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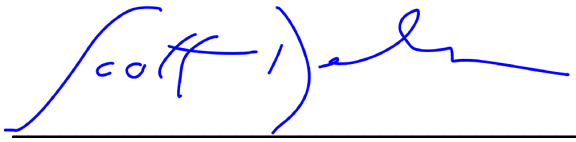

Scott Delman, Director of Publications

Exhibit A

Human Pacman: A Sensing-based Mobile Entertainment System with Ubiquitous Computing and Tangible Interaction

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ABSTRACT
Human Pacman is an interactive ubiquitous and mobile entertainment system that is built upon position and perspective sensing via Global Positioning System and inertia sensors; and tangible human-computer interfacing with the use of Bluetooth and capacitive sensors. Although these sensing-based subsystems are weaved into the fabric of the game and are therefore translucent to players, they are nevertheless the technical enabling forces behind Human Pacman. The game strives to bring the computer gaming experience to a new level of emotional and sensory gratification by embedding the natural physical world ubiquitously and seamlessly with a fantasy virtual playground. We have progressed from the old days of 2D arcade Pacman on screens, with incremental development, to the popular 3D game console Pacman, and the recent mobile online Pacman. With our novel Human Pacman, we have a physical role-playing computer fantasy together with real human-social and mobile-gaming that emphasizes on collaboration and competition between players in a wide outdoor physical area that allows natural wide-area human-physical movements. Pacmen and Ghosts are now real human players in the real world experiencing mixed computer graphics fantasy-reality provided by using wearable computers that are equipped with GPS and inertia sensors for players' position and perspective tracking. Virtual cookies and actual tangible physical objects with Bluetooth devices and capacitive sensors are incorporated into the game play to provide novel experiences of seamless transitions between real and virtual worlds. In short, we believe Human Pacman is pioneering a new form of gaming that is based on sensing technology and anchored on physicality, mobility, social interaction, and ubiquitous computing.

Keywords
Mobile entertainment, ubiquitous computing, tangible interaction, computer entertainment.

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1. INTRODUCTION
In recent years the world has seen the proliferation of highly portable devices, such as personal digital assistants (PDAs), laptops, and cellular telephones. At the same time, trends in computing environment development suggests that users are gradually freed from the constraints of stationary desktop computing with the explosive expansion in mobile computing and an increasing availability of cheap sensors. With this technological progress in mind, we have developed Human Pacman, which serves as a pioneer in the new genre of computer game that is based on real-world-physical, social, and wide area mobile-interactive entertainment. Concepts of context-awareness through location and body tracking, tangible interaction with objectification of virtual objects in game play, ubiquitous computing in the form of mobile and social gaming, and lastly physical gaming supported by the use of wearable computers are explored.

1.1 Context-Awareness in Outdoor Environment
Human Pacman allows players to be physically and immersively role-play the characters of the Pacmen and Ghosts as they move about freely in the real world over wide area outdoor spaces. There is a seamless merging of the fantasy computer digital world with the real physical world realized using location and body tracking technologies, namely the Global Positioning System (GPS), Dead-Reckoning module (DRM), and inertia sensors, to provide the necessary context-awareness of the system for the game play. The players who are role-playing Pacmen have to physically roam around the outdoor area and collect virtual cookies in the process. In addition, they have to find and collect 'Ingredients' that are actually Bluetooth embedded objects for the making of 'Super Cookies' which give them special Ghost-devouring ability. These physical objects are linked in real time to their virtual Pac-world representation, thus providing the player with a sense of presence and immersion with the virtual Pac-world. Another role in Human Pacman is known as the Helper. She is participating in the game remotely via a computer terminal over Wireless LAN. In other words, the Helper role can be played by anyone connected to the game's Wireless LAN network, or an online player who is physically anywhere on earth and is joining the game via Internet.

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Researchers at Olivetti Research Ltd. (ORL) and Xerox PARC Laboratory pioneered the context-aware computing area [Want92, Schilit93] with the introduction of Active Badge System and PARCTab. However, these systems were expensive with the extensive use of infrared transceivers, and were limited in scope as their applications were confined to an indoor room. Therefore with the introduction of GPS and emergence of cheap but accurate sensors, more context-aware systems for outdoor applications were built. One notable system was the Georgia Tech Cyberguide project [Long96] where mobile context-aware tour guide prototypes were made to provide information to a tourist based on her position and orientation. Similarly, at the University of Canterbury, some context-aware fieldwork tools have been developed: an archeological assistant tool [Ryan97], a giraffe observation tool [Pascoe98], and a rhino identification tool [Pascoe99] to enable the users to make location dependent notes using a PalmPilot as terminal and GPS for positioning. Unlike Human Pacman that uses Augmented reality techniques as its main computer human interface, these systems have only primitive 2D maps and text presented on palmtops.

Another tourist assistant called Smart Sight was developed at the Carnegie Mellon University [Yang99], which was able to translate from and to local language, handle queries posed and answer in spoken language, and aid navigational around the campus with the use of wearable computers. Nevertheless since laptops were used as part of the mobile computer system, their sheer weight and bulkiness have greatly reduced user's mobility and comfort of use. In Human Pacman, players are provided with custom-built wearable computers that are designed, built, and developed in our lab especially for this application.

The use of GPS and outdoor physical area for computer gaming is pioneered by ARQuake [Thomas02]. This game is an AR extension of the original desktop Quake game of player shooting virtual monster (in this case the monsters are presented in physical world using AR techniques) in first person perspective. However it is a single player game with practically no social interaction.

1.2 Tangible Interaction at Game Play

Even though Graphical User Interface (GUI) has been and still is the dominant paradigm for interactions with computers, we are increasingly encountering computation that moves beyond the traditional confines of the desk and attempts to incorporate itself more richly into our daily experience of the physical and social world. Work on physical interaction started to appear in literatures in the early 90s with the introduction of Computer-Augmented Environments [Acm93] that have visioned the merging of electronic systems into the physical world instead of attempting to replace them as in virtual reality environments.

