dimensional position as the memory address. Humans can retrieve and store such information by directly indicating the point using their own body, e.g. user's hand and user's head. That's why a point on user's body is called a human indicator. Fig. 1 shows a schematic concept of the spatial memory. The spatial memory system has the following advantages to achieve intuitively and instantaneously access and store computerized information. First, the users are able to arrange computerized information at a suitable location using their own eyes and own body action. While working in the real world, human can obtain environmental information such as arrangements of equipment including desks, file cabinets and so on. Consequently, the users can arrange information in a much easier way and memorize the whereabouts by referring to such environmental information. Also their spatial cognition capabilities such as the motion sense, are utilized for memorizing the whereabouts, and will prompt the users to recall them. Second, the users are able to store computerized information and get access to stored information without interrupting their activities to search for them. The spatial memory adopts an indication of a human body as "store" and "access" operation methods in order to achieve an intuitive and instantaneous access method that anyone can apply.

In Fig. 1, small squares represent virtual tags called Spatial-Knowledge-Tags (SKT), which associate stored

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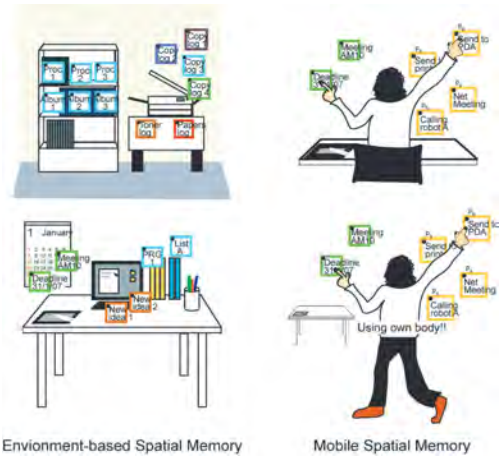


Fig. 1 Schematic concept of the spatial memory

information with a spatial location. Each SKT has three important parameters, namely stored computerized information, a three-dimensional position as a memory address, and a size of an accessible region. An accessible region is necessary for human to smoothly retrieve an SKT by using the human indicator, because he/she can not indicate the exact spatial location. The size of an accessible region should be determined according to accuracy of the human indicator [6] and the type of the human indicator. We improved the system to utilize it for a wide variety of situations.

3. DESIGN OF THE SPATIAL MEMORY SYSTEM AS COLLABORATION SUPPORT SYSTEM

In this section, a design of the spatial memory system to apply for collaboration works is described. We focus on sharing information in collaboration works. Information includes not only data and knowledge which are used for work, but also progress and status of the work. When using the spatial memory system, workers can share spatially stored information as well as the real environment as shown in Fig. 2. This kind of information sharing method for support of remote collaboration has been proposed in [5].

Considering the collaborative situations at office, laboratory, hospital and factory, information to utilize for

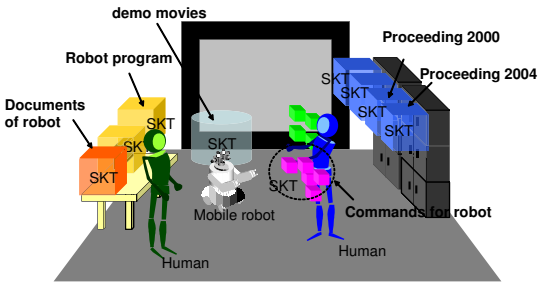


Fig. 2 Illustration of the spatial memory

works involves both of information relating to personal affairs and relating to group affairs. In order to realize sharing information with security, the spatial memory system should have three functions as follows:

1. Sharing information for multi-users and multi-terminals

The spatial memory system should be available to multi-users and multi-terminals. Multi-terminals means that users are able to retrieve spatially stored information by using multiple terminals such as personal computers and PDAs. SKTs are arranged according to setting of the environments such as the whereabouts of desks, whiteboards and meeting tables and so on. Therefore, SKTs depend on the environment, but not on terminals. In order to retrieve the information independent of the terminals, the spatial memory system provides a function to share the information.

2. Access privileges for SKTs

Ensuring security is very important issue of the spatial memory system. Access privileges for SKTs should be set so that the users can utilize the system for both of information relating to the personal affairs and relating to group affairs.

3. User identification

To set access privileges, user identification is necessary. The spatial memory has been designed to realize easily and quickly storing and retrieving method. Therefore, the system should not deteriorate the operability. In this paper, a method of user identification using the spatial memory is proposed. A set of SKTs as an authentication key is introduced. By storing and retrieving a set of SKTs, login authentication is performed. The set of SKTs is called “key-SKTs”. An arrangement of a set of key-SKTs depends on users individually. Thus, it is expected that users other than the owner hardly find his/her key-SKTs.

In next section, implementation of each function is explained.

4. IMPLEMENTATION OF THE SPATIAL MEMORY SYSTEM

The spatial memory system consists of four parts as follows: (a) Measurement unit of human indicator, (b) Spatial memory core unit, (c) Spatial memory input unit and (d) Spatial memory output unit, as shown in Fig. 3.

4.1 Measurement unit of human indicator

Measurement unit of human indicator is implemented by using an ultrasonic 3D positioning system [7] as shown in Fig. 4. The positioning system is able to measure three-dimensional positions of ultrasonic transmitters. The transmitters are activated based on time division multiple access method. Therefore, sampling frequency depends on the number of transmitters. For applying to the spatial memory, sampling frequency is important to measure motion of human indicator. From the view point of the measurement of human indicator motion, the number of transmitters is fixed to four. The position of trans-

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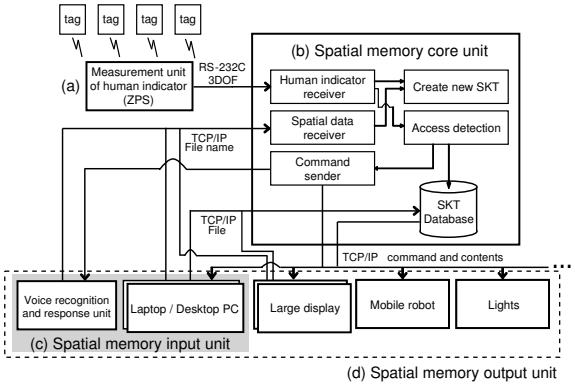


Fig. 3 System configuration

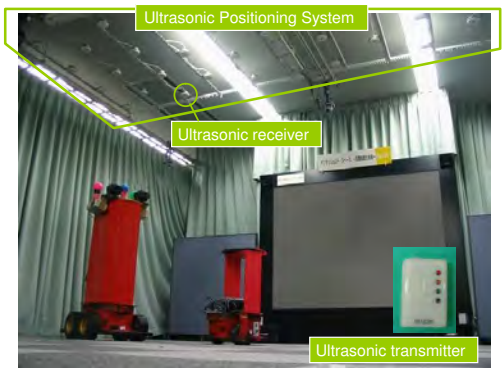


Fig. 4 Ultrasonic 3D positioning system as the measurement unit of human action

mitters is regarded as human indicator. Based on the observation of each transmitter, indication action of each user is obtained [3].

4.2 Spatial memory core unit

The spatial memory core unit implements core functions such as determination of indication action, creating SKTs, retrieving and delivering SKTs. Therefore, this unit is the only unit connected with all other units. The spatial memory core unit allows multiple spatial memory input/output units to connect with it asynchronously. When receiving information from the spatial memory input units, the core unit assigns a unique ID number to the information and creates a new SKT. SKT data structure is shown in Table. 1.

Table 1 Data structure of SKT

SKT data
ID
Spatial memory address (x, y, z)
Path of spatial memory (contents)
Size of accessible region
Number of access times
Type of contents
User name
Time stamp

When delivering an SKT to a spatial memory output unit, the spatial memory core unit chooses the nearest spatial memory output unit from the human indicator which is used to access the SKT. In addition to distance, functions of spatial memory output units should be considered, because different functions are included. For example, not only computers but also mobile robots are available as spatial memory output units. In order to discriminate functions of spatial memory output units, each output unit has a label to describe attribute identifier. The label is notified by the spatial memory output unit to the core unit. The core unit chooses a spatial memory output unit to deliver an SKT according to labels of output units, distance between a user and output units, and file extensions of information.

Fig. 5 shows principal messages between units and the sequence. The notations such as "(c1)" or "(c2)" represent the operation status and the order of processes. For example, when a spatial memory input unit sends information to the spatial memory core unit, firstly the input unit sends the message (s1) to the core unit. Then, the core unit assigns a unique ID number to the information and creates an SKT. After that, the core unit delivers the message (s2) to a spatial memory output unit. The spatial memory output unit obtains the ID number and the information. The output unit executes the information and store the information into an SKT database by assigning the ID number as the process (s3).

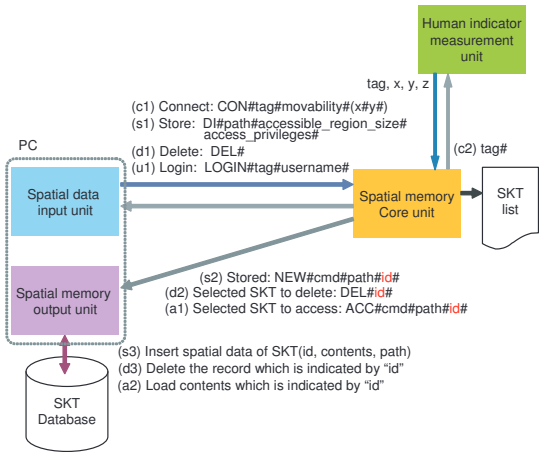


Fig. 5 Connection and messages among all units

4.3 Spatial memory input unit

Fig. 6 shows the interface of the spatial memory input unit. The interface plays a role of the front-end of the spatial memory system for users. In addition to the shown graphical interface, voice input method is also available.

When starting to use the spatial memory, user identification is required. Users choose a login mode either as anonymous or as specified user. If a user choose specified user mode, the user inputs user's name into the text field as shown in Fig. 6 (u1) area. Then, the user arranges three key-SKTs as his or her password. When the user is able to access all SKTs under specific conditions, the spa-

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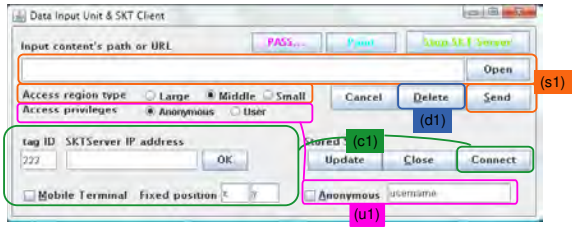


Fig. 6 Spatial data input unit –main window

tial memory system becomes available. The specific conditions and the user identification method are discussed later.

By using the interface, a user chooses or draws information which is stored as the spatial memory. After preparing the information, the user sets access privileges for the SKT. If the user sets access privileges as "anonymous" for SKTs, the SKTs can be retrieved by any users. On the other hand, if the user sets access privileges as "user" for SKTs, the SKTs can be retrieved only by the user who stored the information. Finally, the input unit sends the path of the information, accessible region size and access privileges to the core unit. Multiple input units are able to connect with the core unit asynchronously.

4.4 Spatial memory output unit

Spatial memory output unit executes the information of accessed SKTs when receiving it from the core unit. Also, the output unit operates an SKT database according to the messages from the core unit as shown in Fig. 5.

To share SKTs which are stored by different users and different input units, an architecture of sharing SKTs is needed. Namely, an SKT database which gathers the stored information (contents of SKTs) is introduced.

Contents of SKTs should be stored after assigned a unique ID number to an SKT. Therefore, a spatial memory input unit is not able to store contents into the database, because the contents have not been assigned ID.

Based on the discussion, two types of the architectures can be considered as shown in Fig. 7 (a) and (b): (a) the spatial memory core unit operates the database, (b) each spatial memory output unit operates the database.

From the view points of communications traffic and processing time, a desirable architecture is (b). If the architecture (a) is applied, input units are required to send

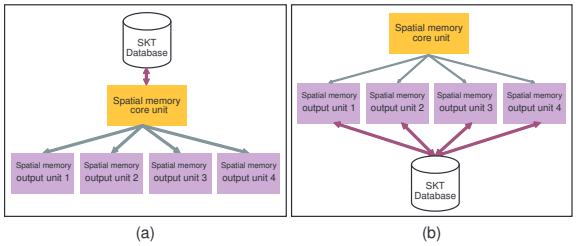


Fig. 7 Configuration of the SKT database

not only the path of contents but also data of the contents to the core unit. It is not efficient for the core unit to operate the database to deliver accessed SKTs to multiple output units. The functions of determination of human indicator and retrieving SKTs are more important for the core unit.

Therefore, if the architecture (b) is applied to share the information, communication load to retrieve information can be reduced.

