Chapter 2
Human Pacman: A Mobile Augmented Reality Entertainment System Based on Physical, Social, and Ubiquitous Computing

2.1 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 suggest that users are gradually freed from the constraints of stationary desktop computing with the explosive expansion in mobile computing and networking infrastructure. 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. The novelty of this computer game has the following aspects: Firstly, the players physically and immersively role-play the characters of the Pacmen and Ghost, as if a fantasy computer digital world has merged with the real physical world. Secondly, users can move about freely in the real world over wide area indoor and outdoor spaces whilst maintaining seamless networked social contact with human players in both the real and virtual world. Thirdly, Human Pacman also explores novel tangible aspects of human physical movement and perception, both on the player's environment and on the interaction with the digital world. In other words, objects in the real world are embedded and take on a real-time link and meaning with objects in the virtual world. For example, to devour the virtual "enemy", the player has to tap on the real physical enemy's shoulder; to obtain a virtual "magic" ingredient, the player has to physically pick up a real physical sugar jar with an embedded Bluetooth device attached.

In this system, players are provided with custom-built wearable computers, and they interact both face-to-face with other players when in proximity or indirectly via a wireless LAN network. Also fully utilizing the high computing power of wearable computers and the underlying network support, Human Pacman takes mobile gaming to a new level of sophistication by incorporating virtual fantasy and imaginative play activity elements that have made computer game popular [21] with the implementation of Mixed Reality on the Head Mounted Displays (HMD). The players also experience seamless transitions between real and virtual worlds as they swap between immersive first person augmented reality view (with virtual cookies in the real world) and full virtual reality view of the Pac-world throughout the game.

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Another important feature of Human Pacman is its inherent support of networked mobile gaming. Mobile gaming is already a big business in Japan and South Korea where up to 70% of users on some networks regularly use the service [7]. According to Forrester Research [31] of the US, within three years 45% of European mobile subscribers will regularly play games on their mobile phones. London-based Ovum [14] forecasts that global spending on mobile games will reach €4.4 billion by 2006. Well-known mobile entertainment success stories in Japan include NTT DoCoMo's IMode. Games that it carries, such as Sega's Space Harrier and ChuChu Rocket, will bring in nearly US $830 million this year (Source: Datamonitor). As will be shown below, Human Pacman takes mobile entertainment to a new level of interactivity through its emphasis on seamlessly merging the physical real world with the virtual world, maintaining networked social contacts through out and across the real and virtual world boundaries, and emphasizing physical and tangible contacts with the digital world.

Björk suggested ubiquitous games as a new form of gaming [4]. A ubiquitous game is a game that explores the use of ubiquitous computing (ubicomp) [36] as defined by Weiser. He painted a picture where computers would be embedded in everyday object, and computing is invisible because there is "intelligent" communication between the objects. Employing this philosophy, we have implemented a system that embeds everyday physical objects, which seamlessly take on a digital fantasy meaning, throughout the wide area real-world environment. For example, we have attached Bluetooth devices to sugar jars which when being picked up, will automatically communicate with the wearable computer by adding the corresponding virtual ingredient to the inventory list of the player.

Human Pacman ventures to elevate the sense of thrill and suspended disbelief of the players in this untypical computer game. Each of the novel interactions mentioned is summarized in Table 2.1. We will proceed with details to Human Pacman by firstly giving a research background to this system and previous works that have motivated us. Then we proceed to detail gaming experiences involved by clarifying the actual game play designed. We venture to explore the intricate issues of interaction versus experience in mobile mixed reality gaming that arise between physical mobile players together with virtual online players in this game. We study and elaborate on the impacts of mixed reality gaming on users' experience arising from a unique combination of physical, virtual and social interactions. We also demonstrate how this novel form interactions provide entertaining and fulfilling sensations and present our user study results to support our arguments. After that we will discuss the various mobile service issues with respect to the system; as well as analyze the system in the context of addressing various ubicomp concerns. Lastly, we conclude with our reflections on the future impacts of the system on everyday life.