Over the years, a number of projects have explored this new paradigm of interaction termed tangible computing. Early attempts include Bishop's Marble Answering Machine [Smith95] that has made a compelling demonstration of passive marbles as "containers" for voice messages; "Bricks" by Fitzmaurice [Fitzmaurice95] that are essentially new input devices that can be tightly coupled to virtual objects for manipulation or for expressing action (e.g., to set parameters or for initiating processes); "Tangible Bits" and "mediaBlocks" from MIT media lab [Ishii97] that allows users to "grasp & manipulate" bits in the center of their attention by coupling the bits with everyday physical objects and architectural surfaces, and "contain, transport, & manipulate" online media using small, electronically tagged wooden blocks that serve as physical icons ("phicons") respectively. Nevertheless in all of these implementations of tangible computing, computer interaction remains passive with human initiates communication with the tangible object, and confined only between virtual objects and humans. However, in Human Pacman, with the use of embedded Bluetooth devices for tangible interactions, we explore the active communication between computers and human players instantiated by Bluetooth devices as the players walk within the range of objects which Bluetooth devices are attached. Also, the use capacitive sensors on objects as well as wearable computers allow the game play to include graspable interaction between humans and computers, and between human players themselves. Thus there is tangible touch interaction between humans which has real time affects on the virtual computer world.

1.3 Ubicomp elements in connected mobility for social and interactive gaming

Björk suggested ubiquitous games [Björk02] as a new form of gaming. Coupling that with the development in Wireless LAN technology and mobile computing using wearable computers, we have combined connected mobility with elements in ubicomp (i.e. natural interfaces, context-awareness, and automated capture and access) for realizing social gaming components in Human Pacman.

Several pioneering works have been developed on ubiquitous and social gaming. Multi-players mobile gaming is demonstrated in 'Pirates!'[Björk01]. 'Pirates!' implements the game on PDAs with proximity sensing technology to incorporate a player's contextual information (such as physical co-location of players and objects in the world) into the game context as important elements of the game mechanics. However, visual and sound effects of game play are limited by relatively low computing power of PDAs. Augmented Reality and Virtual Reality cannot be implemented; therefore immersive experience is rather limited due to the flat 2-D display used on PDAs. The E3 project [Mandryk01] examines the essential elements of free play, and multi-user social interaction. It focuses on human-to-physical interaction and human-to-human interaction. However it does not explore large-scale configuration where users walk around.

Today's mainstream entertainment revolves around interactivity. Gone are the days when people were satisfied with passive form of entertainment as provided by television and cinema. People today enjoy entertainment they can control, and experience in which they are full involved [IDSA01]. In fact not only do they want such entertainment; people want to enjoy it together with family and friends. As shown in a certain survey [IDSA02] one of the top reasons why game players like to play games is that game playing is a social activity people can enjoy with family and friends. With advancement in networking technology, social gaming has gained popularity since the introduction of networked games [IDSA02]. Networked games overcame the barrier of distance, enabling real people to play against each other over large areas. After all there is no opponent like a live opponent since no computer model will rival the richness of human interaction [Dodsworth98a]. According to a recent study by Nezlek [Nezlek02], enjoyable and responsive

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interactions increase life satisfaction scores among people. Nevertheless, even in networked computer games, social interaction between players is limited since natural interactions such as gestures, body language and movement, gaze, and physical awareness are lost. Thus, by bringing players in physical proximity for interaction, Human Pacman brings networked social computer gaming to a novel higher level because humans enjoy being physically together, and socially interacting with each other (as mentioned in the following section with the work from [Bowlby83]). Essentially, Human Pacman brings the exciting interactive aspects of networked gaming, and merges it with the real physical world, allowing social translucence between humans players in both the real and virtual worlds simultaneously.

1.4 Physical Gaming with Wearable Computers

Human Pacman has its roots in serious research about human's interaction with their world. Human, as social creatures find physical interaction, touch, and human-to-human presence essential for the enjoyment of life [Bowlby83]. In pre-computer age, games were designed and played out in the physical world with the use of real world properties, such as physical objects, our sense of space, and spatial relations. Nowadays computer games focus the user's attention mainly on the computer screen or 2D/3D virtual environment, therefore constraining physical interactions. However, there seems to be a growing interest in physical gaming and entertainment. Commercial arcade games have recently seen a growing trend of games that require human physical movement as part of interaction. For example, dancing games such as Dance Dance Revolution and ParaParaParadise [Konami01] are based on players dancing in time with a musical dance tune and moving graphical objects, as seen in Figure 1.

Figure 1. A player dancing to the music in ParaParaParadise arcade game

However these systems still force the person to stand in more or less the same spot, and focus on a computer screen in front of them. Nevertheless, our philosophy is similar as one of the goals for Human Pacman to bring physical gaming into computer entertainment. The game of Pacman has come a long way from the 2D arcade version to the current popular game console and computer version of 3D Pacman. Now with Human Pacman, we have a physical role-playing computer fantasy that takes place in a wide outdoor physical area, and promotes natural wide-area human-physical movements.

1.5 Overview

In this article, we present a novel game system, Human Pacman, which anchors upon sensing-based subsystems that are the GPS merged with Dead Reckoning module and inertia sensor; and Bluetooth device and capacitive sensor. Firstly we describe the roles of the various sensors and tracking devices that are made used of in Human Pacman. Then we proceed to detail gaming experiences involved by clarifying the actual game play designed. More importantly in the section that follows, the details of the sensing-based subsystems are analyzed in the context of addressing various Human Computer Interaction issues. Lastly we conclude with our reflections on the future impacts of the system on everyday life.

2. ROLE OF SENSORS AND TRACKING DEVICES

Numerous sensors and tracking devices that are used in the system – dead reckoning module (DRM) with GPS and digital compass, inertia sensor, Bluetooth device, and capacitive sensor – are vital to the manifestation of Human Pacman. First of all, the DRM provides the all-important mobile and physical gaming infrastructure for indoor and outdoor location tracking of players. It is an electronic module comprising of a 12-channel Global Positioning System (GPS) receiver, digital compass, pedometer, and altimeter from Point Research Corporation [Pointgrey02]. The DRM measures the displacement of the user from an initialization point by measuring the direction (with data obtained from the compass), and distance traveled (using accelerometer data) with each footstep taken. Although the DRM is a self-contained navigation unit, when GPS position data is available, it can be used to correct both the distance and direction calculations with the help of a Kalman filter algorithm. Besides, in conjunction with the step detection logic (pedometer), the module can detect running, sideways, and backwards walking which is necessary for our application.