5. EXPERIMENTS

5.1 User identification based on the spatial memory

To set access privileges, user identification is necessary. Requirements for a user identification method are described as follows:

1. Users are able to use the function easily.
2. The spatial memory system should prevent impersonating a user by someone else.
3. It should not make the operability of the spatial memory worse.

In order to satisfy the three requirements, this paper proposes a new user identification method using the spatial memory. The procedure of the method is described as follows: First of all, users of the spatial memory create their own "key-SKTs" as the password to use the spatial memory system. Then, when the users are able to access the all key-SKTs, the spatial memory becomes available for the users.

The spatial memory is designed to realize easily and quickly storing and retrieving information, and smoothly recalling the whereabouts of the information [2]. By using the same method of the spatial memory, the users can operate the user identification process in the same way as when using the usual spatial memory. Therefore, the method based on the spatial memory is able to satisfy the two requirements (1 and 3).

What is expected to satisfy the second requirement is the difference of actual motion among individuals. The arrangements of key-SKTs deeply depend on users, because the whereabouts of SKTs are chosen by each user based on the user's subjective visual recognition and kinesthesis. Therefore, we can assume that other people can hardly find the set of someone's key-SKTs.

Experiment to verify the assumption is performed.

5.1.1 Purpose of the experiment

The purpose of the experiment is to investigate possibility of the user identification method based on the spatial memory. Namely, we investigate if users are able to retrieve other's key-SKTs or not, if specific conditions to distinguish a target user from others can be set or not.

5.1.2 Experimental setting

The experiment is carried out by three user subjects (Subject A, Subject B and Subject C). The procedure is shown as follows:

(1) A subject creates three key-SKTs freely, while other subjects don't see the scene.

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(2) The subject tries to access the key-SKTs, while other subjects see the scene.
(3) The other subjects try to access the stored key-SKTs, while other two subjects see the scene.
(4) Finally, the subject who created the key-SKTs tries to access them again.

Conditions for the experiments:

Other subjects can't see the process (1), but they can see the process (2). The condition is set on the assumption that the arrangements are visually known.

The process (3) is carried out by one at a time. Therefore, another subject can see the scene twice.

The process (4) is carried out to confirm that the subject who arranged key-SKTs can retrieve them correctly.

Conditions for successful access:

When accessing an SKT, an accessible region is set for each SKT [2]. In this experiment, the size of an accessible region is defined as a sphere with radius 10 cm. When the distance between indicated position and a position of an SKT is less than 10 cm, the access to the SKT succeeds.

Time restriction to finish the processes (2) and (3) is not specified. Subjects can quit the processes when they want. And if subjects can find the all key-SKTs, each experiment will be finished.

Time restriction between accesses is also not specified. Therefore, subjects can try to access again and again.

The only condition for complete successful access is that subjects have to access all key-SKTs by following the order arranged. However, it is easy for subjects to know the order, because they can see the correct order through the process (2).

5.1.3 Experimental results

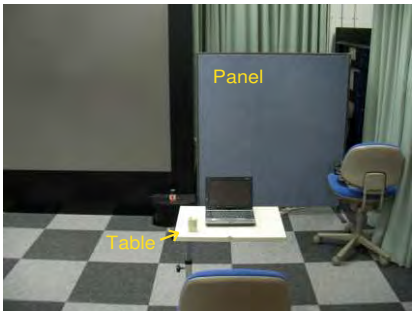
Above figure in Fig. 8 shows the experimental environment, and figures below depict the arrangements of key-SKTs which are created by each subject. Table 2 shows the order of subjects' performances. The first and last subject creates his key-SKTs, called "target subject".

Figs. 9–11 present experimental results. Filled squares (■) show successful accesses by other subjects. Plus-marks (+) and x-marks (×) represent indication actions of target subjects and other subjects respectively. Results of target subjects are shown by using their second (last) performances respectively.

As shown the results, the number of indication actions by other subjects is overwhelmingly more than the number of target subjects' actions. The case that all key-SKTs

Table 2 The order of subjects' performances

	Order of the subjects' performances
<1>	Subject A → Subject B → Subject C → Subject A
<2>	Subject B → Subject C → Subject A → Subject B
<3>	Subject C → Subject A → Subject B → Subject C



Experimental environment

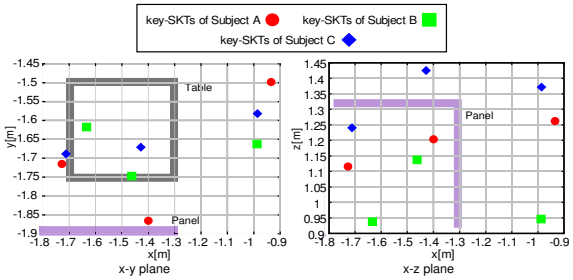


Fig. 8 Arrangements of key-SKTs

were accessed by other subjects was only the case <2> as shown in Fig. 10. Other than the case <2>, completely successful accesses were not achieved.

When we focus on time interval between accesses and total time to complete accesses, time interval took ten seconds at minimum in the case of Fig. 10 (i), and total time took twenty seconds in the same case. In other cases, for example case Fig. 9, both of Subject B and C were not able to access a key-SKT even though they tried for more than two minutes. On the other hand, all subjects were able to access their own key-SKTs in total ten seconds and with less than five indication actions.

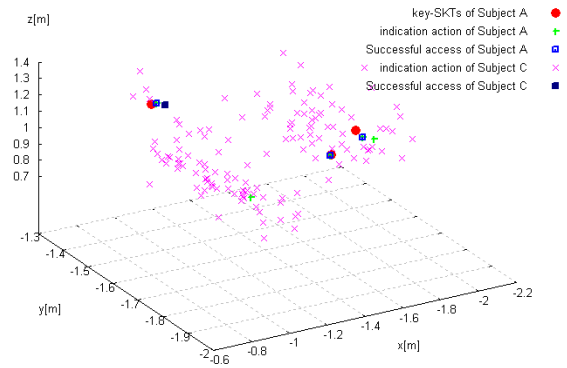
Therefore, we can specify limiting conditions for the user identification by using the parameters such as the order of access, total accessing time and the number of indication actions. Interval time can be also included, because each user will get better with increasing the number of usage of the spatial memory. Moreover, if users can indicate positions of SKTs more precisely than 10 cm, the size of an accessible region can be smaller. Table. 3 shows the distance between indicated positions and each key-SKT. All results are smaller than 10 cm. Therefore, the size of an accessible region will also be redefined according to the number of access times.

5.1.4 Discussion on the experiment

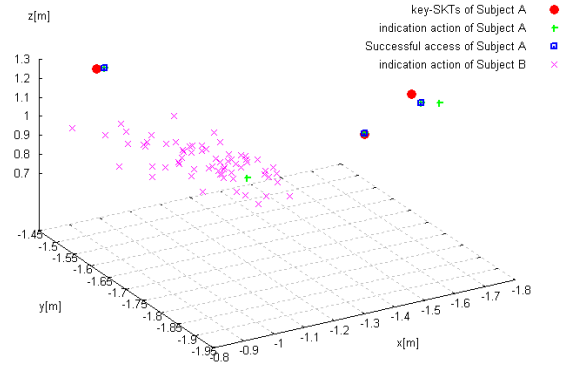
We discuss the results of the case <2> as shown in Fig. 10 which is the only case that other subjects were able to complete the accesses.

The difference between <2> and <1>, <3> is that the key-SKTs of the case <2> are arranged near objects such as a table and a laptop computer. Therefore, it would appear that other subjects could catch the positions easily by referring to the objects. That's why the key-SKTs

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(i) Results of Subject C → Subject A



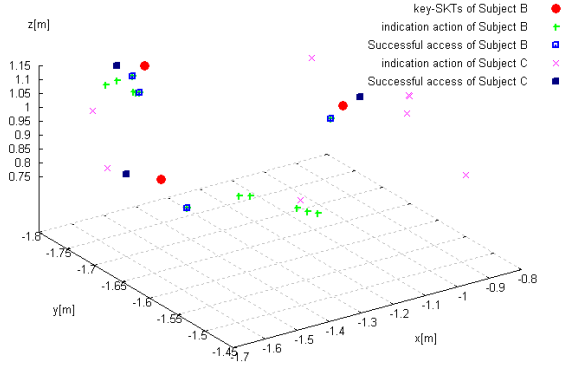
(ii) Results of Subject B → Subject A

Fig. 9 Results of the performance <1>

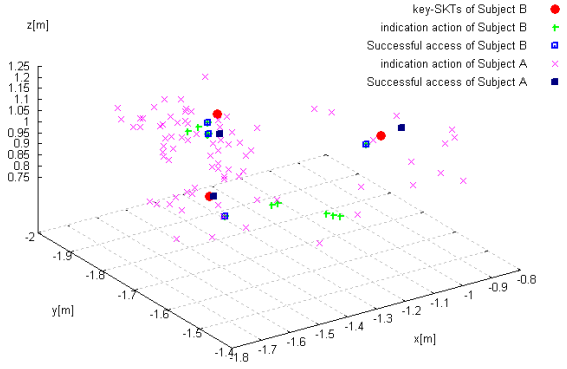
Table 3 Distance between indicated position and each key-SKT

Subject	Distance [cm]
Subject A	2.7
	3.7
	2.1
Subject B	7.7
	4.4
	7.0
Subject C	5.1
	1.9
	5.7

were completely accessed. Another possible reason is considered as subjects' body size. Table. 4 shows subjects' body height and arms length. As shown in the table, arms length of Subject B and Subject C is the same. However, Subject B was not able to access key-SKTs of Subject C even though Subject C could access key-SKTs of Subject B. Thus, we can conclude that if other users can find someone's key-SKTs depends more on the arrangement than the difference of body size.



(i) Results of Subject C → Subject B



(ii) Results of Subject A → Subject B

Fig. 10 Results of the performance <2>

Table 4 Subjects' body height and arms length

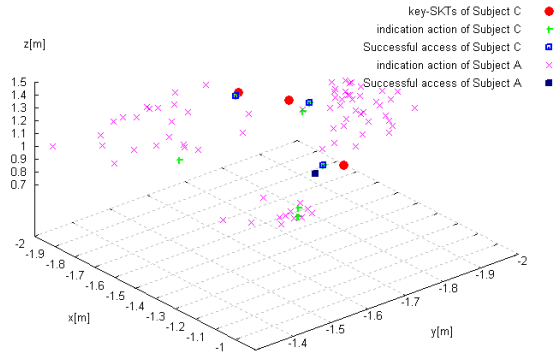
Subject	Body height [cm]	Arms length [cm]
Subject A	154.5	67
Subject B	169.9	74
Subject C	168.3	74

5.1.5 Discussion on comparison with other methods

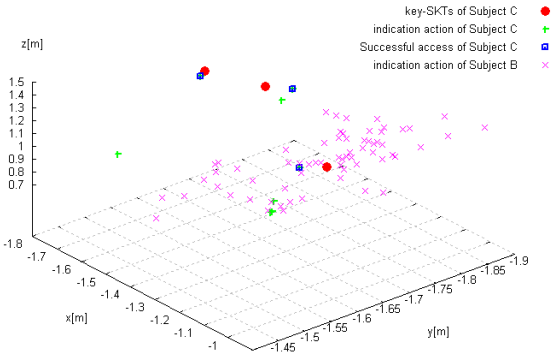
The spatial memory based user identification is compared with other methods qualitatively.

- Comparison with character password based user identification
  Character password based user identification is often used for our daily life. Users should memorize each password and corresponding target systems. Therefore, when increasing the number of character based passwords, it is difficult to distinguish corresponding target from others. If, in an effort to avoid confusion of his passwords, a user uses only one password, he will take risks that other people can impersonate him for corresponding systems when coming out it. On the other hand, key-SKTs as a password for a system are created by referring to setting of the real environment. Therefore, users can recall the set of key-SKTs according to environments.
- Comparison with biometrics based user identification

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(i) Results of Subject A → Subject C



(ii) Results of Subject B → Subject C

Fig. 11 Results of the performance <3>

Biometrics based user identification methods share the same problem with the case of using only one password. However, it is difficult to steal biological information. Therefore, it is suitable to apply to high confidential targets. On the other hand, key-SKT is suitable for episodic use or public spaces, because it can be easily created and changed.

- Comparison with IC tag based user identification
  IC tag based user identification is often used for our daily life. It is also convenient for storing personal information. In addition, users don't need to memorize passwords to enter target systems. However, users will have several cards when using several systems. In the case of using the same card for several systems, the risk of impersonation gets higher. And it is very easy to impersonate card holders if someone gets them. On the other hand, detection of the set of key-SKTs and complete successful access are hardly achieved by other people. In addition to the high secrecy, of course, the spatial memory system can store personal information associated with the key-SKTs.