2.2 Background

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

Table 2.1 Detailed feature descriptions of Human Pacman

Feature	Details
Physical gaming	Players are physically role-playing the characters of Pacmen and Ghost; with Wearable Computers donned, they use free bodily movements as part of interaction between each person, between the real and virtual world, and among objects in the real wide area landscapes 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 perfectly coherent networked social contact among players in both the real 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
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
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 the immersive first person augmented reality view (with virtual cookies and instructions overlay the real world) and the full virtual reality view of the Pac-world in the game

in which they are full involved [39]. In fact, not only do they want such entertainment; people want to enjoy it together with family and friends. As shown in a survey [11], 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 [11]. 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 [9]. According to a recent study by Nezlek [22], enjoyable and responsive interactions increase life satisfaction scores among people. Nevertheless, even in networked computer games, social interaction between players is limited since natural interactions such as behavioral engagement, and cognitive states are lost. Thus, by bringing players in physical proximity for interaction, Human Pacman brings networked social computer gaming to a new ground because humans enjoy being physically together, and socially interacting with each other [5]. Essen-

tially, Human Pacman brings the exciting interactive aspects of networked gaming, and merges it with the real physical world, to allow a seamless real-time networked social contact between humans in both the real and virtual worlds simultaneously.

Human Pacman has also aspects derived from pioneering work that has been developed on ubiquitous gaming. Multi-players mobile gaming is demonstrated in 'Pirates!' [3]. '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 2D display used on PDAs. The E3 project [18] 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.

Human Pacman has its roots in serious research about people's interaction with their world. People as social creatures find physical interaction, touch, and human-to-human presence essential for the enjoyment of life [5]. We remember that 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 [16] are based on players dancing in time with a musical dance tune and moving graphical objects (see Fig. 2.1). However, these systems still force the person to stand at more or less the same spot, and focus on a computer screen in front of them. Nevertheless, our underpinning philosophy is similar. One of the goals for Human Pacman is to bring physical gaming into computer entertainment.

Even though Human Pacman uses augmented reality techniques as part of its interface, it is only for providing a comprehensive user interface for the players. There were some previous works done on using augmented reality in entertainment. AR2 Hockey [24] is a system that allows two users to hit a virtual puck on a real table, as seen through a HMD. AquaGaunlet [33] is a multi-player game where players fight with strange invaders coming from the virtual world through some egg-shape objects into the physical space. These games are played in a small and restricted area, with limited movement, and little interaction with physical space. The games have no transitions between AR and VR. There is also no exploration on the physical environment the player is in. Another important mobile game is known as ARQuake [34], which is an AR extension of the popular computer game Quake. Using Wearable Computer equipped with global positioning system, ARQuake can be played indoor and outdoor. However, it is a single player game with practically no social interaction.

Fig. 2.1 A player at the ParaParaParadise arcade game

Lastly, the transitions between the real and physical world in Human Pacman are derived from research that has been done on continual transversal along the Reality–Virtuality continuum [19]. The Magic Book [2] uses a book metaphor to demonstrate the seamless transitions between augmented and virtual reality. Collaboration is carried out only in a small-scale and closed-up configuration. Touch-Space [6] is an embodied computing based mixed reality game space with free movement between the real world and virtual world. Players are tracked with inertial-acoustic hybrid tracking devices mounted on the ceiling. However, since they are restricted to a small indoor area, there is limited physical movement in game play. In Human Pacman, the interface and transition between the real world and virtual world is achieved in real time throughout the spacious indoor and outdoor physical world.

2.3 System Design and Game Play

Human Pacman features a centralized architecture that is made up of four main entities, namely the central server, wearable computers, laptops, and Bluetooth embedded objects. An overview of the system is shown in Fig. 2.2.