The real-time position of each mobile user is sent periodically to the server through wireless LAN. Upon receiving the position data, the server sends an update to each wearable computer the position of other mobile players, as well as the positions of all "non-eaten" plain cookies.

The position of a player with respect to another player or location in the physical world is calculated as follows. Taking two physical locations as *point1* and *point2*, the distance *d* between *user1* and *user2* in radian can be calculated by:

$$d = \cos^{-1}\{\sin(lat1)\sin(lat2) + \cos(lat1)\cos(lat2)\cos(lon1 - lon2)\}$$

Where *lon1*, *lat1*, *lon2* and *lat2* are the longitude and latitude of user1 and user2, respectively which all are in radian. To compute the distance in kilometers instead of radians, d is multiplied by the radius of earth, which is estimated at 6371.0km.

The course *c12* from *user1* to *user2* will be:

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$$IF \quad \sin(lon\,2 - lon\,1) < 0$$

$$c12 = \cos^{-1}\left\{\frac{\sin(lat\,2) - \sin(lat\,1)\cos(d)}{\sin(d)\cos(lat\,1)}\right\}$$

$$ELSE$$

$$c12 = 2\pi - \cos^{-1}\left\{\frac{\sin(lat\,2) - \sin(lat\,1)\cos(d)}{\sin(d)\cos(lat\,1)}\right\}$$

The above *c12* is valid when the *user1* is facing to the North Pole. Otherwise the yaw of the North Pole for the *user1* must be subtracted from *c12*.

Since augmented reality is implemented as an interface feature between the players and their wearable computers, head tracking for the calculation of view perspective of each player is important. We use Inertiacube2 from InterSense [InterSense01] for this purpose. It is an inertial three degree-of-freedom orientation tracking system that gives yaw, pitch and roll of the object that it is attached on. By placing the sensor on the cap of each player, her head movement and orientation is tracked to high accuracy.

Consequently using the player's position and head movement, the wearable computer calculates the relative position of each plain cookie within the view of the camera, and superimposes a 3-D virtual cookie image of a proportionate size on corresponding position on the video stream. The position of other mobile players obtained from the server is used to update the 2-D virtual map in the HMD view of the player. Similarly the point-of-view of each mobile player is sent to the computer of a helper through the server, and the corresponding view in the virtual Pac-World can be displayed.

As for the Bluetooth device, it is embedded in a physical object (as the sugar jar in Figure 2) which seamlessly correlates to a particular virtual ingredient in the game play. When a player is within range of the Bluetooth object (about a distance of 10 meters), communication takes place between the wearable computer and the Bluetooth device. The wearable computer sends the unique address of the Bluetooth device to the server, upon receiving it, the server will then decide if the player is eligible to collect the virtual ingredient that is associated with the physical Bluetooth object. If the player is not eligible (for example she has already collected the ingredient), she will not be alerted to the object. Otherwise, an alert message will be shown on the player's HMD display.

Most importantly, when the player collects the object in the real world, her action can be seen in real time in the virtual Pac-world. The Bluetooth-embedded object is a direct link between the real world and fantasy world. When Pacman collects the physical sugar object in the real world, it is shown as a sugar collection seamlessly in the corresponding position in the virtual Pac-world. This highlights how the object is directly embedded in both the physical and virtual world. The object (physical sugar can) has a direct link and representation with the virtual Pac-World (virtual sugar can). Thus, this further increases the sense of presence and embodiment of the virtual world in the real world for the players.

The player has to hunt for the Bluetooth embedded object upon receiving the alert message in the surrounding physical area and thus adding elements of fun and adventure to the game play. Once the object is found, she has to physically hold the object in her hands in order to collect the virtual ingredient associated with it. This is achieved by the use of charge transfer sensing on the object that detects the player's touch. We have designed this capacitive sensor using QT161 IC chip from Quantum Research Group [Quantum02]. Once haptic data is collected by the sensor, the Bluetooth device embedded on the object will send an alert message to the wearable computer, which will in turn be relayed to the server. The server performs legitimacy check on the player's action, and then proceeds to updating its database as well as informing the wearable computer.

Figure 2. Bluetooth-Embedded object

Capacitive sensing is also important in another part of the game play where a player devours her enemy by tapping on the shoulder of the latter. When player A taps on the shoulder on player B where the sensor is attached, the sensor is activated. Then the wearable computer on player B sends this information to the server via Wireless LAN communication. The server, after considering the positional and status information of player A and B, will decide if it is legal for player A to devour player B. If the devouring action is legitimate, both wearable computers on player A and B are notified and the databases on the server are updated.

Devouring involves tangible physical touching contact between two players. As close proximity is involved, other forms of human interaction come into play. The act of devouring makes the game more tangible and fun by involving more types of natural physical movement. As in when a Pacman player is the prey, her agility determines the "life-and-death" of her virtual Pacman role. Not only tangibility is brought to play in this fantasy world, but also other human perceptions and instincts. Thus this computer game provides the benefits of natural wide area free bodily movements as part of humanistic interaction between each person.

3. BRIEF SYSTEM DESCRIPTIONS AND GAME PLAY

Human Pacman features a centralized architecture that is made up of four main entities, namely the central server, wearable computers, Sony VAIO laptops, and Bluetooth embedded objects. An overview of the system is shown in Figure 3.

The Wireless LAN serves as a communication highway between the wearable computers, the helper computers (Sony VAIOs laptops), and the server desktop computer. The underlying

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program is built on a client/server model with wearable computers and helper laptops as clients, and the desktop computer as a central server. Physical location and players' status updates are done between the client wearable computers and the server on a frequent and regular basis. The server maintains up-to-the-minute players' information (location, status etc.), and presides over any communication between Bluetooth objects and the wearable computers.