6. CONCLUSION

This paper presented the design and the implementation of the spatial memory system for supporting collaboration activity in Intelligent Space. In this paper, the requirements for the spatial memory as a collaboration support system were described as follows: (1) Sharing information for multi-users and multi-terminals, (2) Access privileges for SKTs and (3) User identification. Then, a design of the new spatial memory system based on the requirements and the implementation were explained. This paper proposed a new user identification method by using the spatial memory system. More specifically, users create their own key-SKTs as the password to use the spatial memory system, and then access all key-SKTs. The new user identification method was evaluated through user experiments. The method may appear very simple, but the results showed high secrecy. The experimental results demonstrated that other users were not able to complete accesses to all key-SKTs as well as the owner. Based on the experimental results, we described a design of the limiting conditions for the user identification from the view points of the order of access, total accessing time and the number of indication actions. The effectiveness of the limiting conditions will be verified. For future investigation, effective and practical collaboration activity to utilize the spatial memory can be considered.

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Appendix G-1

Screen capture completed by J L Mullins from Western University, London, Ontario, Libraries OPAC on September 12, 2023

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504     ##$aIncludes bibliographical references and author index.
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Volume Editors

Shin'ichi Satoh
National Institute of Informatics
Digital Content and Media Sciences Research Division
2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo 101-8430, Japan
E-mail: satoh@nii.ac.jp

Frank Nack
University of Amsterdam
Human-Computer Studies Laboratory (HCS), Institute for Informatics
Kruislaan 419, 1098 VA Amsterdam, The Netherlands
E-mail: Frank.Nack@cwi.nl

Minoru Etoh
NTT DoCoMo Research Laboratories
3-5 Hikarionoka, Yokosuka 239-8536, Japan
E-mail: etoh@ieee.org



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LightCollabo: Distant Collaboration Support System for Manufacturers

Tetsuo Iyoda, Tsutomu Abe, Kiwame Tokai, Shoji Sakamoto, Jun Shingu, Hiroko Onuki, Meng Shi, and Shingo Uchihashi

Fuji Xerox, Co., Ltd.
430 Sakai, Nakai-machi, Ashigarakami-gun, Kanagawa, Japan

Abstract. This paper introduces our LightCollabo system which is a distant collaboration tool designed for manufacturers. For distant collaboration between factory workers and members of a product design team, it is important to support interactive discussion over actual objects. LightCollabo enables remotely located people to share a view of actual objects and to annotate on the objects by using a camera and a projector whose optic axes and view angles are precisely aligned. LightCollabo has been experimentally deployed in several locations in China and Japan and proven to be effective. Initial results of our use case study are also described.

1 Introduction

We have been designing a distant collaboration system for manufacturers. Globalization is an inevitable trend in industry and demands for efficient telecommunication are increasing. Production engineers have special needs. Most video conference systems in the market are designed to support face-to-face communication, however, watching views from remote sites is not sufficient for distant collaboration. We consider the capability to interact with remotely located objects to be crucial. For example, when a problem is found with a product component at a factory, remotely located engineers of the design team would want to not only see the componet but also indicate where to investigate. Initial interviews with engineers revealed that sending digital images via email is a popular solution to report problems and to send feedback for the reported problems. This scheme obviously lacks interactivity and often cannot meet with time requirements. Without a proper solution, manufacturing companies are reconciled to either sending people to the factory or shipping the defective product by express to the design branch. Both methods are costly and the expense may ruin other advantages of running factories globally.

Our LightCollabo system enables distant collaboration by making any physical object surface into a virtually shared workspace. Remote users can see the object and activities of local users through video. They can also draw annotations on the video image and the annotations are projected back onto the original object so that the local users can see. To handle 3D objects, we added several implementation efforts upon preceding systems including iLight [3].

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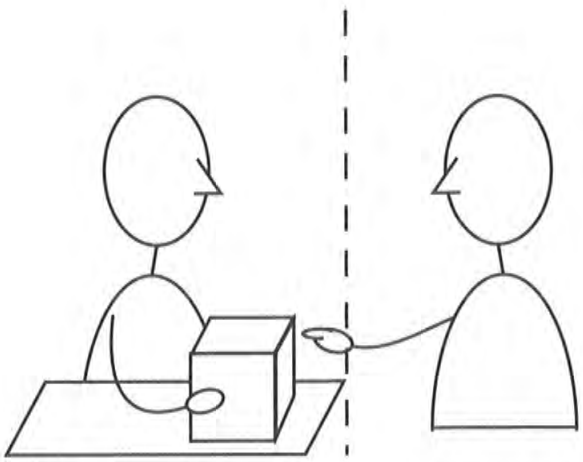


Fig. 1. A scene of collaboration over a physical object

This paper describes the design process of our LightCollabo system. We adapted a request-based approach to incrementally improve the system. Several LightCollabo systems have been already installed in our factories and product design centers located in China and Japan. Demands and feedbacks from the installed sites are collected and analyzed to update the system. This paper summarizes our activities in the last two years.

2 Problem with Distant Collaboration

2.1 Outline of Problem

Figure 1 illustrates a typical collaboration scene that we are considering. The person on the left has an object and the person on the right is pointing at a region of the object to call attention to it. Even a simple situation like this becomes a challenging task when the two people are not at the same location. The distance between them makes the dashed line in the middle of Figure 1 very difficult to get across. We need to provide a way for the person on the right to point at the remote object and for the person on the left to see the *hand* of the partner.

2.2 Current Solutions

We investigated how engineers communicate over distance especially in cases of problem solving by interviewing seven production engineers in Japan. Each interview session was organized in a semi-structured manner and lasted approximately 30 to 40 minutes. From the investigation we learned that telephone and email are the main tools of communication. Digital photos of problem scenes are often attached with email messages.

What happens frequently is that the photos and associated reports do not carry enough information for remotely located engineers to figure out the cause of the problem so that they have to request photos taken from different angles

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and additional descriptions of the scene. Typically, they have to iterate the process several times to establish a common understanding of the problem scene. Obviously, current solutions are not satisfactory for supporting the above communication: sending photos by email takes too long and phones alone cannot carry visual information. Video conferencing systems are not suitable either because they send blurred images tuned for face-to-face communication. Needless to say, people cannot point at an object to show "here" from a remote site using a video conferencing system.

3 LightCollabo System: Basic Design

3.1 Remote Workspace Sharing with Procam

LightCollabo uses a **pro**jector and a **cam**era (procam) to mix the local scene with gestures from the remote site. The camera captures a targeted object as well as hand movements of local participants and annotations they make around the object. The captured images are delivered through the network to remote participants for viewing. The remote participants can draw annotations on the images and the annotations are projected back onto the object. The basic design concept of LightCollabo is to let remotely located people virtually share the same workspace. As the first step, we let them share the same view and be jointly aware of it. We consider this design to facilitate joint visual attention, which is a notion known to development psychologists as the first step to establish communication [2][5].

Wellner proposed an interface using a camera and a projector to interact with both physical and virtual worlds [11]. Underkoffler *et al* investigated various arrangements of a camera and a projector for displaying virtual information onto the physical world [10]. Among others, we have chosen the 'zero-parallax' configuration where a camera and a projector are optically aligned (See Figure 2). It is the only arrangement with which annotations made by remote participants are projected as intended on any 3D object surface (See Figure 3).

Providing support for distant collaboration using a camera and a projector is an actively researched topic [3,6,9]. Most previously reported work adapts simpler arrangements so that their workspaces are restricted to near the desktop surface. To avoid the parallax issue, Bauer *et al* used a head-mounted display instead of a projector [1].

Remote collaboration using a tabletop configuration is an emerging research area [8]. We consider the tabletop as a workspace and interacting with both physical and digital objects in the workspace from local and remote sites is important.

3.2 Implementation Efforts

To make the LightCollabo procam unit practical, we had to overcome three major issues. The first issue is stray light. As Underkoffler pointed out, the 'zero-parallax' scheme is an ideal method, however it inherently suffers from stray

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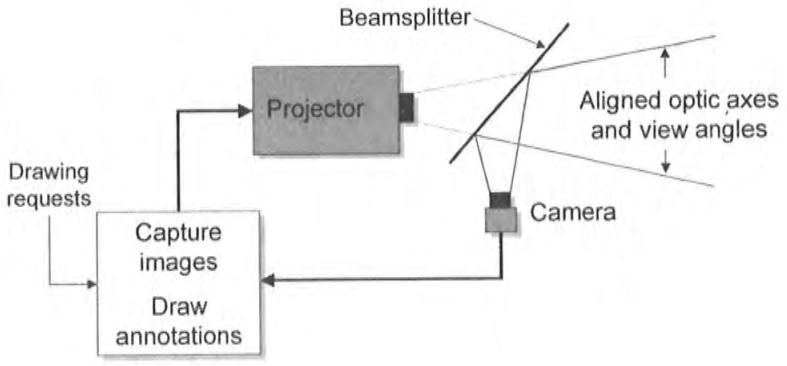
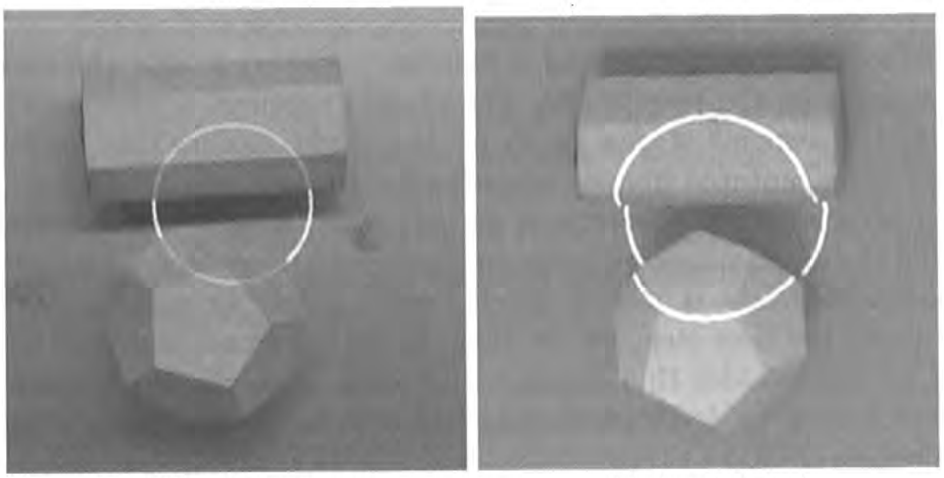


Fig. 2. Diagram of LightCollabo server



(a) Optically aligned. (b) Not aligned.

Fig. 3. View comparisons of differently arranged cameras

light [10]. Light from the projector partially travels through the beamsplitter and becomes stray light that is eventually captured by the camera causing contrast degradation in the captured image. We collect and absorb such light using a light trap as shown in Figure 4.

The second and the third issues are both related to the projector lens. Projectors in the market have shifted lens with which images are projected upward from a horizontally set up device. This disagrees with our assumption illustrated in Figure 2 and Figure 4 where images are projected straight in front. Also, a regular projector lens has a focal depth that is just wide enough for projecting an image onto a flat surface and is too narrow for projecting annotations onto an object with modest depth. To solve the shifted-projection and the off-focus issues, we installed a specially tailored zero-shift lens with large focal depth in our system (See Figure 5).

3.3 Remote Participation

Remote participants interact with the collaborative workspace using view application software. A sequence of JPEG images from the LightCollabo procam

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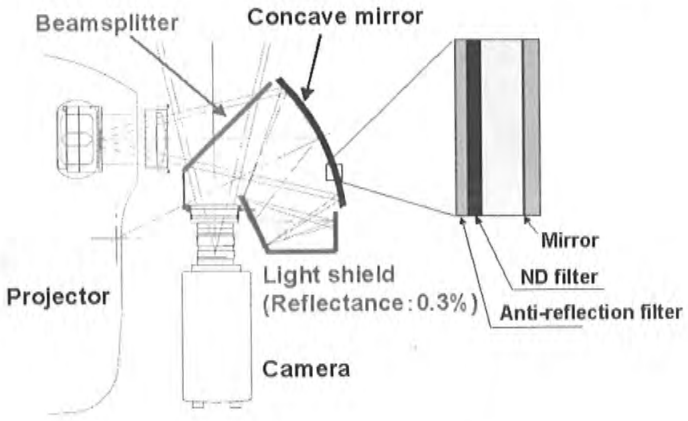


Fig. 4. Light trap structure

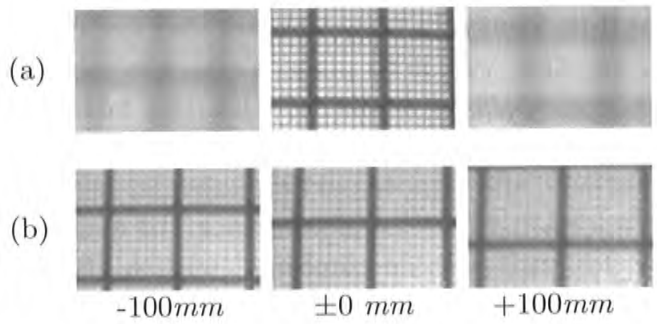


Fig. 5. Captured images around 1,000mm from the projector taken by (a)regular lens, and (b)zero-shift lens

unit is delivered through the network and shown in the application window. The remote participants can draw annotations on the images and the annotations are projected back onto the physical object through the procam unit. Figure 6 shows the interface of the viewer. Buttons are provided for selecting annotation types including text and various shapes such as eclipse, rectangle, line, and arrow. Annotations can be put in several different colors.