The wireless LAN serves as a communication highway between the wearable computers, the helper computers (laptops), and the server desktop computer. The underlying program is built on a client–server architecture 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-

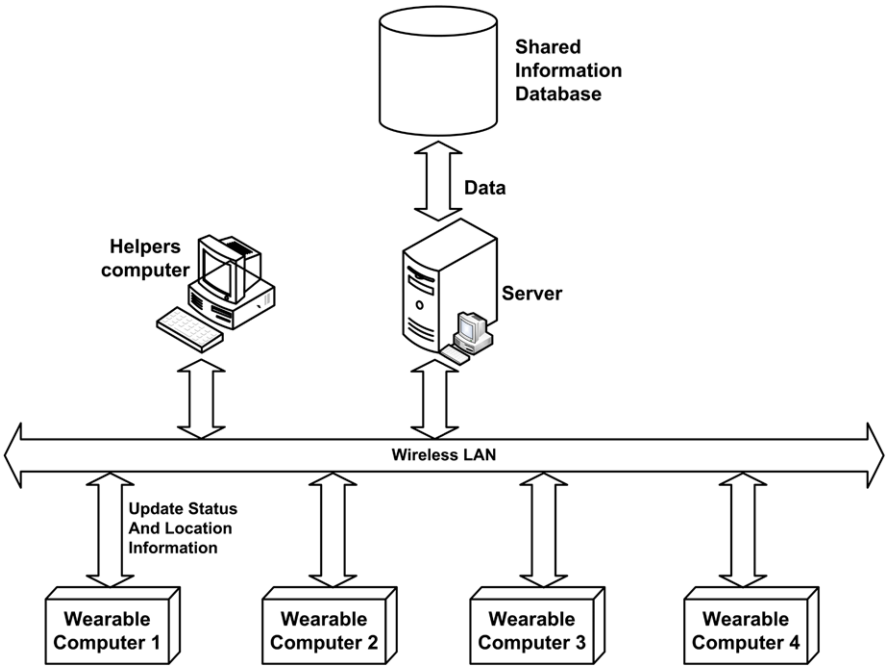


Fig. 2.2 Top level system design overview of Human Pacman

minute players' information (location, status, etc.), and presides over any communication between Bluetooth objects and the wearable computers. The wearable computers were developed in the lab and the main components are a Single Board Computer, Twiddler2 (handheld keyboard and mouse), Cy-Visor Head Mounted Display (video see-through HMD) with FireWire camera attached, InertiaCube2 (inertia sensor from Intersense), and DRM-III module (GPS and Dead-Reckoning device from Point Research Corporation).

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.

2.3.1 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,

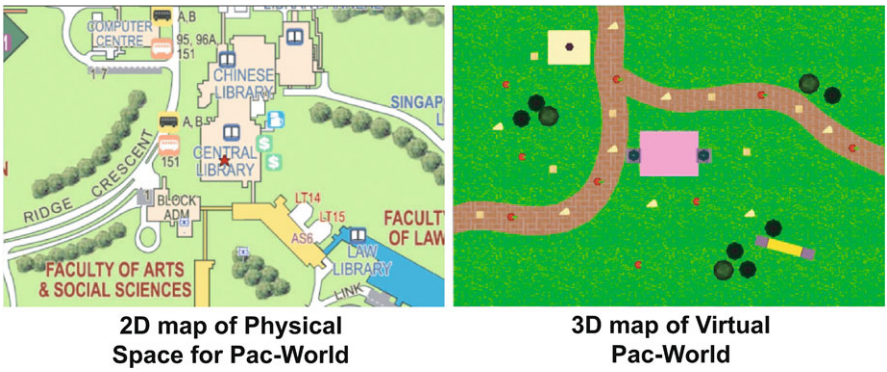


Fig. 2.3 2D map of game area and its corresponding 3D map of Pac-world

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 gameplay remotely using a computer terminal over a 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.