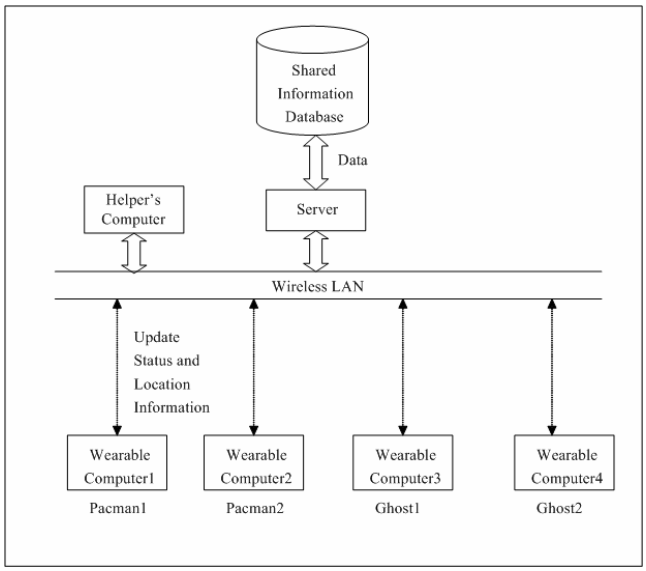

Figure 3. Complete system overview of Human Pacman

Since the wearable computers were designed and developed in the lab, we proceed to discuss its detail configuration as seen in Figure 4. The main components are Transmeta Single Board Computer (PC104 plus compliant motherboard running on Crusoe processor), Twiddler2 (handheld keyboard and mouse), Cy-Visor Head Mounted Display (video see-through HMD) with FireWire camera attached, two Sony F960 InfoLithium batteries, InertiaCube2 (inertia sensor), DRMIII module (GPS and Dead-Reckoning device from Point Research Corporation), and JVC Bluetooth device.

With the software architecture mentioned as the backbone of the game engine and the hardware as enabling tools, we proceed to describe the game play of Human Pacman. The main concepts of the game are first given in terms of team collaboration, ultimate game objectives, and essential nature of the game's playground named Pac-World. Then, we move on to present the details on the players' roles as Pacman, Ghost, and Helper respectively. We end this section by giving examples on several actual game play situations.

3.1 Main concepts: team collaboration, ultimate game objectives and the nature of Pac-World

The players are assigned to two opposing teams, namely the Pacman team and the Ghost team. The former consists of two Pacmen and two Helpers; correspondingly, the latter consists of two Ghosts and two Helpers. Each Pacman/Ghost is in coalition with one Helper, promoting collaboration and interaction between the users. Since a Helper player is essentially participating in the game remotely using a computer terminal over Wireless LAN, Human Pacman can effectively be expanded to include online players anywhere on earth who can view and collaborate via the Internet with real human Pacmen and Ghosts who are immersed in the physical playground.

Figure 4. Detail configuration of wearable computer

Ever since its introduction by Namco to Japanese arcade fans in 1979, Pacman has gone through numerous stages of development yet the ultimate goal of the game remains fundamentally unchanged. We have designed Human Pacman to be in close resemblance to the original Pacman in terms of game objectives so that the players' learning curves are very much leveled to the point that they can pick up the game in no time and enjoy the associated familiarity. Basically the goal of the Pacman team is to collect all virtual plain cookies and hidden ingredients in Pac-World while avoiding the Ghosts. On the other hand, the aim of the Ghost team is to devour all Pacmen in the Pac-World. To add to the excitement of game play, after 'eating' certain special ingredients, a Pacman gains Ghost-devouring capability and henceforth can attack her enemy head on for a limited period of time.

Pac-World is a fantasy world existing dualistically in both Augmented Reality (AR) and Virtual Reality (VR) mode. Pacmen and Ghosts, who are walking around in the real world with their networked wearable computers and head mounted displays (HMD), are allowed to switch between the two viewing mode. Helpers, on the other hand, can only view in VR mode since they are stationed in front of networked computers. Most importantly there is a direct and real time link between the wide-area physical world and the virtual Pac-World at all times, thus providing the users with a ubiquitous and seamless merging of the fantasy digital world and the realistic physical world. As seen in Figure 5 where the 2D map of the selected game play area in our university campus and the 3D map of Pac-World are shown side-by-side, we have converted the real world to a fantasy virtual world while ingrained the latter with direct physical correspondences.

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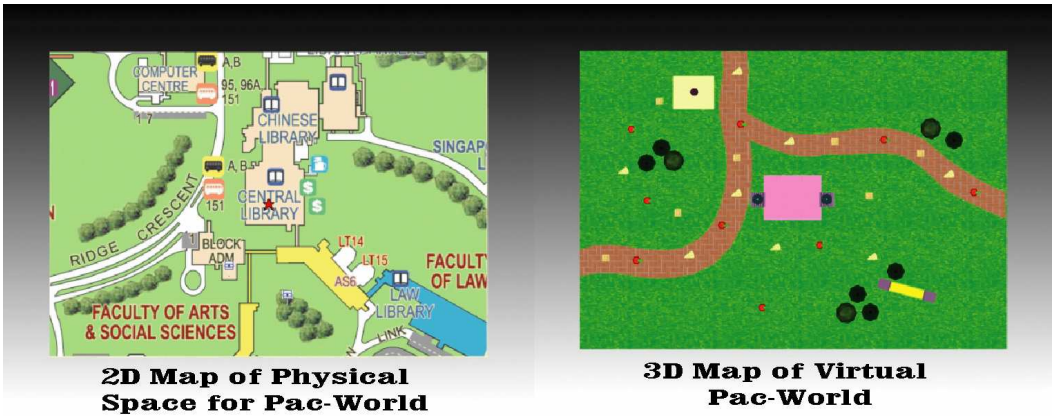

Figure 5. 2D map of game play area and its corresponding 3D map of Pac-world

Figure 6. Correspondence between the physical world and the virtual Pac-world

3.2 Pacman, Ghost, and Helper

Pacman has to physically move around the game area attempting to collect all virtual cookies. When she is in AR mode, through the HMD, she sees the real world being overlaid with virtual plain cookies as shown in Figure 7. In addition to the virtual plain cookies, she has to find and collect physical ingredients that are actually Bluetooth embedded objects (Figure 2). These objects have direct links and representations in the virtual Pac-World. This provides a sense of presence and immersion with the virtual Pac-World, as well as a feeling of actively participating in the game in the real world.