We chose to deliver images as a sequence instead of video stream because of the limited bandwidth to remote factories. Most of factories are located in distant places from major cities. Even today, network connection to such places is still costly and unreliable. In addition, international connectivity tends to be narrower than domestic network. Given these considerations, we concluded that sending high-resolution images at lower rate is more suitable for our purpose than streaming low-resolution video.

3.4 Sharing Physical Workspace

Local and remote participants can virtually share the same physical object in the sense that they all can see the object and locate any region on the object surface. We consider there are two ways to set up the LightCollabo procam unit. The

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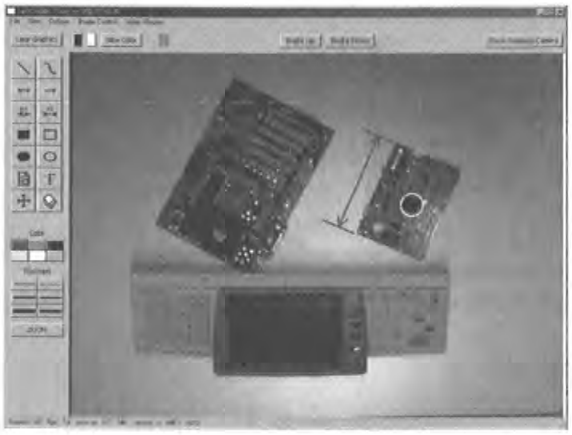


Fig. 6. GUI of client viewer application



Fig. 7. LightCollabo system

first way is to place it in front of a target object just like a projector is placed in front of a screen. The other way is to place it above a table looking down using a mirror. A larger workspace is available with the latter configuration; local participants can put related objects and documents on the table and even write on the table with markers, and remote participants can also put their annotations on the tabletop in addition to the object surface. To enable switching between the two setups, we designed a table combined with a lift (See Figure 7). Note that LightCollabo in Figure 7 is equipped with devices that were not included in the initial prototype. The additional devices are described in Section 4.

4 Preliminary Deployment

4.1 Experimental Launch

We demonstrated an early prototype of the LightCollabo system to our engineers in production sections and it was well-accepted. To further understand how they collaborate over distance and what support can be added to LightCollabo, we installed our system in several locations and observed the system usage in practical environments. Feedback from users was collected through informal interviews. We spent several months for the observation. Training sessions were held each time a system was installed at a new location for promotion.

4.2 Feedback Analysis

Considerable feedback on a wide range of topics was obtained through our deployment efforts. Below we list summaries of what we learned from the feedback and observations focusing on functionality for effective remote collaboration. Although feedback such as requests for user interface improvements is not discussed in this section, it was taken care of separately.

First, we observed that the tabletop configuration described in Section 3.4 was used most of the time. We consider it is partially because the size of physical

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objects that our trial users typically handle were more appropriate for placing on the table. Another explanation is that people simply wanted a larger space to work with. It was observed that people sometimes used the tabletop for chatting; local participants wrote their messages on the table with markers and messages from remote participants responded were projected on the table. The chatting worked effectively especially in multi-lingual situations. People also wrote notes on the table. The LightCollabo in the table configuration certainly provided a remotely shared physical and contextual workspace.

Secondly, we found that demands for 'zoom-up' views are high. Since the camera in the LightCollabo procam unit covers the entire tabletop, it is only good for table-top-size objects. The scale of the workspace varies depending on objects. Multiresolution structure of the workspace has to be considered to capture finer objects or even more subtle details.

Third, people occasionally see documents with objects during a distant collaboration session. Document sharing has been a popular collaboration tool. It will be ideal to incorporate document sharing capability into our system.

5 LightCollabo Updates

In response to the feedbacks from users described in Section 4, we updated our LightCollabo system. The modifications focused on handling objects in different scales and documents.

5.1 Optional Cameras

We provided two optional cameras to capture objects in different scales. The first solution uses a Pan-Tilt-Zoom (PTZ) camera. Coordinates of the procam unit's camera and parameters to drive a PTZ camera are registered in advance so that remote participants can simply specify a desired region on a viewer screen to let the system steer and zoom in the PTZ camera to obtain a detailed view of the specified region [7]. The obtained image is converted to a JPEG image and delivered by the image server. The viewer software receives the image and shows it in a pop-up window. Figure 8 shows the pop-up window. It is also equipped with control buttons of the PTZ camera. For on-site participants, the captured region is highlighted by a projected rectangle so that they can see where remote participants are looking at.

The second solution is a free arm camera which is an endoscope with a grip (See Figure 9). This camera is provided for viewing details in sub-millimeters. LED lights are placed around the lens for illuminating a target area. NTSC signals from a free arm camera are digitized as a JPEG image sequence and delivered to clients. Figure 10 illustrates a pop-up window showing a view from a free arm camera.

Note that shared workspaces using the above described cameras will be too small for projecting remote annotations and also for direct observation. Hence the workspaces are shared only on computer screens.

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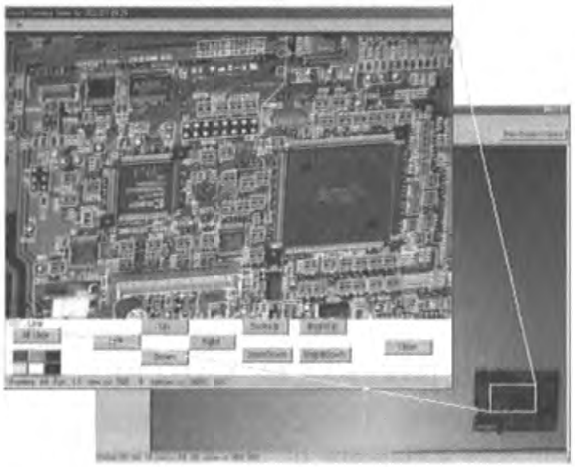


Fig. 8. Sub-window for PTZ camera

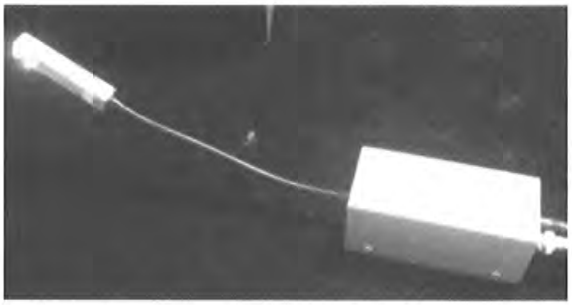


Fig. 9. A free-arm camera

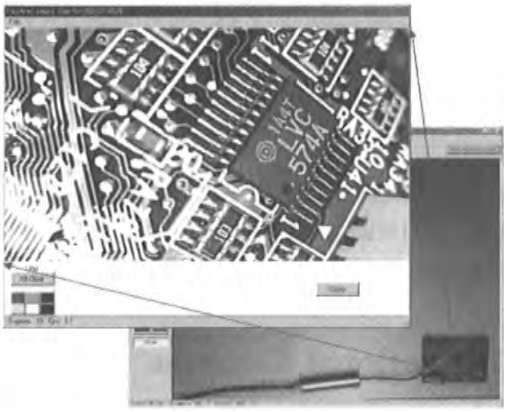


Fig. 10. Sub-window for free arm camera

5.2 Document Sharing

We implementeded a primitive document sharing feature to the viewer application. In addition to regular annotations such as line and circle, remote participants can place any image file for sharing. The contents of the image file is projected onto the physical object or the tabletop as specified. Naturally, the system should evolve such that a remote participant can retrieve a document from a regular document sharing system and the document is projected as an image.

6 Field Test

6.1 Expectation

With the above updates, we continued installing LightCollabo in our factories and product design centers located in China and Japan. In total, 15 systems

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have been deployed. By observing how the systems are used, we expect we can spot the cases where LightCollabo works most effectively, and evaluate strengths and shortcomings of the current system. Especially, we expected LightCollabo can contribute in the following three areas.

- Pointing at a problem region
- Sharing circumstances where a problem occured
- Understanding what caused the problem

6.2 Settings

At each site, a LightCollabo system was installed in a conference room equipped with a phone audio teleconferencing. The conference room was located next to production lines so that engineers have immediate access to the system when a problem occurs in the lines.

We conducted intensive investigations of the system usage at 4 domestic sites and 4 oversea sites. Each investigation took one week during the period between November of 2005 and March of 2007. We observed 12 use cases of LightCollabo: 4 cases for solving emergency problems, 4 cases in regular meetings, 2 cases for changing designs, 1 case for training, and 1 case during brainstorming. Except for 1 case used for solving an emergency problem, LightCollabo was used as a part of a scheduled teleconference. Approximately 30 people from 15 different departments used the system among more than 100 participants of the teleconferences.

6.3 Case Study

This section lists scenes from our observations where LightCollabo successfully contributed in problem solving. Combinations of various features of LightCollabo were used to share the workspace. In all cases, we noticed people intensively used reference terms during discussions, for example "Put this part in this hole" or "What is the length of here?". Also they sent many gestures using LightCollabo both conciously by making annotations and unconciously by moving cursors. We consider these natural behaviors in remote communication are evidences that prove local and remote participants successfully share the same workspace using LightCollabo.

Pointing at a problem region. In order to train a product design engineer located at a remote site, local participants indicated improper points in a design plan drawn by the engineer using LightCollabo. Prior to the session, the local participants built a product component for trial based on the plan and found errors. The component was placed on the table of LightCollabo and the local participants explained where the errors are by pointing at the region and drawing on the table using markers. The remote engineer sent his feedback that was projected onto the component with which both sides confirmed that mutual understanding was achieved.

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Sharing circumstances where problem occured. In a regular meeting, an engineer reported problem analysis results to a remote site using LightCollabo. The free arm camera was used to show cases where actual parts were assmbled correctly and incorrectly. The engineer drew arrows on the client view image to emphasize the difference.

Understanding what caused the problem. LightCollabo successfully led to solve a problem that a conventional method could not. A screw was conflicing with other parts of the component. First, the problem was reported by email and attached digital photos. Because none of the photos were not taken from a desired angle, engineers at the remote location decided to use LightCollabo. A local engineer was instructed to hold the component at a certain angle, while the remote engineers watched it using the PTZ camera.

6.4 Discussion

Both the PTZ camera and the free arm camera were frequently used in most of sessions. Interestingly, the free arm camera was used rather like a pointing device. On-site participants held the camera focusing at a spot where they wanted remote participants to see. In other words, the free arm camera was used to "push" the view to be shared from the local site to the remote sites.

Each of the three cameras of LightCollabo has a different role. The main camera of the procam unit is used to provide an overview image or context. Remote participants use the PTZ camera when they want to see an area in details.

Document sharing was also popularly used. People requested more views to be shared such as whiteboard for accelerating remote discussions. Often participants had to confirm whether people on the other end were watching the LightCollabo screen. A support for people on one side to know what people on the other side are watching is neccessary for fully realizing the joint visual attention concept.

7 Conclusions and Future Work

We introduced our LightCollabo system. A procam unit for LightCollabo was built by optically aligning a camera and a projector. Using the unit, LightCollabo allows remote and on-site participants to share the same workspace where all participants can see physical objects, point any region, and annotate on the objects. In response to feedbacks from our deployment efforts, two optional cameras were added to handle objects in different scales as well as a capability to share digital images along with physical objects. Observations from our deployment indicated that our system facilitates distant collaboration.

As a next step, we are planning to conduct formal user study to evaluate advantages of LightCollabo quantitatively. The task for the evaluation will be determined based on our observation. Analysis on usage logs and feedbacks from our test users in the field should reveal where users need more support and how we should further improve the LightCollabo system. To make the system more

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durable in practical environment, new features such as session contents archiving, network traffic control and managing secured connections, must be investigated from both system and computer-human interaction aspects.

Further, there is a challenge of expanding the shared workspace beyond the tabletop. People want to share not only viewing physical objects, but also documents, computer screens, whiteboard, and other activities in the rooms for smoother discussion over distance.