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 modes. 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 Fig. 2.3 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 playground by in-

graining the latter with direct physical correspondences. This is done with the help of the Dead Reckoning Module (DRM) and inertia sensors.

The DRM is an electronic module comprising a 12-channel Global Positioning System (GPS) receiver, digital compass, pedometer, and altimeter. 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.

InertiaCube2 is used for head tracking for the implementation of augmented reality display in the HMD. 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. 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 3D 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 2D 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.

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 with 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:

$$d = \cos^{-1}\{\sin(lat1)\sin(lat2) + \cos(lat1)\cos(lat2)\cos(lon1 - lon2)\}, \quad (2.1)$$

where $lon1$, $lat1$, $lon2$ and $lat2$ are the longitude and latitude of $user1$ and $user2$, respectively, which all are in radians. To compute the distance in kilometers instead of radians, d is multiplied by the radius of the Earth, which is estimated at 6,371.0 km.

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

IF $\sin(lon2 - lon1) < 0$

$$c12 = \cos^{-1}\left\{\frac{\sin(lat2) - \sin(lat1)\cos(d)}{\sin(d)\cos(lat1)}\right\} \quad (2.2)$$

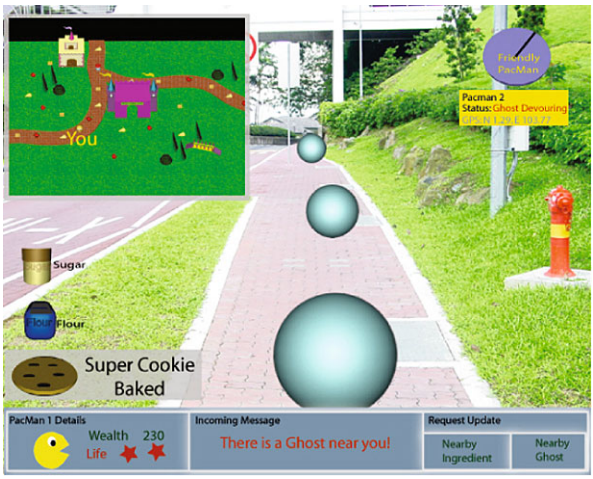


Fig. 2.4 First person view of Pacman

ELSE

$$c12 = 2\pi - \cos^{-1}\left\{\frac{\sin(lat2) - \sin(lat1)\cos(d)}{\sin(d)\cos(lat1)}\right\}. \tag{2.3}$$

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 $c12$.

2.3.2 Pacman and Ghost

Human Pacman offers physical interactions with themes found not dissimilar in sports and childhood games such as rugby and hide-and-seek. The element of physicality is emphasized to explore a new experience in mixed reality gaming played in the city streets.

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 Fig. 2.4. Unlike in PacManhattan [25] where the physical players could only envision the imaginary cookies in their mind, physical players in Human Pacman can view the cookie from the first person point of view. Despite the virtuality of the cookies, the body action of moving through them in order to obtain the cookie provides a realistic sensation of physical–virtual interaction. This is further enhanced by the audible "chomp" sound that would alert the player to signify successful collection.

In addition to the virtual plain cookies, she has to find and collect physical ingredients that are actually Bluetooth embedded objects as shown in Fig. 2.5. Unlike in Mogi [20], where players will be moving in an outdoor area and pick up virtual

Fig. 2.5 Bluetooth embedded object

items through their mobile phone interface (by pressing buttons), the Human Pacman not only has to find the real Special Cookie, but also to hold the box physically in order to gain the Super Pacman skill. 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, 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 a computer gaming arena. Similarly, Pacman gets to do the same after becoming Super Pacman. Hence, Human Pacman demands more physical involvement from both parties, resulting in a more exciting and engaging game play.

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.

It must be noted that when Pacman or Ghost switches to VR mode, she is completely immersed in the virtual Pac-world. However, virtual paths are drawn in close correspondence to roads in the real world as seen in Fig. 2.6. 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.