On the other hand, the Pacman should avoid being devoured by Ghost, i.e. not letting Ghost tapping on her shoulder where the capacitive sensor is attached on. This physical touch interaction between the players exemplifies tangible physical interaction between humans, which is commonly found in traditional games such as hide-and-seek and the classic "catching" game, but is now being revived in computer gaming arena.

The role of a Ghost is rather straightforward; she has to track down all Pacmen and devour them. Nevertheless, she has to beware of Pacmen with Ghost-devouring power and avoid being devoured by them.

Helper is a new character in Human Pacman who does not exist in the original Pacman game. Each Pacman and Ghost will be assigned a partner Helper who acts as an intelligence, advisor, and coordinator for her in her quest for achieving her goal. To enhance gaming experience for Pacman and Ghost, the players in the physical world with wearable computer are not able to see enemy mobile units and hidden ingredients when they are in AR mode. Therefore the Helper, who is always in VR mode and sees all, guides her partner by messaging her with important information as shown in Figure 8 and thus this promotes collaboration and interaction between human.

It must be noted that when Pacman or Ghost switches to VR mode, she is completely immersed in virtual Pac-world. However virtual paths are drawn in close correspondent to roads in real world as seen in Figure 6. Despite being physically separated from one another and highly mobile, each player is constantly tracked and her identity as unique entity in Pac-world is maintained in real time.

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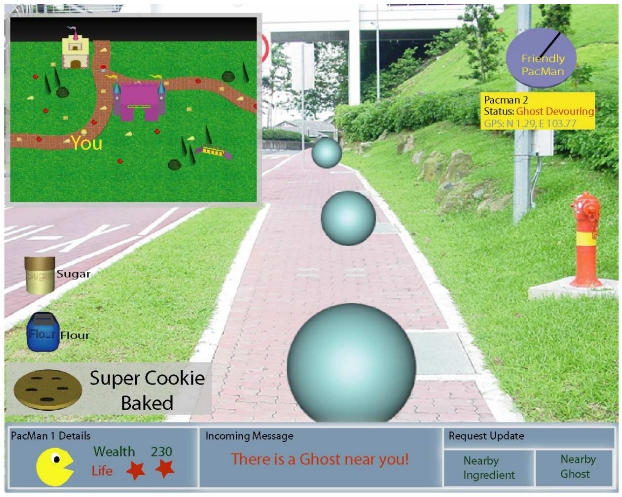

Figure 7. First person view as presented in HMD display of Pacman

Figure 8. Close collaboration between the outdoor Pacman and her Helper

3.3 Actual game play

Starting the game: Pacmen and Ghosts start from the Pac-castle and Ghost-house in Pac-world respectively. These two places correspond to two different physical locations in the game area.

Collection of plain cookies: Pacman collects a cookie by walking through it. Such physical action is reflected visually in Pac-World through the disappearing of the cookie in both the AR and VR mode. The collection of cookies by a Pacman will be reflected in the Pac-World map seen by all players in real time, be it on the player's HMD or the helper's Sony VAIO. In Figure 8, the top images show the HMD view of the Pacman player as she collects a cookie. When she walks through the cookie, the cookie disappears. Note that this is also reflected in the virtual Pac-World in real time by the disappearing of the cookie in the corresponding location. This is shown in the images of the figure on the next page.

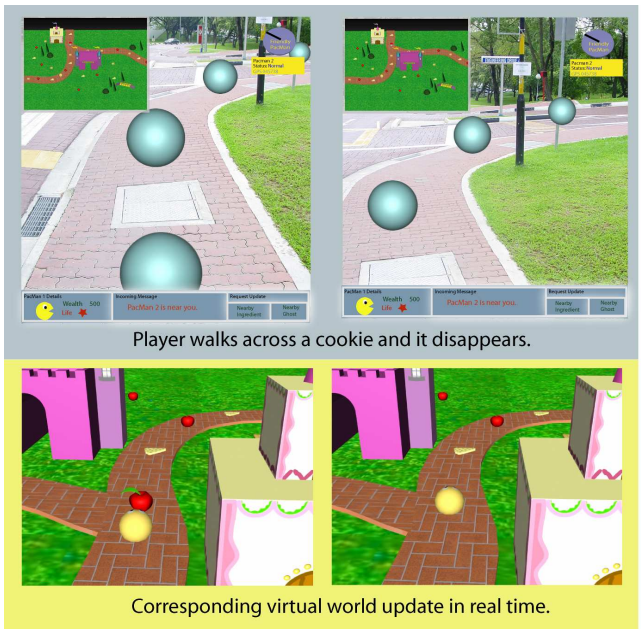

Figure 9: Pacman collecting cookies

Ghosts are not allowed to collect cookies. Although a Ghost is not able to see enemy Pacman on the map, the disappearing of cookies in her map can give her a hint to where to find a Pacman. Therefore a Pacman has to be careful as her physical interaction with the real world (i.e. movement) can be digitally reflected in the virtual world, and be made used of by a Ghost. Novelty is again seen in such intimate relationship between interaction in the physical world and its effect in the fantasy virtual world. Neither physical distance nor mobility could restrict each player from seeing this effect real-time as all players, including the Ghosts can see an update of the virtual map in real-time.

Collection of ingredients: In the game, Pacmen collects ingredients to make special cookies. Ingredients include flour, butter, sugar, and special ingredients (e.g. Chocolate Chip, Almond). There are two types of special cookies; a butter cookie is made up of flour, butter, and sugar; a super cookie is made up of butter cookie and a special ingredient.

When Pacman eats a butter cookie, she achieves 10 seconds immunity from being consumed by a Ghost. When Pacman eats a super cookie, it takes a time lag of 5 seconds before she achieves 10 seconds of ghost-devouring power. (5 seconds is for the Ghost to run or devour the Pacman).