Acknowledgement

Our partners experimentally produced various components of LightCollabo. Among others, we thank Fujinon Corporation, Saitama, Japan, for their efforts in making the zero-shift projector lens.

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Appendix G-2

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Volume Editors

Shin'ichi Satoh
National Institute of Informatics
Digital Content and Media Sciences Research Division
2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo 101-8430, Japan
E-mail: satoh@nii.ac.jp

Frank Nack
University of Amsterdam
Human-Computer Studies Laboratory (HCS), Institute for Informatics
Kruislaan 419, 1098 VA Amsterdam, The Netherlands
E-mail: Frank.Nack@cwi.nl

Minoru Etoh
NTT DoCoMo Research Laboratories
3-5 Hikarionoka, Yokosuka 239-8536, Japan
E-mail: etoh@ieee.org

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LightCollabo: Distant Collaboration Support System for Manufacturers

Tetsuo Iyoda, Tsutomu Abe, Kiwame Tokai, Shoji Sakamoto, Jun Shingu, Hiroko Onuki, Meng Shi, and Shingo Uchihashi

Fuji Xerox, Co., Ltd.
430 Sakai, Nakai-machi, Ashigarakami-gun, Kanagawa, Japan

Abstract. This paper introduces our LightCollabo system which is a distant collaboration tool designed for manufacturers. For distant collaboration between factory workers and members of a product design team, it is important to support interactive discussion over actual objects. LightCollabo enables remotely located people to share a view of actual objects and to annotate on the objects by using a camera and a projector whose optic axes and view angles are precisely aligned. LightCollabo has been experimentally deployed in several locations in China and Japan and proven to be effective. Initial results of our use case study are also described.

1 Introduction

We have been designing a distant collaboration system for manufacturers. Globalization is an inevitable trend in industry and demands for efficient telecommunication are increasing. Production engineers have special needs. Most video conference systems in the market are designed to support face-to-face communication, however, watching views from remote sites is not sufficient for distant collaboration. We consider the capability to interact with remotely located objects to be crucial. For example, when a problem is found with a product component at a factory, remotely located engineers of the design team would want to not only see the componet but also indicate where to investigate. Initial interviews with engineers revealed that sending digital images via email is a popular solution to report problems and to send feedback for the reported problems. This scheme obviously lacks interactivity and often cannot meet with time requirements. Without a proper solution, manufacturing companies are reconciled to either sending people to the factory or shipping the defective product by express to the design branch. Both methods are costly and the expense may ruin other advantages of running factories globally.

Our LightCollabo system enables distant collaboration by making any physical object surface into a virtually shared workspace. Remote users can see the object and activities of local users through video. They can also draw annotations on the video image and the annotations are projected back onto the original object so that the local users can see. To handle 3D objects, we added several implementation efforts upon preceding systems including iLight [3].

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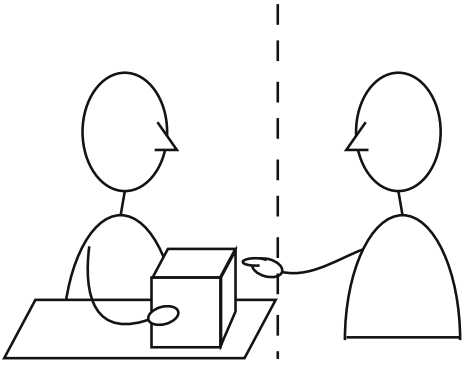


Fig. 1. A scene of collaboration over a physical object

This paper describes the design process of our LightCollabo system. We adapted a request-based approach to incrementally improve the system. Several LightCollabo systems have been already installed in our factories and product design centers located in China and Japan. Demands and feedbacks from the installed sites are collected and analyzed to update the system. This paper summarizes our activities in the last two years.

2 Problem with Distant Collaboration

2.1 Outline of Problem

Figure 1 illustrates a typical collaboration scene that we are considering. The person on the left has an object and the person on the right is pointing at a region of the object to call attention to it. Even a simple situation like this becomes a challenging task when the two people are not at the same location. The distance between them makes the dashed line in the middle of Figure 1 very difficult to get across. We need to provide a way for the person on the right to point at the remote object and for the person on the left to see the *hand* of the partner.

2.2 Current Solutions

We investigated how engineers communicate over distance especially in cases of problem solving by interviewing seven production engineers in Japan. Each interview session was organized in a semi-structured manner and lasted approximately 30 to 40 minutes. From the investigation we learned that telephone and email are the main tools of communication. Digital photos of problem scenes are often attached with email messages.

What happens frequently is that the photos and associated reports do not carry enough information for remotely located engineers to figure out the cause of the problem so that they have to request photos taken from different angles

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and additional descriptions of the scene. Typically, they have to iterate the process several times to establish a common understanding of the problem scene. Obviously, current solutions are not satisfactory for supporting the above communication: sending photos by email takes too long and phones alone cannot carry visual information. Video conferencing systems are not suitable either because they send blurred images tuned for face-to-face communication. Needless to say, people cannot point at an object to show "here" from a remote site using a video conferencing system.

3 LightCollabo System: Basic Design

3.1 Remote Workspace Sharing with Procam

LightCollabo uses a **pro**jector and a **cam**era (procam) to mix the local scene with gestures from the remote site. The camera captures a targeted object as well as hand movements of local participants and annotations they make around the object. The captured images are delivered through the network to remote participants for viewing. The remote participants can draw annotations on the images and the annotations are projected back onto the object. The basic design concept of LightCollabo is to let remotely located people virtually share the same workspace. As the first step, we let them share the same view and be jointly aware of it. We consider this design to facilitate joint visual attention, which is a notion known to development psychologists as the first step to establish communication [2][5].

Wellner proposed an interface using a camera and a projector to interact with both physical and virtual worlds [11]. Underkoffler *et al* investigated various arrangements of a camera and a projector for displaying virtual information onto the physical world [10]. Among others, we have chosen the 'zero-parallax' configuration where a camera and a projector are optically aligned (See Figure 2). It is the only arrangement with which annotations made by remote participants are projected as intended on any 3D object surface (See Figure 3).

Providing support for distant collaboration using a camera and a projector is an actively researched topic [3,6,9]. Most previously reported work adapts simpler arrangements so that their workspaces are restricted to near the desktop surface. To avoid the parallax issue, Bauer *et al* used a head-mounted display instead of a projector [1].

Remote collaboration using a tabletop configuration is an emerging research area [8]. We consider the tabletop as a workspace and interacting with both physical and digital objects in the workspace from local and remote sites is important.

3.2 Implementation Efforts

To make the LightCollabo procam unit practical, we had to overcome three major issues. The first issue is stray light. As Underkoffler pointed out, the 'zero-parallax' scheme is an ideal method, however it inherently suffers from stray

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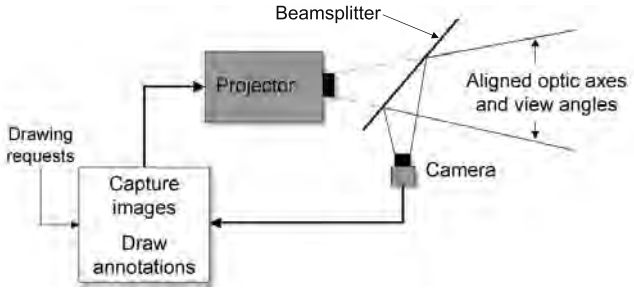
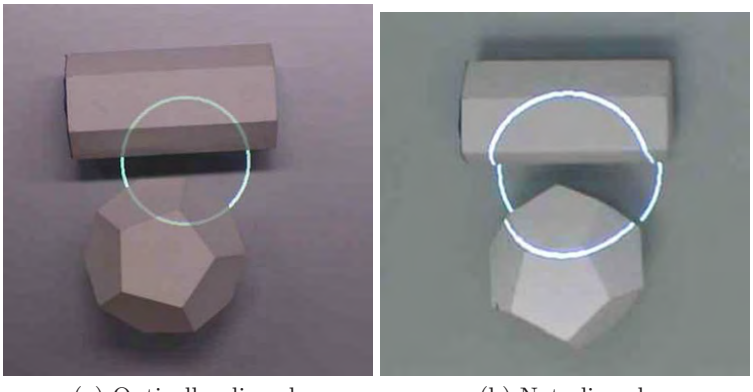


Fig. 2. Diagram of LightCollabo server



(a) Optically aligned. (b) Not aligned.

Fig. 3. View comparisons of differently arranged cameras

light [10]. Light from the projector partially travels through the beamsplitter and becomes stray light that is eventually captured by the camera causing contrast degradation in the captured image. We collect and absorb such light using a light trap as shown in Figure 4.

The second and the third issues are both related to the projector lens. Projectors in the market have shifted lens with which images are projected upward from a horizontally set up device. This disagrees with our assumption illustrated in Figure 2 and Figure 4 where images are projected straight in front. Also, a regular projector lens has a focal depth that is just wide enough for projecting an image onto a flat surface and is too narrow for projecting annotations onto an object with modest depth. To solve the shifted-projection and the off-focus issues, we installed a specially tailored zero-shift lens with large focal depth in our system (See Figure 5).

3.3 Remote Participation

Remote participants interact with the collaborative workspace using view application software. A sequence of JPEG images from the LightCollabo procam

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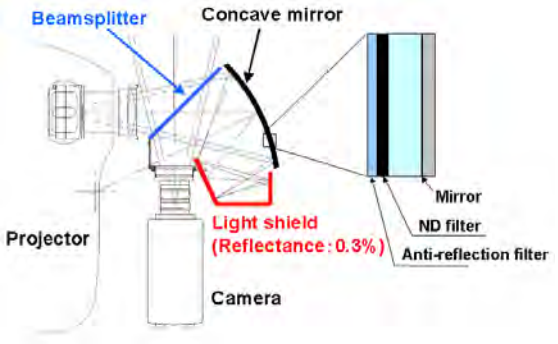


Fig. 4. Light trap structure

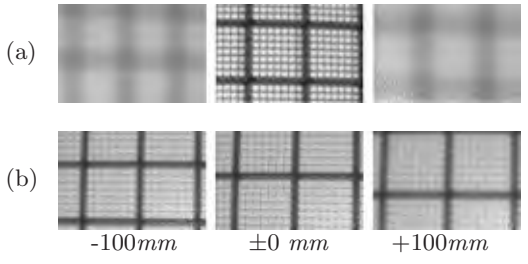


Fig. 5. Captured images around 1,000mm from the projector taken by (a)regular lens, and (b)zero-shift lens

unit is delivered through the network and shown in the application window. The remote participants can draw annotations on the images and the annotations are projected back onto the physical object through the procam unit. Figure 6 shows the interface of the viewer. Buttons are provided for selecting annotation types including text and various shapes such as eclipse, rectangle, line, and arrow. Annotations can be put in several different colors.

We chose to deliver images as a sequence instead of video stream because of the limited bandwidth to remote factories. Most of factories are located in distant places from major cities. Even today, network connection to such places is still costly and unreliable. In addition, international connectivity tends to be narrower than domestic network. Given these considerations, we concluded that sending high-resolution images at lower rate is more suitable for our purpose than streaming low-resolution video.

3.4 Sharing Physical Workspace

Local and remote participants can virtually share the same physical object in the sense that they all can see the object and locate any region on the object surface. We consider there are two ways to set up the LightCollabo procam unit. The

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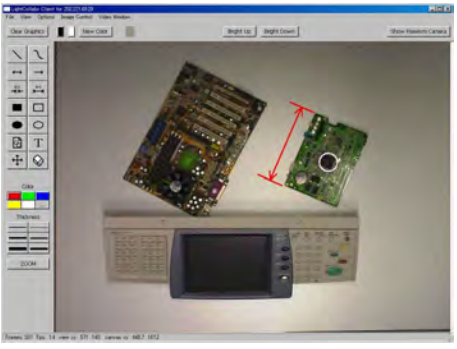


Fig. 6. GUI of client viewer application



Fig. 7. LightCollabo system

first way is to place it in front of a target object just like a projector is placed in front of a screen. The other way is to place it above a table looking down using a mirror. A larger workspace is available with the latter configuration; local participants can put related objects and documents on the table and even write on the table with markers, and remote participants can also put their annotations on the tabletop in addition to the object surface. To enable switching between the two setups, we designed a table combined with a lift (See Figure 7). Note that LightCollabo in Figure 7 is equipped with devices that were not included in the initial prototype. The additional devices are described in Section 4.

4 Preliminary Deployment

4.1 Experimental Launch

We demonstrated an early prototype of the LightCollabo system to our engineers in production sections and it was well-accepted. To further understand how they collaborate over distance and what support can be added to LightCollabo, we installed our system in several locations and observed the system usage in practical environments. Feedback from users was collected through informal interviews. We spent several months for the observation. Training sessions were held each time a system was installed at a new location for promotion.