Searching is yet another important activity for both players; be it Ghost searching for Pacman, or the other way round when Pacman has become Super Pacman. Since players are facing the real opponents instead of computer artificial intelligence created ones, the hunted real players will be definitely seeking smarter ways to evade and hide in ways that would not be required with present console or PC based computer games. On top of that, Pacman needs to search for cookies and hidden special cookies as well. The physical process of searching consequently demands coordination between players' movements, observations and reactions to the immediate environment. For instance, an observant Ghost could even trail the physical path of the Pacman in the real world through the disappeared cookies that were seen earlier. Players are thus constantly being challenged

Fig. 2.6 Correspondence between the physical world and virtual Pac-world

to inquire further into the actual physical neighborhood area within finite period of time.

The physical interaction, however, does have its limitations and shortcomings in the context of providing a fulfilling and entertaining experience for players. In examining physical interactions in Human Pacman, we have merely focused on users using their body movements to stay engaged in the game. While contact in terms of competition exists between both parties, collaborations is lacking. As the law of physics binds every player to the ground, collaborations between members of same team could prove to be too difficult when they are physically far apart.

Of course, we can seek ways to enhance the cooperation between the physical players, for instance, using voice for long distance communication through a walkie-talkie or mobile phone. However, it would be more interesting if we could bring in another kind of player who is not being restricted by the physical world limitations to participate in the game. The new interaction between the original physical players and this new type of players should be refreshing and could spark off more interactive innovations. In the light of this, we introduce a new virtual team member – the Helper – as a new genre of player which we will elaborate further in the next section.

2.3.3 Helper

Helper is a new character in Human Pacman who does not exist in the original Pacman game. This new role is created to enhance the game by contributing an alternate means of hybrid interaction between the real and virtual players. In this context, being a virtual player implies that the participation of the Helper does not take into account of her physical presence relative to the actual location of Pacman

Fig. 2.7 Close collaboration between Pacman and her Helper

and Ghost. She could connect to the game server from almost anywhere in the world through the Internet. Each Pacman and Ghost will be assigned a partner Helper who acts as an intelligence advisor and coordinator in her quest for achieving the goal. Helper, who is always in the VR mode and sees all, guides her partner by messaging her with important information as shown in Fig. 2.7, and thus this promotes collaboration and interaction between humans.

We have integrated the elements of situated actions into the role of Helper. For instance, one of the exciting virtual interaction features is the ability of Helper to watch the game in a unique way. A football game or a TV show normally can only allow viewers to accept passively whatever is shown. However, here we allow Helper to view the game "live" in virtual reality form anywhere through the Internet from any angle and distance. Every movement in the physical world will be reflected immediately in the virtual realm. Even when Pacman becomes Super Pacman, Helper would see a corresponding change in the 3D graphic model. This mode of virtual viewing (watching the real live event in alternate graphical form) provides a new dimension of watching experience for participants, which is both efficient and entertaining.

Helpers, however, are not restricted to watching the game passively. They can actually communicate with Pacman or Ghost in real time via text messaging bi-directionally. While Helpers use computer keyboard for text-inputting, Pacman and Ghost communicate and respond to their Helpers in the chat by using the Twiddler, a handheld inputting device. The communication that takes place could be either a casual chat or a discussion on the winning strategy. Such interactions could promote social cooperation and establish relationships between humans who are operating across radically different contexts.

From the viewpoint of Helpers, while communicating and watching the Pacman/Ghost avatar move around, they should realize that it is different from other common online games; both Pacman and Ghost are actually bodily moving somewhere in the physical world, and are not just any other players who sit in front of the computer screen like them. Every piece of information they can provide matters as it can consequently affect the physical player's next movement in the actual location which Helpers can see virtually. Also Helper cannot ask physically impossible movements, for example, to move from one street to another in too short a time.