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Figure 10: Sequence of pictures showing the collection of an ingredient

Figure 11: HMD display and the corresponding label under VR mode when Pacman gains power

In the game, real Bluetooth-embedded objects are placed in different parts of the game area. In Figure 10 on the next page, a sequence of pictures shows a Pacman collecting an ingredient. When Pacman is within ten meters range from the object, she will be alerted to its presence visually with an alert message as seen in the figure. However she still has to search for the Bluetooth-embedded object, as it might not be in her line of sight. Having found the object, collection is done simply by physically holding the object in her hands. This exemplifies a natural tangible interaction is involved through physically interacting with this object by human touch. Pacman is able to hold a real object naturally in hand as should be in real-life treasure finding. Such tangible action is provides the player a sense of touch to the fantasy world. The collection of the ingredient will be kept in a virtual inventory list and be immediately reflected in the display as well as having the action occurs in real-time in the virtual world. As seen in the figure, collection is shown as an addition of an icon of a sugar jar to the inventory list after the ingredient has been collected. Pacman need not lug the physical object with her as she has collected the ingredient virtually.

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Collaboration between players: There is an essential element of collaboration in the game play between a Pacman/Ghost with her Helper, and between any allied Pacmen.

(i) Pacman/Ghost and Helper Collaboration - The Helper is in a good position to assist her partner as she has a complete view of Pac-world all the time, including the positions of all players and ingredients. Mobile players can only see the complete Pac-World under the VR mode. However AR mode is more advantageous for mobility because under VR mode, movement is restricted since she does not have a view of the real world. Furthermore as Helpers within the same team are physically close, they are able to collaborate between themselves and work out a strategy to achieve the team's goal. The advantage of this setup is that social interaction and collaboration is significant between Helpers, as well as between Helpers and her partner.

(ii) Pacman and Pacman Collaboration -- Pacman players can collaborate through transferring of ingredient between them, even if they are physically far from each other with the support of Wireless LAN. For example Pacman A can initiates request for the list of unused ingredients Pacman B has. Upon approval, A can request for transfer of ingredient from B, subjected to approval by B. Transfer of ingredient is important as Pacman may not be able to comb the whole game area for ingredients. She may lack some ingredients, which may have been collected by her ally. Strategy could be implemented, with the coordination from the Helpers, to distribute ingredients between the Pacmen. However, Pacman are not allowed to transfer special cookies so as not to disadvantage the Ghosts.

Using special cookies: All special cookies can only be used once. When a Pacman consumes a special cookie, she will see an alert message in her HMD, informing her of the power she acquired. Furthermore, in real-time a label describing her acquired-power will be placed on top of her Pacman avatar in the VR mode. This serves to inform all Helpers, including those from the Ghost-team, of her ability. These are illustrated in Figure 11.

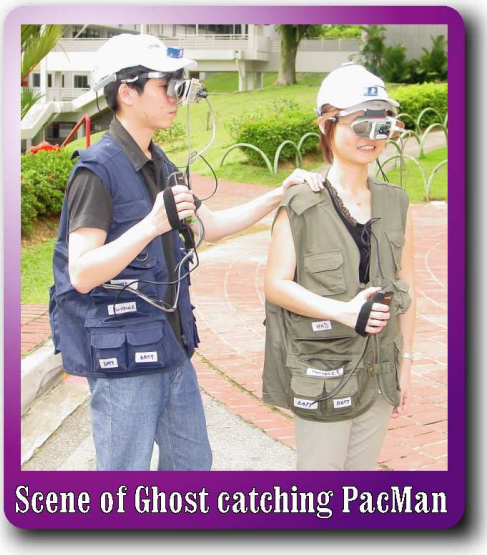

Figure 12: Ghost catching a Pacman

Devouring enemy player: To devour a Pacman, a Ghost must physically touch the Pacman's capacitive sensor pads on her shoulders as shown in Figure 12. The same applies when a Pacman with Ghost-devouring capability devours a Ghost. When a Pacman is devoured, she is loses one life point. Each Pacman is given two life points. The same goes for the Ghost.

Ending the game: The game ends when either team meets their goal or when a time limit of ten minutes has been reached.

4. UBICOMP AND SENSOR TRACKING ISSUES

Ubicomp, also known as "Ubiquitous Computing", is a phrase which late Mark Weiser (1952-1999) described in 1988 as "calm technology that recedes into the background of our lives". Though not strictly making computers available throughout the physical environment but invisible to the user as described by Weiser [Weiser93], Human Pacman envisions applying the same concept of calm technology into computer gaming by experimenting with tangible interfaces and context-awareness entertainment and communication, which are two of the interaction themes in Ubicomp.

4.1 Tangible Interfaces

There are two distinctive manifestations of tangible interfaces in Human Pacman; the first is being implemented in 'Special Ingredient', which is actually a Bluetooth embedded object with capacitive sensor, and the second is the capacitive sensor shoulder pads on the wearable computers for Pacmen and Ghosts. Bluetooth is incorporated into the system where there is already Wireless LAN support for communication because firstly it provides paired communication with security which is essential for one-to-one communication between the 'Ingredient' and the player; secondly Bluetooth devices support automatic device discovery and connection setup when they are within range therefore provide the backbone for reasoning by close physical proximity in the game play. This allows Pacman to search nearby area for 'Ingredient' once being alerted of the presence of Bluetooth embedded device.

Tangible interaction between the Bluetooth embedded object and the player is made possible by using capacitive sensor for detecting the action of touch by the player. In this way, we harness the physical and tactile abilities of Pacmen to support the computational task of registering the discovery and collection of virtual ingredient. Another important aspect of this design is the clever exploitation of the affordances of the object's physical properties whereby without prior training, players can intuitively associate the action of picking up the 'Ingredient' object with the collection of it in their virtual inventory as well as having the action simultaneously occur in the virtual world.

The use of capacitive sensor shoulder pads of wearable computer for the detection of 'Devouring' action in game play, serves the purpose of demonstrating how computation can be used in concert with naturalistic activities, in this case, the action of physically catching the enemy on the shoulder. Also, by making the distinction between "interface" and "action" very much reduced, i.e. physical action of tapping versus a mouse-click for interaction, Human Pacman allows the players to experience transparent interchange between human and computer as never before in computer gaming.