4.2 Feedback Analysis

Considerable feedback on a wide range of topics was obtained through our deployment efforts. Below we list summaries of what we learned from the feedback and observations focusing on functionality for effective remote collaboration. Although feedback such as requests for user interface improvements is not discussed in this section, it was taken care of separately.

First, we observed that the tabletop configuration described in Section 3.4 was used most of the time. We consider it is partially because the size of physical

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objects that our trial users typically handle were more appropriate for placing on the table. Another explanation is that people simply wanted a larger space to work with. It was observed that people sometimes used the tabletop for chatting; local participants wrote their messages on the table with markers and messages from remote participants responded were projected on the table. The chatting worked effectively especially in multi-lingual situations. People also wrote notes on the table. The LightCollabo in the table configuration certainly provided a remotely shared physical and contextual workspace.

Secondly, we found that demands for 'zoom-up' views are high. Since the camera in the LightCollabo procam unit covers the entire tabletop, it is only good for table-top-size objects. The scale of the workspace varies depending on objects. Multiresolution structure of the workspace has to be considered to capture finer objects or even more subtle details.

Third, people occasionally see documents with objects during a distant collaboration session. Document sharing has been a popular collaboration tool. It will be ideal to incorporate document sharing capability into our system.

5 LightCollabo Updates

In response to the feedbacks from users described in Section 4, we updated our LightCollabo system. The modifications focused on handling objects in different scales and documents.

5.1 Optional Cameras

We provided two optional cameras to capture objects in different scales. The first solution uses a Pan-Tilt-Zoom (PTZ) camera. Coordinates of the procam unit's camera and parameters to drive a PTZ camera are registered in advance so that remote participants can simply specify a desired region on a viewer screen to let the system steer and zoom in the PTZ camera to obtain a detailed view of the specified region [7]. The obtained image is converted to a JPEG image and delivered by the image server. The viewer software receives the image and shows it in a pop-up window. Figure 8 shows the pop-up window. It is also equipped with control buttons of the PTZ camera. For on-site participants, the captured region is highlighted by a projected rectangle so that they can see where remote participants are looking at.

The second solution is a free arm camera which is an endoscope with a grip (See Figure 9). This camera is provided for viewing details in sub-millimeters. LED lights are placed around the lens for illuminating a target area. NTSC signals from a free arm camera are digitized as a JPEG image sequence and delivered to clients. Figure 10 illustrates a pop-up window showing a view from a free arm camera.

Note that shared workspaces using the above described cameras will be too small for projecting remote annotations and also for direct observation. Hence the workspaces are shared only on computer screens.

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Fig. 8. Sub-window for PTZ camera



Fig. 9. A free-arm camera

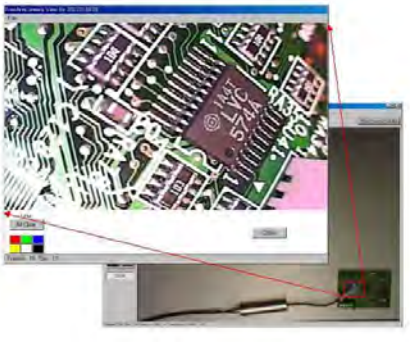


Fig. 10. Sub-window for free arm camera

5.2 Document Sharing

We implementeded a primitive document sharing feature to the viewer application. In addition to regular annotations such as line and circle, remote participants can place any image file for sharing. The contents of the image file is projected onto the physical object or the tabletop as specified. Naturally, the system should evolve such that a remote participant can retrieve a document from a regular document sharing system and the document is projected as an image.

6 Field Test

6.1 Expectation

With the above updates, we continued installing LightCollabo in our factories and product design centers located in China and Japan. In total, 15 systems

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have been deployed. By observing how the systems are used, we expect we can spot the cases where LightCollabo works most effectively, and evaluate strengths and shortcomings of the current system. Especially, we expected LightCollabo can contribute in the following three areas.

- Pointing at a problem region
- Sharing circumstances where a problem occured
- Understanding what caused the problem

6.2 Settings

At each site, a LightCollabo system was installed in a conference room equipped with a phone audio teleconferencing. The conference room was located next to production lines so that engineers have immediate access to the system when a problem occurs in the lines.

We conducted intensive investigations of the system usage at 4 domestic sites and 4 oversea sites. Each investigation took one week during the period between November of 2005 and March of 2007. We observed 12 use cases of LightCollabo: 4 cases for solving emergency problems, 4 cases in regular meetings, 2 cases for changing designs, 1 case for training, and 1 case during brainstorming. Except for 1 case used for solving an emergency problem, LightCollabo was used as a part of a scheduled teleconference. Approximately 30 people from 15 different departments used the system among more than 100 participants of the teleconferences.

6.3 Case Study

This section lists scenes from our observations where LightCollabo successfully contributed in problem solving. Combinations of various features of LightCollabo were used to share the workspace. In all cases, we noticed people intensively used reference terms during discussions, for example “Put this part in this hole” or “What is the length of here?”. Also they sent many gestures using LightCollabo both conciously by making annotations and unconciously by moving cursors. We consider these natural behaviors in remote communication are evidences that prove local and remote participants successfully share the same workspace using LightCollabo.

Pointing at a problem region. In order to train a product design engineer located at a remote site, local participants indicated improper points in a design plan drawn by the engineer using LightCollabo. Prior to the session, the local participants built a product component for trial based on the plan and found errors. The component was placed on the table of LightCollabo and the local participants explained where the errors are by pointing at the region and drawing on the table using markers. The remote engineer sent his feedback that was projected onto the component with which both sides confirmed that mutual understanding was achieved.

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Sharing circumstances where problem occured. In a regular meeting, an engineer reported problem analysis results to a remote site using LightCollabo. The free arm camera was used to show cases where actual parts were assmbled correctly and incorrectly. The engineer drew arrows on the client view image to emphasize the difference.

Understanding what caused the problem. LightCollabo successfully led to solve a problem that a conventional method could not. A screw was conflicing with other parts of the component. First, the problem was reported by email and attached digital photos. Because none of the photos were not taken from a desired angle, engineers at the remote location decided to use LightCollabo. A local engineer was instructed to hold the component at a certain angle, while the remote engineers watched it using the PTZ camera.

6.4 Discussion

Both the PTZ camera and the free arm camera were frequently used in most of sessions. Interestingly, the free arm camera was used rather like a pointing device. On-site participants held the camera focusing at a spot where they wanted remote participants to see. In other words, the free arm camera was used to "push" the view to be shared from the local site to the remote sites.

Each of the three cameras of LightCollabo has a different role. The main camera of the procam unit is used to provide an overview image or context. Remote participants use the PTZ camera when they want to see an area in details.

Document sharing was also popularly used. People requested more views to be shared such as whiteboard for accelerating remote discussions. Often participants had to confirm whether people on the other end were watching the LightCollabo screen. A support for people on one side to know what people on the other side are watching is neccessary for fully realizing the joint visual attention concept.

7 Conclusions and Future Work

We introduced our LightCollabo system. A procam unit for LightCollabo was built by optically aligning a camera and a projector. Using the unit, LightCollabo allows remote and on-site participants to share the same workspace where all participants can see physical objects, point any region, and annotate on the objects. In response to feedbacks from our deployment efforts, two optional cameras were added to handle objects in different scales as well as a capability to share digital images along with physical objects. Observations from our deployment indicated that our system facilitates distant collaboration.

As a next step, we are planning to conduct formal user study to evaluate advantages of LightCollabo quantitatively. The task for the evaluation will be determined based on our observation. Analysis on usage logs and feedbacks from our test users in the field should reveal where users need more support and how we should further improve the LightCollabo system. To make the system more

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durable in practical environment, new features such as session contents archiving, network traffic control and managing secured connections, must be investigated from both system and computer-human interaction aspects.

Further, there is a challenge of expanding the shared workspace beyond the tabletop. People want to share not only viewing physical objects, but also documents, computer screens, whiteboard, and other activities in the rooms for smoother discussion over distance.

Acknowledgement

Our partners experimentally produced various components of LightCollabo. Among others, we thank Fujinon Corporation, Saitama, Japan, for their efforts in making the zero-shift projector lens.

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Accurate Identifying Method of JPEG2000 Images for Digital Cinema

Takahiro Fukuhara[1], Kazuhisa Hosaka[1], and Hitoshi Kiya[2]

[1] Sony Corporation B2B Solution Department,
4-14-1, Asahi-chou, Atsugi-city, Kanagawa, 243-0014
[2] Faculty of System Design, Tokyo Metropolitan University,
6-6, Asahigaoka, Hino-city, Tokyo, 191-0065

Abstract. JPEG2000 has been selected as the image compression and decompression technology for digital cinema by DCI(Digital Cinema Initiatives). In a few years, large amount of JPEG2000 compressed files will be widely used and delivered. Identifying a target compressed file out of image sequences or database is highly demanded. In this paper, very unique identifying method is presented. It takes advantage of the feature of JPEG2000 codestream structure. The proposed method has advantages of low computation and high accuracy over conventional methods.

Keywords: JPEG2000, Digital Cinema, Image Compression, Image Identification, Image Search.

1 Introduction

JPEG2000[1][2] is standardized by ISO in December, 2000. JPEG2000 has lots of functions such as high compression efficiency, lossless/lossy compression, scalability and adaptation for motion pictures. The lossy compression efficiency of JPEG2000 is about two times of that of JPEG. In 2005, JPEG2000 Part-1 was officially selected as the standard compression/decompression technology for digital cinema by DCI(Digital Cinema Initiatives)[3]. It is expected that more and more JPEG2000 files of movies will be widely used. At the same time, in the committee of ISO/IEC/JTC1/SC29/WG1, a new standardization related to JPEG2000 search[4][5] has just begun. The goal of the standardization is to define a new framework to search effectively JPEG2000 compressed files spread on the Internet and database.

One of the conventional methods to identify JPEG2000 images is to use sign(+/-) information of DWT(Discrete Wavelet Transform) coefficients[6]. This method consists of the following procedures; (1)extract sign information of DWT coefficients of both JPEG2000 compressed images(in database) and a query image, (2)calculate the similarity of the sign information in each subband region. However, this method inevitably requires entropy decoding(EBCOT:Embedded Block-based Coding with Optimized Truncation) that is the most heavy-duty part of JPEG2000 elements. It leads to lots of calculation time to identify a target JPEG2000 image. It is a bottleneck for fast identification. New study on identifying JPEG images has also been underway[7][8][9].

S. Satoh, F. Nack, and M. Etoh (Eds.): MMM 2008, LNCS 4903, pp. 380–390, 2008.
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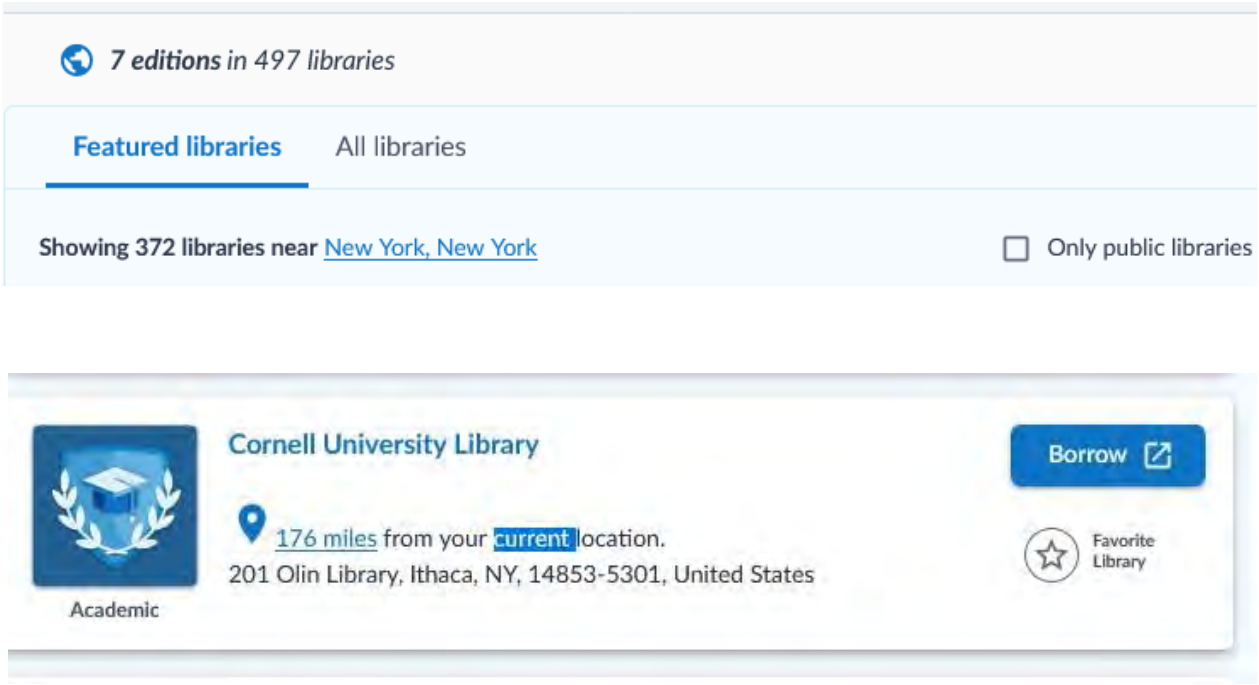
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JAMES L. MULLINS, PhD

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Library Experience:

2018-present Dean Emeritus, Libraries & Norton Professor Emeritus, Purdue University

2011 - 2017 Dean of Libraries & Esther Ellis Norton Professor, Purdue University

2004 - 2011 Dean of Libraries & Professor, Purdue University, West Lafayette, IN

2000-2004 Assistant/Associate Director for Administration, MIT Libraries, Massachusetts Institute of Technology, Cambridge, MA.