From another perspective, with the assistance of Helper, Pacman/Ghost will be having a guardian watching over her, even though the identities or whereabouts of Helpers might be unknown. It would be as if they possess an extra pair of eyes roaming in the sky (like a bird) aiding and advising them. For an outdoor wide area game such as Human Pacman, a human's assistance would definitely prove to be more useful than some raw numbers to pinpoint the player to her current coordinates.

As the complexity of the game in terms of area space or number of Pacman/Ghost players is increased, we foresee social interaction among players should be even more active and necessary. The role of Helper is more critical in these cases, in order to support the players by providing even more knowledge on the current states and brainstorming for the next move or strategies with limited resources available.

To a great extent, the existence of Helpers for both teams resulted in a powerful synergy of interaction between real and virtual domains in the social context of mixed reality gaming. Collaboration within each team becomes more effective despite being bridged by only text messages. Winning or losing largely becomes a function of teamwork, and this adds a greater thrill and fun factor to the game as a whole. In short, the introduction of the role of Helper certainly enriches the interaction theme of Human Pacman.

Figure 2.8 shows the overall picture for the different forms interactions that we have discussed so far. In the figure, Pacman is assisted by her Helper, who is sitting in front of a screen. The screen is displaying the virtual Pac-world, which is in direct real time correspondence to the real world. Similarly, Ghost is also assisted by a different Helper. As both Helpers are able to see positions of Pacman, Ghost, virtual cookies and Bluetooth cookies in the Pac-world, they can guide Pacman or Ghost by using text-based messaging to achieve their ultimate goal of winning the game.

2.3.4 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.

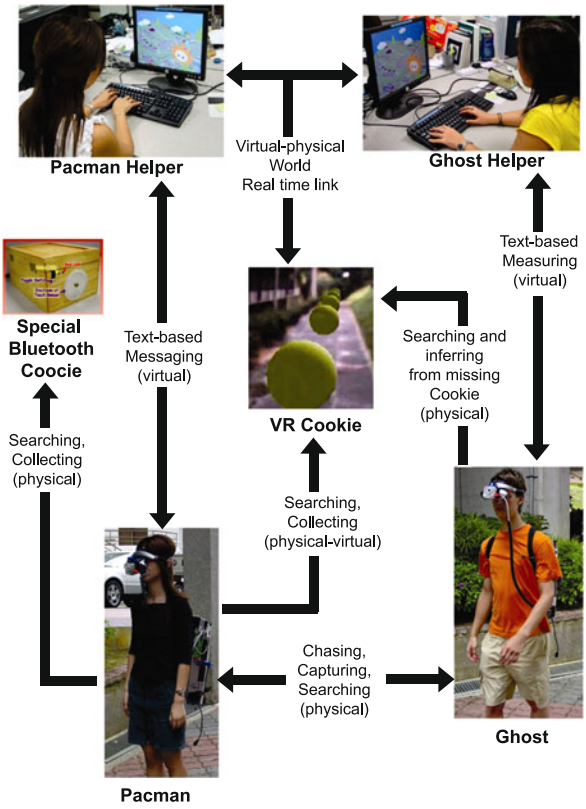


Fig. 2.8 Overall game flow in Human Pacman

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 modes. 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 laptop. In Fig. 2.9, 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 at the corresponding location. This is shown in the images of the figure.

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, 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 used 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

