

# LightCollabo: Distant Collaboration Support System for Manufacturers

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**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 component 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].

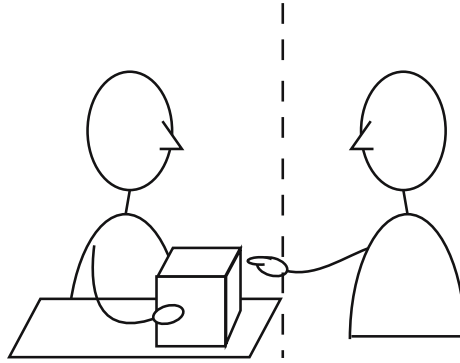


**Fig. 1.** A scene of collaboration over a physical object

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

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 **projector** and a **camera** (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

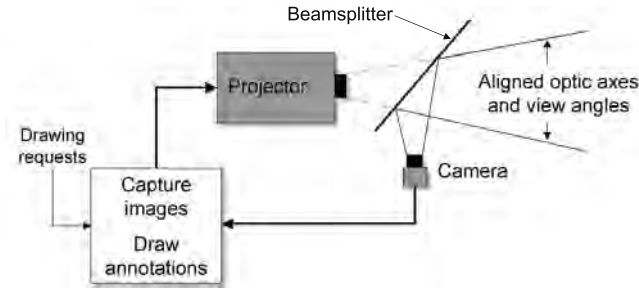


**Fig. 2.** Diagram of LightCollabo server

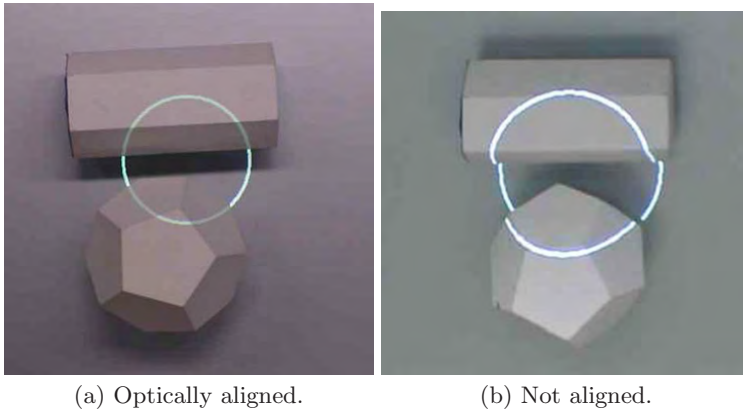


**Fig. 3.** View comparisons of differently arranged cameras

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

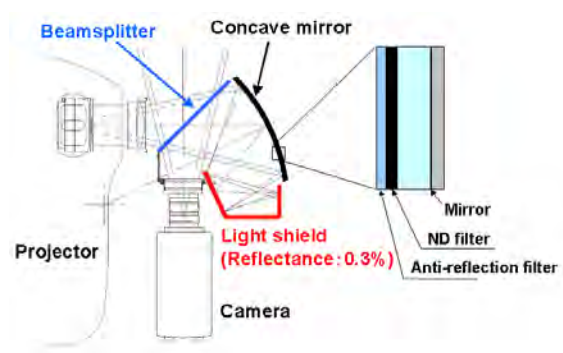


Fig. 4. Light trap structure

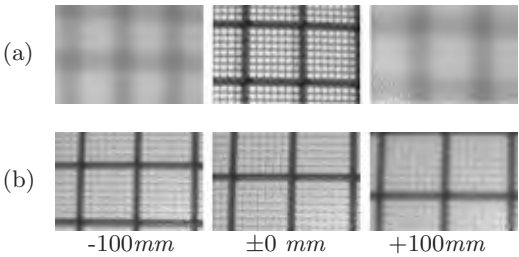


Fig. 5. Captured images around 1,000mm from the projector taken by (a)regular lens, and (b)zero-shift lens

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



**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

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.

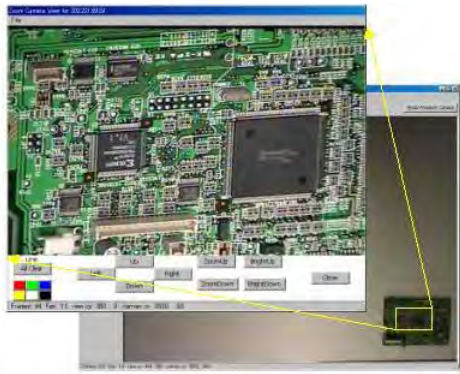


Fig. 8. Sub-window for PTZ camera

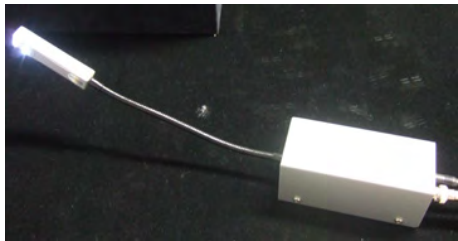


Fig. 9. A free-arm camera

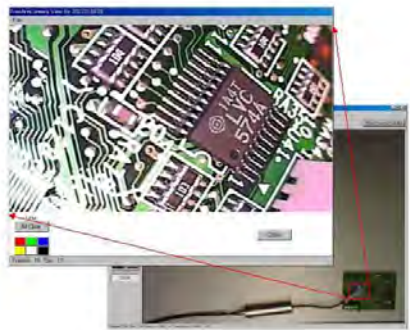


Fig. 10. Sub-window for free arm camera

## 5.2 Document Sharing

We implemented 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

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 occurred
- 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 overseas 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 consciously by making annotations and unconsciously 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.

**Sharing circumstances where problem occurred.** 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 assembled 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 conflicting 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 necessary 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

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

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