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Table I. Five questions and answers posing human-computer communication challenges for interaction design in the case of Human Pacman.

Basic Question	Human Pacman Interface Answers
Address: How do I address one (or more) of many possible devices?	With the implementation of Ubiquitous Computing, the system constitutes a more amorphous concept with automated interactions between sensors and computer. The existence of unique address for each Bluetooth device disambiguates the Bluetooth embedded objects. Furthermore, centralized control of the server prevents ambiguity of intended target system even when there are more than one players are near the Bluetooth device. Keyboard and mouse are used for messaging and selection of the 'Ingredients' to be exchanged between Pacmen.
Attention: How do I know the system is ready and attending to my actions?	Graphical feedback is used extensively from providing alert message in popped up window, to refreshing virtual inventory after Pacman picked up Bluetooth embedded object. Also, since this graphical information is provided in the HMD directly in the zone of the user's attention, they are highly effective.
Action: How do I effect a meaningful action, control its extent and possibly specify a target or targets for my action?	The Pacman/Ghost click on preset messages to be sent to Helpers. Pacmen click on graphical representation of 'Ingredient' to be exchanged. Clearly labeled Bluetooth embedded objects are to be found in physical space where interaction is intuitive. According to Norman's Theory of Action [Norman90], this form of tangible interface bridges the 'Gulf of Execution'.
Alignment: how do I know the system is doing (has done) the right thing?	Real time graphical feedback presents distinctive and timely graphical elements establishing the context of the system.
Accident: How do I avoid mistakes?	Pacman right-click on virtual ingredient in order to dump the ingredient.

4.2 Context Awareness in Entertainment and Communication

There are three different ways in which the idea of context awareness is being applied to in Human Pacman. Firstly, with the use of GPS and DRM to provide various data required for tracking the players in wide area outdoor environment, location awareness of the system is made possible. Despite being the most widely publicized and applied location-sensing system, GPS suffers from accuracy and selective availability. The problems are compensated through sensorfusion with DRM. In Human Pacman, we are taking advantage of user's mobility in the wide outdoor area to adapt the system's behavior based on her current location. This location context is being made use of throughout the game play for augmented reality (AR) placing of virtual cookies, as well as calculating the relative positions of allied players.

Another important component in realizing AR elements in Human Pacman is the inertia sensor. Through data collected from it, the system is aware of current perspective of the player and thereby displays virtual objects accordingly. Besides, Human Pacman also experiment with information context in Human Computer Interface with the Helper player having information access to other players via Wireless LAN and providing them with necessary and timely information.

4.3 Addressing sensor-tracking issues

In Human Pacman, we tried to combine materials from cognitive psychology and sociology with that from computer science. However the vast amount of issues encountered have exceeded the scope of this paper. Therefore we will concentrate on discussing sensor-tracking issues with respect to Human Computer Interface design. According to Bellotti [Bellotti02], there are five questions posing human-computer communication challenges for interaction design. In Table I, we summarize the sensing approaches to interaction in Human Pacman with respect to the five questions raised.

5. CONCLUSION

In this paper we presented a sensing-based mobile entertainment system that brings computer gaming experience to permeate natural physical world ubiquitously and seamlessly. Context awareness computing is being applied to wide outdoor physical area for realizing mobile gaming and social collaboration elements in Human Pacman. At the same time, tangible interface is being explored with tangible physical objects incorporated into the game play to provide the novel experience of seamless transitions between real and virtual worlds. These objects in the real world are embedded with a real-time link and meaning with objects in the virtual world. Table II summarizes the various novelties about Human Pacman.

The continual propagation of digital communication and entertainment in recent years forces many changes in societal psyche and lifestyle, i.e. how we think, work and play. With physical and mobile gaming gaining popularity, traditional paradigms of entertainment will irrevocably shake from the stale television-set inertia. We believe that Human Pacman heralds the conjuration and growth of a new genre of computer game that is built on mobility, physical actions and the real world as a playground. Reality, in this case, is becoming more exotic than fantasy because of the Mixed Reality element in the game play. On the other hand, emphasis on physical actions might even bring forth the evolvement of professional physical gaming as competitive sport of the future, for example 'PacMan International League'. Element of social gaming in Human PacMan symbolizes the nascence of humanity in future digital entertainment. People are looking forward to widening their circle of friends and colleagues through social collaboration in game play. A new form of interactive entertainment is evolved. Another important area of impact is the field of education. The technology presented in Human PacMan can be exported to applications in educational training that stresses on "learn by experience".

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Students are immersed in real site of action, and are given instructions visually through head mounted display or verbally through speaker/earphone. This technology serves as a powerful instrument of cognition since it can enhance both experimenting and reflective thoughts through mixed reality and interactive experience.

In conclusion, we believe Human PacMan is a pioneer in the new hybrid of physical, social, and mobile gaming that is built on ubiquitous computing and networking technology. The players are able to experience seamless transition between real and virtual world and therefore a higher than ever level of sensory gratification are obtained.

Table II. Novel features of Human Pacman

Novelty	Improvement
Ubiquitous Computing	Everyday objects throughout the environment seamlessly have a real-time fantasy digital world link and meaning. There is automatic communication between Wearable Computers and Bluetooth devices embedded in certain physical objects used in game play.
Tangible Interaction	Throughout the game people interact in a touch and tangible manner. For example, Players need to physically pick up objects and tap on the shoulder of other players to devour them.
Physical Gaming	Players are physically role-playing the characters of Pacmen and Ghost; with Wearable Computers donned, they use wide area free bodily movements as part of interaction between each person, the real and virtual world, and objects in the real and virtual environments.
Social Gaming	Players interact both directly with other players when they are in physical proximity or indirectly via the Wireless LAN network by real time messaging. There is a seamless networked social contact with players in both the real-world and virtual-worlds, as well as throughout their boundaries. People from all around the world can also participate in the Human Pacman experience by viewing and collaborating in real time over the internet with the physical Human Pacmen and Ghosts who are immersed in the physical real world game.
Mobile Gaming	Players are free to move about in the indoor/outdoor space without being constrained to the 2D/3D screen of desktop computers.
Outdoor Wide-Area Gaming Arena	Large outdoor areas can be set up for the game whereby players carry out their respective missions for the role they play. This could even be linked throughout cities.
Seamless Transition between real and virtual worlds	Players swap freely between immersive first person augmented reality view (with virtual cookies and instructions overlay the real world) and full virtual reality view of the Pac-world in the game.