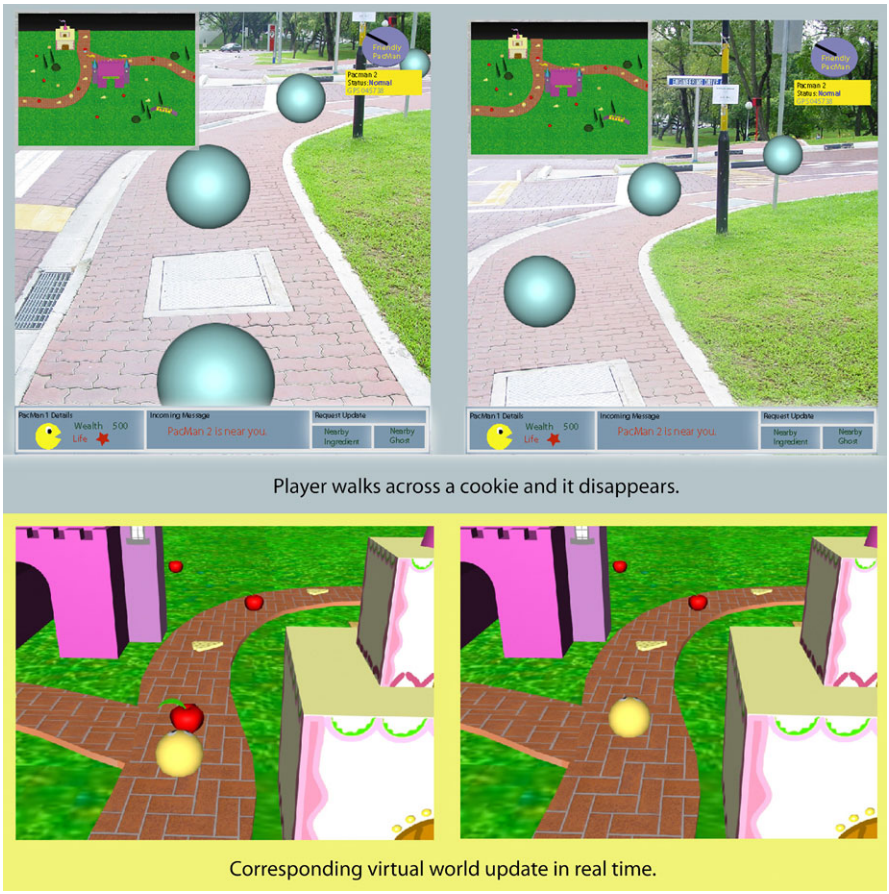


Fig. 2.9 Pacman collecting cookies

effect real-time as all players, including Ghosts can see an update of the virtual map in real-time.

Collection of Ingredients In the game, Pacmen collect 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 1 minute immunity from being consumed by a Ghost. When Pacman eats a super cookie, it takes a time lag of 30 seconds before she achieves 3 minutes of ghost-devouring power (30 seconds is for the Ghost to run or devour the Pacman).

Fig. 2.10 Sequence of pictures showing the collection of an ingredient

In the game, real Bluetooth-embedded objects are placed in different parts of the game area. In Fig. 2.10, a sequence of pictures shows a Pacman collecting an ingredient. When the Pacman 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.

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. Having found the object, collection is done simply by physically holding the object in her hands. 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 [28]. 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. The collection of ingredient exemplifies a natural tangible interaction that is involved through physically interacting with this object by human touch. Pacman is able to

hold a real object naturally in hand as it should be in real-life treasure finding. Such a tangible action provides the player a sense of touch to the fantasy domain of gameplay. The collection of the ingredient will be kept in a virtual inventory list and be immediately reflected in the display; moreover, 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.

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 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, the 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 their partners.

(ii) Pacman/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 initiate a request for the list of unused ingredients Pacman B has. Upon approval, A can request a transfer of an ingredient from B, subject to approval by B. Transfer of an 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 Helpers, to distribute ingredients between Pacmen. However, Pacmen are not allowed to transfer special cookies so as not to disadvantage the Ghosts.

Use of Special Cookie All special cookies can only be used once. When a Pacman consumes a special cookie, she will see an alert message on 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. This is illustrated in Fig. 2.11.