1996-2000 University Librarian & Director, Falvey Memorial Library. Villanova University, Villanova, PA.

1978-1996 Director of Library Services, Indiana University South Bend.

1974-1978 Associate Librarian, Indiana University Bloomington, School of Law.

1973-1974 Instructor/Catalog Librarian. Georgia Southern College (now University).

Teaching Experience:

1977-1996 Associate Professor (part-time), School of Library and Information Science, Indiana University. Subjects taught: Cataloging, Management, and Academic Librarianship.

Education:

1972 - University of Iowa. Honors Bachelor of Arts, History, Religion & Political Science.

1973 - University of Iowa. Master of Arts in Library Science.

1984 - Indiana University. Doctor of Philosophy. Concentration: Academic Library Administration. Emphasis: Law Librarianship.

Awards and Recognition:

2017 Wilmeth Active Learning Center/Library of Engineering and Science, Grand Reading Room, was announced by President Mitch Daniels, Purdue University, that it would be re-named the James L. Mullins Reading Room to honor his leadership and reputation in the academic library profession. September 2017. Portrait unveiled December 2017.

2017 Distinguished Alumnus Award by the School of Informatics and Computing, Indiana University, Bloomington. Given June 25, 2017.

2016 Hugh C. Atkinson Memorial Award, jointly sponsored by the four divisions of the American Library Association (ALA), June 27, 2016.

2015 ACRL Excellence in University Libraries Award, April 23, 2015.

Named Esther Ellis Norton Professor of Library Science by Purdue Trustees, December 11, 2011.

International Review Panel to evaluate the University of Pretoria Library, February 20 – 24, 2011. Pretoria, South Africa.

Publications: (selected)

Designing the Academic Library, Chapter Contributor. Association of College and Research Libraries, American Library Association, 2022.

A Purdue Icon: Creation, Life, and Legacy, edited by James L. Mullins, Founder's Series, Purdue University Press, 138pp., August 2017.

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"The Challenges of e-Science Data-set Management and Scholarly Communication for Domain Sciences and Technology: a Role for Academic Libraries and Librarians," chapter in, *The Digital Deluge: Can Libraries Cope with e-Science?"* Deanna B. Marcum and Gerald George, editors, Libraries Unlimited/Teacher Ideas Press, 2009. (a monograph publication of the combined proceedings of the KIT/CLIR proceedings).

"Bringing Librarianship to e-Science," *College and Research Libraries.* vol. 70, no. 3, May 2009, editorial.

"The Librarian's Role in e-Science" *Joho Kanri (Journal on Information Processing and Management),* Japan Science and Technology Agency (formerly Japan Information Center of Science and Technology), Tokyo, Japan. Translated into Japanese by Taeko Kato. March 2008.

The Challenge of e-Science Data-set Management to Domain Sciences and Engineering: a Role for Academic Libraries and Librarians," KIT (Kanazawa Institute of Technology)/CLIR (Council of Library and Information Resources) International Roundtable for Library and Information Science, July 5-6, 2007. Developments in e-science status quo and the challenge, The Japan Foundation, 2007.

"An Administrative Perspective," Chapter 14, *Proven Strategies for Building an Information Literacy Program*, Susan Curzon and Lynn Lampert, editors, Neal-Schuman Publishers, Inc., New York, 2007. pp. 229-237.

Library Management and Marketing in a Multicultural World, proceedings of the IFLA Management and Marketing (M&M) Section, Shanghai, China, August 16-17, 2006, edited. K.G. Saur, Munchen, Germany, June 2007. 390 pp.

Top Ten Assumptions for the Future of Academic Libraries and Librarians: a report from the ACRL Research Committee, with Frank R. Allen and Jon R. Hufford. *College & Research Libraries,* April 2007, vol.68, no.4. pp.240-241, 246.

To Stand the Test of Time: Long-term Stewardship of Digital Data Sets in Science and Engineering. A report to the National Science Foundation from the ARL Workshop on New Collaborative Relationships: the Role of Academic Libraries in the Digital Data Universe. September 26-27, 2006, Arlington, VA. p.141. http://www.arl.org/bm~doc/digdatarpt.pdf

"Enabling Interaction and Quality in a Distributed Data DRIS," *Enabling Interaction and Quality: Beyond the Hanseatic League*. 8th International Conference on Current Research Information Systems, with D. Scott Brandt and Michael Witt. Promoted by euro CRIS. Leuven University Press, 2006. pp.55-62. Editors: Anne Garns Steine Asserson and Eduard J. Simons.

"Standards for College Libraries, the final version approved January 2000," prepared by the ACRL College Libraries Standards Committee (member), *C&RL News*, March 2000, p.175-182.

"Standards for College Libraries: a draft," prepared by the ACRL College Libraries Section, Standards Committee (member), *C&RL News*, May 1999, p. 375-381.

"Statistical Measures of Usage of Web-based Resources," *The Serials Librarian,* vol. 36, no. 1-2 (1999) p. 207-10.

"An Opportunity: Cooperation between the Library and Computer Services," in *Building Partnerships: Computing and Library Professionals.* Edited by Anne G. Lipow and Sheila D. Creth. Berkeley and San Carlos, CA, Library Solutions Press, 1995. p. 69-70.

"Faculty Status of Librarians: A Comparative Study of Two Universities in the United Kingdom and How They Compare to the Association of College and Research Libraries Standards, " in *Academic Librarianship, Past, Present, and Future: a Festschrift in Honor of David Kaser.* Englewood, Colorado; Libraries Unlimited, 1989. p. 67-78. Review in: *College & Research Libraries,* vol. 51, no. 6. November 1990, p. 573-574.

Presentations: (Representative)

"How Long the Odyssey? Transitioning the Library and Librarians to Meet the Needs and Expectations of the 21st Century University," David Kaser Lecture, School of Informatics & Computing, Indiana University, Bloomington, IN, November 16, 2015.

Presentation at University of Cape Town, Cape Town, South Africa, August 20, 2015.

"The Challenge of Discovering Science and Technology Information," Moderator, International Federation of Library Associations (IFLA) Science and Technological Libraries Section Program, Cape Town, South Africa, August 18, 2015.

"An Odyssey in Data Management: Purdue University," International Federation of Library Associations (IFLA) Research Data Management: Finding Our Role – A program of the Research Data Alliance, Cape Town, South Africa, August 17, 2015.

Presentation at University of Pretoria, Pretoria, South Africa, August 11, 2015.

Co-Convener with Sarah Thomas, Harvard University, at the Harvard Purdue Symposium on Data Management, Harvard University, Cambridge, MA, June 15-18, 2015.

"Strategic Communication," panel discussion on the Director's role and perspective on library communications at Committee on Institutional Cooperation (CIC) Center for Library Initiatives (CLI) Annual Conference, University of Illinois Urbana-Champaign, May 20, 2015.

"Issues in Data Management," panel discussion moderated by Catherine Woteki, United States Undersecretary for Research, Education & Economics at 20th Agriculture Network Information Collaborative (AgNIC) Annual Meeting in the National Agricultural Library, Beltsville, MD, May 6, 2015.

"Active learning/IMPACT & the Active Learning Center at Purdue University," Florida Institute of Technology, Melbourne, FL, February 11, 2015.

"Science+art=creativity: libraries and the new collaborative thinking," panel moderator, International Federation of Library Associations (IFLA) 80th General Conference and Assembly, Lyon, France, August 19, 2014.

"Purdue University The Active Learning Center—A new concept for a library," Association of University Architects 59th Annual National Conference, University of Notre Dame, South Bend, IN, June 23, 2014.

"Big Data & Implications for Academic Libraries," keynote speaker, Greater Western Library Alliance (GWLA) Cyber-infrastructure Conference, Kansas City, MO, May 28, 2014.

"Research Infrastructure," panel moderator, Association of Research Libraries (ARL) 164th Membership Meeting, Ohio State University, Columbus, OH, May 7, 2014.

"An Eight Year Odyssey in Data Management: Purdue University," International Association of Scientific and Technological University Libraries (IATUL) 2013 Workshop Research Data Management: Finding Our Role, University of Oxford, UK, December 2013.

"Purdue University Libraries & Press: from collaboration to integration," Ithaka Sustainable Scholarship, The Evolving Digital Landscape: New Roles and Responsibilities in Higher Education, libraries as publishers, New York, New York, October 2013.

"Tsinghua and Purdue: Research Libraries for the 21st Century," Tsinghua University, Tsinghua, China, August 2013.

"Purdue Publishing Experience in the Libraries Publishing Coalition," Association of American University Presses Annual Meeting, Press-Library Coalition Panel, Boston, Massachusetts, June 21, 2013.

"Indiana University Librarians Day: Purdue University Libraries Ready for the 21st Century," Indiana University Purdue University Indianapolis (IUPUI), June 7, 2013.

"Purdue University Libraries and Open Access; CNI Project Update," Coalition for Networked Information, San Antonio, TX, April 5, 2013.

Memorial Resolution, honoring Joseph Brannon, to the Board of the Association of College & Research Libraries, Seattle, WA, January 2013.

"An overview of sustaining e-Science collaboration in an Academic Research Library—the Purdue experience," Duraspace e-Science Institute webcast, October 17, 2012.

"The Role of Libraries in Data Curation, Access, and Preservation: an International Perspective, " Panel Moderator, 78th General Conference and Assembly, International Federation of Library Associations, Helsinki, Finland, August 15, 2012.

"21st Century Libraries," moderator of First Plenary Session, International Association of Technological University Libraries 33rd Annual Conference, Singapore, June 4, 2012.

"Planning for New Buildings on Campus," panel presenter, University of Calgary Building Symposium on Designing Libraries for the 21st Century, Calgary, Alberta, Canada, May 17, 2012.

"Data Management and e-Science, the Purdue Response." Wiley-Blackwell Executive Seminar-2012, Washington, DC, March 23, 2012.

"An overview of Sustaining e-Science Collaboration in Academic Research Libraries and the Purdue Experience." Leadership & Career Development Program Institute, Association of Research Libraries (ARL). Houston, TX, March 21, 2012.

"An overview of Data Activities at Purdue University in response to Data Management Requirements." Coalition for Academic Scientific Computation (CASC). Arlington, VA, September 8, 2011.

"Getting on Track with Tenure," Association of College and Research Libraries (ACRL) Research Program Committee. Washington, DC, June 26, 2011.

"Integration of the Press and Libraries Collaboration to Promote Scholarly Communication," Association of Library Collections & Technical Services (ALCTS) Scholarly Communication Interest Group – American Library Association, New Orleans, Louisiana, June 25, 2011.

"Cooperation for improving access to scholarly communication," with N. Lossau (Germany), C. Mazurek (Poland), J. Stokker (Australia), panel moderator and presenter, Second Plenary Session, International Association of Scientific and Technological University Libraries (IATUL) 32nd Conference 2011, Warsaw, Poland. May 29-June 2, 2011.

"Riding the Wave of Data," STM Annual Spring Conference 2011. Trailblazing & transforming scholarly publishing **2011**. Washington, D.C., April 28, 2011.

"Confronting old assumptions to assume new roles: physical and operational integration of the Press and Libraries at Purdue University," keynote speaker, 2011 BioOne Publishers & Partners Meeting. Washington, D. C., April 22, 2011.

"Are MLS Graduates Being Prepared for the Changing and Emerging Roles that Librarians must now assume within Research Libraries?" University of Oklahoma Libraries Seminar, March 4, 2011, Oklahoma City, Oklahoma.

"The Future Role of University Librarians," the University of Cape Town, South Africa, February 25, 2011.

"New Roles for Librarians: the Application of Library Science to Scientific/Technical Research – Purdue University – a case study. International Council for Science and Technology (ICSTI); Ottawa, Canada. June 9, 2009.