6. REFERENCES

[Acm93] Computer Augmented Environments: Back to the Real World. Communications of the ACM, July 1993, 36, 7.

[Bellotti02] BELLOTTI, V.M.E., BACK, M.J., EDWARDS, W.K., GRINTER, R.E., LOPES, C.V. AND HENDERSON, A., 2002. Making sense of sensing systems: Five questions for designers and researchers. Proc. CHI 2002, 415-422. ACM.

[Björk01] BJÖRK, S., FALK, J., HANSSON, R., AND LJUNGSTRAND, P., 2001. Pirates! – Using the physical world as a game board, Interact 2001, IFIP TC. 13 Conference on Human-Computer Interaction, Tokyo, Japan 2001.

[Björk02] BJÖRK, S., HOLOPAINEN, J., LJUNGSTRAND, P., AND MANDRYK, R., 2002. Special Issue on Ubiquitous Games, Personal and Ubiquitous Computing, 6, 5-6, 358-361.

[Dodsworth98a] CRAWFORD, C., 1998. Live: What a Concept!…Networked Games. Digital Illusion, DODSWORTH, C. JR, Ed. ACM Press, 241-248.

[Bowlby83] BOWLBY, J., 1983. Attachment and Loss, Volume I: Attachment. Basic Books, New York, 1983.

[Fitzmaurice95] FITZMAURICE, G., et al., 1995. Bricks: Laying the Foundations for Graspable User Interfaces, Proceedings of the Conference on Human Factors in Computing Systems (CHI '95), ACM, Denver, May 1995, 442-449.

[IDSA01] Interactive Digital Software Association, State of the Industry – Report 2000-2001, [online document] 2001, Available at http://www.idsa.com

[IDSA02] Interactive Digital Software Association, Essential Facts About the Computer and Video Game Industry, [online document] 2002, Available at http://www.idsa.com

[InterSense01] InterSense Inc, Inertia Cube2 Bringing 3D To Life – Manual for Serial Port Model, 2001.

[Ishii97] ISHII, H., AND ULLMER, B., 1997. Tangible Bits: Towards Seamless Interfaces between People, Bits, and Atoms. Proceedings of the Conference on Human Factors in Computing Systems (CHI '97), March 22-27, 1997.

[Konami01] Konami Corporation, ParaParaParadise, [online document] 2001. Available at http://www.konami.com.hk/am/ppp.html

[Long96] LONG, S., et al. 1996. Rapid Prototyping of Mobile Context-aware Applications: The Cyberguide Case Study. 2nd ACM International Conference on Mobile Computing and Networking (MobiCom'96) 1996 November 10-12, 1996.

[Mandryk 01] MANDRYK, R.L., INKPEN, K.M., 2001. Supporting free play in ubiquitous computer games, Workshop on Designing Ubiquitous Computer Games, UbiComp 2001, Atlanta, GA 2001.

[Nezlek02] NEZLEK, J.B., RICHARDSON, D.R., GREEN, L.R., AND SCHATTEN-JONES, E., 2002. Psychological well-being and day-to-day social interaction among older adults, Personal Relationships, 9, 57-71.

[Norman90] NORMAN, D.A., 1990. The Design of Everyday Things. Doubleday: New York, New York.

[Pascoe98] PASCOE, J., RYAN, N.S., MORSE, D.R. 1998. Human Computer Giraffe Interaction - HCI in the Field. Workshop on Human Computer Interaction with Mobile Devices.

<http://www.dcs.gla.ac.uk/~johnson/papers/mobile/HCIMD1.html>

[Pascoe99] PASCOE, J., RYAN, N.S., AND MORSE, D.R. 1999. Issues in Developing Context-Aware Computing. Proceedings of the International Symposium on Handheld and Ubiquitous Computing, Karlsruhe, Germany, September 1999, Springer-Verlag, 208-221.

[Pointgrey02] Point Grey Research Corporation, http://www.ptgrey.com

[Quantum02] Quantum Research Group Ltd, [online document] 2002, Available at http://www.qprox.com.

[Ryan97] RYAN, N., PASCOE, J., MORSE, D. 1997. Enhanced Reality Fieldwork: the Context-Aware Archaeological Assistant. V., GAFFNEY, M., VAN LEUSEN, S., EXXON, Eds. Computer Applications in Archaeology. <http://www.cs.ukc.ac.uk/pubs/1998/616/content.html>

[Schilit93] SCHILIT, B.N., THEIMER, M.M., AND WELCH, B.B. 1993. Customizing mobile applications. In Proceedings of USENIX Mobile & Location-Independent Computing Symposium, Cambridge, Massachusetts, August 1993. USENIX Association, 129-138.

[Smith95] SMITH, C.G., 1995. The Hand That Rocks the Cradle. I.D., May/June 1995, 60-65.

[Thomas02] THOMAS, B., CLOSE, B., DONOGHUE, J., SQUIRES, J., BONDI, P.D., AND PIEKARSKI, W., 2002. First Person Indoor/Outdoor Augmented Reality Application: ARQuake, Personal and Ubiquitous Computing, 6, 1, 75-86.

[Want92] WANT, R., HOPPER, A., FALCÃO, V., AND GIBBONS, J. 1992. The Active Badge location system. ACM Transactions on Information Systems, 10(1):91-102, January 1992.

[Weiser93] WEISER, M., 1993. Some computer science issues in ubiquitous computing, Communications of ACM, 36, 7: Special issue on computer augmented environments: back to the real world.

[Yang99] YANG, J., YANG, W., DENECKE, M., AND WAIBEL, A. 1999. Smart sight: a tourist assistant system. 3rd International Symposium on Wearable Computers, San Francisco, California, 18-19 October, 1999, 73-78.

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