"Reinventing Science Librarianship: Models for the Future," Association of Research Libraries / Coalition for Networked Information. October 16-17th, 2008, Arlington, VA. Moderator and convener of Data Curation: Issues and Challenges.

"Practical Implementation and Opportunities Created at Purdue University," African Digital Curation Conference, Pretoria, South Africa, (live video transmission), February 12, 2008.

Keynote speaker. "*Scholarly Communication & Academe: The Winter of Our Discontent,"* XXVII Charleston Conference on Issues in Book and Serial Acquisition, Charleston, South Carolina. November 8, 2007.

Keynote speaker. "*Enabling Access to Scientific & Technical Data-sets in e-Science: a role for Library and Archival Sciences,"* Greater Western Library Alliance (GWLA), Tucson, Arizona. September 17, 2007. A meeting of library directors and vice presidents for research of member institutions.

"*The Challenge of e-Science Data-set Management to Domain Sciences and Engineering: a Role for Academic Libraries and Librarians,"* KIT (Kanazawa Institute of Technology)/CLIR (Council of

Library and Information Resources) International Roundtable for Library and Information Science, July 5-6, 2007. Invited to participate by the Deputy Librarian of Congress.

International Association of Technological University Libraries (IATUL), Stockholm, Sweden. June 8, 2007**.** Invited paper**,** *Enabling International Access to Scientific Data-sets: creation of the Distributed Data Curation Center (D2C2).*

"A New Collaboration for Librarians: The Principles of Library and Archival Sciences Applied to the Curation of Datasets," Symposium of the Libraries and the College of Engineering, University of Louisville, April 6, 2007.

"Purdue University Libraries: Through Pre-eminent Innovation and Creativity, Meeting the Challenges of the Information Age," Board of Trustees, Purdue University, February 15, 2007.

ARL Workshop on New Collaborative Relationships: The Role of Academic Libraries in the Digital Data Universe, September 26-27, 2006, Arlington, VA. Invited participant.

NARA and SDSC: A partnership. A panel before the National Science Foundation, June 27, 2006. Arlington, VA. Invited participant.

"Kaleidoscope of Scientific Literacy: fusing new connections," with Diane Rein, American Library Association, Association of College and Research Libraries, Science & Technology Section, Annual Conference, New Orleans, June 26th, 2006.

"Leadership for Learning: Building a Culture of Teaching in Academic Libraries – an administrative perspective," American Library Association, Association of College and Research Libraries, Instruction Section, Annual Conference, New Orleans, June 25th, 2006.

"Building an interdisciplinary research program in an academic library:
how the Libraries'associate dean for research makes a difference at Purdue University," International Association of Technological University Libraries (IATUL), Porto, Portugal, May 23rd, 2006.

"Enabling Interaction and Quality in a Distributed Data DRIS," *Enabling Interaction and Quality: Beyond the Hanseatic League*. 8th International Conference on Current Research Information Systems, with D. Scott Brandt and Michael Witt. Promoted by euro CRIS, Bergen, Norway, May 12th, 2006, Brandt, and Witt presented in person

"Interdisciplinary Research," with D. Scott Brandt, Coalition for Networked Information (CNI) Spring Meeting: Project Briefing, Washington, D.C., April 3rd, 2006.

"An Interview with Purdue's James Mullins," a podcast submitted by Matt Pasiewicz, on *Educause Connect,* http://connect.educause.edu/James_L_Mullins_Interview_CNI_2005

"Managing Long-Lived Digital Data-sets and their Curation: Interdisciplinary Policy Issues," Managing Digital Assets Forum, Association of Research Libraries (ARL), Washington, D.C., October 28th, 2005.
"The Odyssey of a Librarian." Indiana Library Federation (ILF), District 2 Meeting, South Bend, Indiana. October 4th, 2005.
"New College Library Standards," Standards Committee Presentation, ALA, Chicago, July 7, 2000.
SUNY Library Directors, Lake George, New York. "*The College Library Standards: a Tool for Assessment."* April 5, 2000.
Tri-State College Library Association, *Finding You Have Talents You Never Knew You Had,* Penn State Great Valley, March 25, 2000.
Using Web Statistics, American Library Association, New Orleans, June 24, 1999.
Keynote speaker at the JSTOR Workshop, January 29, 30, 1999. University of Pennsylvania, Philadelphia, PA.
"The New Standards for Electronic Resources Statistics," Society of Scholarly Publishers, Washington, D.C., September 17, 1998.
"Evaluating Online Resources: Now that you've got them what do you do?," joint presenter with Chuck Hamaker, LSU, at the NASIG Conference, Boulder, Colorado. June 1998.
"What Employers Are Looking for in New Librarians?" Pennsylvania Library Association, Philadelphia. September 26, 1997.
"The Theory of Matrix Management" panel presentation of the Comparative Library Organization Committee of the Library Organization and Management Section of the Library Administration and Management Association, a division of the American Library Association, Annual Meeting, Chicago, June 24, 1990.

Professional Involvement: (summary of recent emphasis)

The focus for my professional involvement and research has moved recently toward managing massive data-sets. This has resulted in working with faculty in the sciences and technology to determine how librarians can collaborate in managing, curating, and preserving data-sets for future access and documentation. This has included various speaking opportunities as well as participation in planning with the National Science Foundation (NSF) on ways in which librarians can be integrated more completely into the funded research process. Participation in the Kanazawa Institute of Technology/Council of Library Resources Roundtable was particularly rewarding and provided new opportunities to share with international colleagues the issues surrounding data-set management. I was

the champion for the creation of the Distributed Data Curation Center (D2C2) at Purdue University (http://d2c2.lib.purdue.edu/)

Throughout my career, beginning with my dissertation, I have been actively involved with assessing and evaluating libraries. In the fall of 1999, I contacted twenty-two academic library directors to determine whether the need was also felt by others. The response was overwhelmingly affirmative. This resulted in a meeting at ALA Midwinter, January 2000. A formal meeting followed at Villanova University in April 2000. As convener, I helped to form the University Libraries Group (ULG), modeled after the Oberlin Group for college libraries. The ULG is made up of university libraries that support diverse wide-ranging programs through doctoral level and have a level of support that places them in the top tier of academic institutions. A few of the member libraries, along with Villanova, are William and Mary, Wake Forest, Lehigh, Carnegie-Mellon, Tufts, Marquette, Miami of Ohio, and Southern Methodist.

In 1994 appointed to the Standards Committee, College Section, Association of College and Research Libraries. During the next six years, the Committee concentrated on changing the focus of the standards from quantitative analysis of input and output factors to emphasis on assessment of the outcome. Culmination of the work was a re-issue of the *Standards for College Libraries* in 2000. The knowledge gained through my work experience enabled me to formulate the changes needed in the standards. This work allowed for close collaboration with accrediting agencies, both professional and regional.

During this same time another focus emerged, the impact of digital resources. Through my work on the JSTOR Statistics Task Force, standards were developed on the collection of use of electronic databases. This Standard was later adopted in 1998 by the International Consortium of Library Consortia (ICOLC).

In 2002, the American Library Association appointed me to serve as the liaison to the Marketing and Management Section of the International Federation of Library Associations (IFLA).

Professional Service: (representative list)

Nominations Committee, Association of Research Libraries (ARL), 2016.

Steering Committee, Scholarly Publishing and Academic Resources Coalition (SPARC), 2016 – 2017.

"Excellence in Library Services," Chair, Review Team, University of Hong Kong, Hong Kong, August 24-27, 2015.

Chair, Management Advisory Board, 2015-2017; Member, Scientific Advisory Board, arXiv, Cornell University, 1/1/2013 – present.

Advisory Board for the Wayne State University School of Library and Information Science, July 2012 – present.

Advisory Board for Microsoft Academic Search, 2012 – 2015. Redmond, WA.
Transforming Research Libraries, a Strategic Direction Steering Committee of the Association of Research Libraries (ARL), 2012-2015.
Science and Technology section, representing ARL, International Federation of Library Associations (IFLA), Chair, 2013 – 2017; Member, 2011 to present.
Member of University of Pretoria, South Africa, Library Review Committee. August 2013.
Co-chair, Local Arrangements Planning Committee for 2013 Conference, Association of College and Research Libraries (ACRL), a division of the American Library Association (ALA).
Association of Research Libraries Leadership & Career Development Program Mentor, 2011-2017.
e-Science Task Force, Association of Research Libraries. July 2006 – present. Chair, October 2011 – October 2012.
Board of Directors, International Association of Technological University Libraries (IATUL). January 2008 – December 2014.
Midwest Collaborative for Library Services (MCLS); Board Member, October 2010 – December 2012.
Chair, Library Directors, Committee on Institutional Cooperation (CIC), July 2010 – June 2012.
Board of Directors, Association of Research Libraries (ARL); October 2008 – October 2011.
Scholarly Communication Steering Committee, Association of Research Libraries (ARL) 2008-2011.
Editorial Board, *College and Research Libraries*, Association of College and Research Libraries, American Library Association. January 2008 – December 2014.
Chair, Organizing Committee for IATUL Conference 2010, June 21-24, 2010, Purdue University, West Lafayette, Indiana/Chicago, Illinois.
Conference Planning Committee for National Conference of the Association of College and Research Libraries, 2009, Seattle, Washington.
Research Committee, Association of College and Research Libraries, ACRL, division of ALA. 2002-2007, chair, 2005-2007.
Association of Research Libraries, Search and Screen Committee, Executive Director. March – January 2008.
Center for Research Libraries, Board of Directors. April 2006 – April 2012.
Academic Libraries of Indiana, Board of Directors, 2004 – present. Vice-president, 2005-2007. President, 2007- 2009.

ALA Representative to the International Federation of Library Associations (IFLA), Marketing and Management (M&M) Section, initial term 2003-2007, re-appointed for second term, 2007-2011.
Invited to represent Research Libraries at the ACRL/3M Wonewok Retreat to assess Marketing of Academic Libraries, October 2002.
Hugh A. Atkinson Award Committee, LAMA Representative, ALA, 2001-2005.
Program Committee, Library Administrators and Management Association (LAMA), a division of ALA. 1996-2001.
ACRL, Standards and Accreditation Committee, a division of ALA. Liaison to RBMS Section of ACRL. 1997-2002.
Elected to the Executive Committee of LAMA, LOMS, a division of the American Library Association, 1998-2000. Nominated as Chair/Elect for 2003 – 2005.
Columbia University Press Advisory Committee. 1996 - 2000.
LITA/LAMA Conference Evaluation Committee, Pittsburgh, Pennsylvania, October 1996.
"New Learning Communities," Coalition for Networked Information, Indianapolis. November 19-21, 1995. Facilitator for invitational, national conference committed to developing collaborative learning and teaching techniques, involving librarians.
Planning Committee-Evaluation. LITA/LAMA 1996 Conference, Pittsburgh. This first conference, to be held jointly between two divisions of ALA, will focus on new technologies within libraries.
Indiana Cooperative Library Services Authority (InCoLSA), elected to Executive Committee, April 1991, served as President in 1993-94. InCoLSA is a statewide network of academic, public, school, and special libraries that supports library cooperation for cataloging, interlibrary loan, collection development and application of new technologies.
Governor’s Conference on Libraries and Information Services. Served on Planning Committee, Academic Libraries Representative, appointed by the Governor to represent academic libraries in Indiana, Chair, Finance Committee, April 1989-July 1991.
Indiana Library Endowment Foundation Board, 1984-92. Charter Member, 1984, President, 1988-1992. 2004-2005.

University Service: (Summary)

Served on search and screen committees for senior positions including chancellor, dean, and directors; most recently I have been asked to serve on the search committee for the provost of Purdue University. At MIT service included the Library Council & appointment to the Administrative Council by President

Vest, 2001-2003 & Member of the Faculty Committee on the Library System. At Purdue appointed by the President to the Search Committee for the Provost, October 2007 to May 2008; member of the Capital Projects Committee, and IT Operational Oversight Committee as senior academic dean, 2008-2014.

Global Council, Global Policy Institute, 2012 – 2016.

Academic Program Excellence and Rankings (APER) project team, 2014.

Representative of the Academic Deans on the Re-engineering Business Operations, Purdue University, 2016 –

Academic Deans Council chaired by Provost – 2004 – 2017.

University Promotion and Tenure Committee – 2006 – 2017.

"Outstanding Team Award, Electronic Reserve Project," served as Chair, recognition awarded by the President of Villanova University to one team who made an outstanding contribution to the operations of the University, selected by a committee of administrators, faculty, and staff. Awarded September 9, 1999.

Nominated for the IUSB Lundquist Award, 1995 & 1996. The Lundquist award is given to faculty who have "exhibited excellence in teaching, scholarly or artistic achievement, and diversified relevant service..."