Devouring Enemy Player To devour a Pacman, a Ghost must physically touch the Pacman's capacitive sensor pads on her shoulders as shown in Fig. 2.12. The

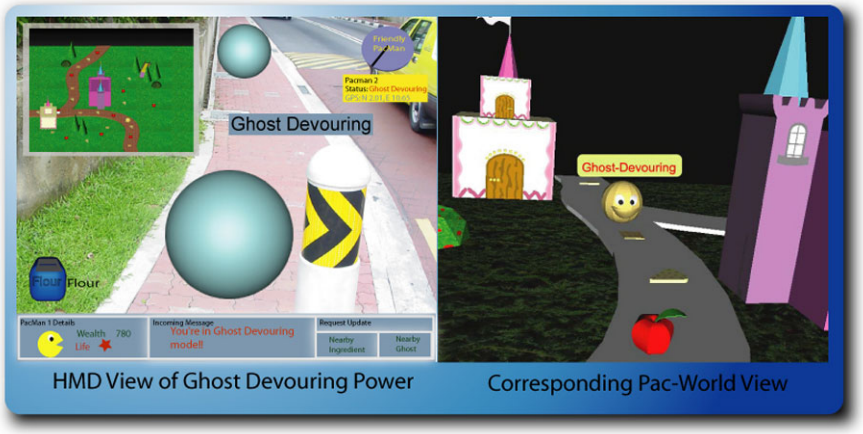


Fig. 2.11 HMD display and the corresponding VR mode view

same applies when a Pacman with Ghost-devouring capability devours a Ghost. When a Pacman is devoured, she loses one life point. Each Pacman is given two life points. The same applies to Ghosts. 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.

Ending the Game The game ends when either team meets its goal or when a time limit of 15 minutes has been reached.

2.4 User Study

To gain useful feedback from the end user, we conducted an experimental user-study survey on the Human Pacman system. Our aim was to find out from actual users their experience of the positive and negative aspects, interaction, and level of enjoyment in using the Human Pacman system. In these tests, the focus was placed on the different novel experiences offered by the game. Our study involved 23 subjects between the age of 21 and 33, of which eight were females and 15 were males. Amongst these people, 39% indicated their level of expertise in computers as advanced, 43% as intermediate, and the rest as beginner.

The experiment setup consisted of four parts. First, the subject was asked to play traditional arcade Pacman game on a desktop computer for five minutes. Then

Fig. 2.12 Ghost catching a Pacman

a three minute Human Pacman video was shown to give him or her a better understanding of the game. This was followed by a 15 minutes trial where the subject tried the roles of Pacman, Ghost and Pacman's Helper for 5 minutes each, along with other subjects taking a different role. An expert user acted as the Ghost's Helper. Finally, the subject had to fill up a questionnaire and to provide comments on the system.

2.4.1 Questions and Aims

Table 2.2 (focussed on the role of real world players of Pacman and Ghost) and Table 2.3 (focussed on the role of Helper) show the list of questions that were asked in the survey. Following each question is the reason for asking this question in the user study.

Figures 2.13 and 2.14 give the user study results of all the multiple-choice questions. The options for each question and the percentage of users who chose each option are given in the figures.

2.4.2 Discussion

In this section, the response to the questions will be discussed. All the data had been analyzed using statistical methods.

Table 2.2 Questions of user study focussing on the real world play role of Pacman and Ghost

Question	Reason for asking
(i) How do you rank Human Pacman as compared with the normal Pacman game in terms of entertainment value? Please rate between 1 (normal Pacman more entertaining) to 7 (Human Pacman more entertaining)	As the idea of Human Pacman originates from the previous arcade Pacman, the fundamental concepts of game play are similar. The question aims to find out if any value has been added to the old Pacman game in the new system
(ii) How comfortable do you feel when using the Human Pacman system?	The wearable computer system is still rather bulky and heavy compared to mobile devices such as phones, Game Boys, and PDAs. We want to find out if and how much it affects the level of comfort of the user when the user dons it
(iii) How intuitive do you think it is to collect cookies by physically walking through them?	In everyday life, collection of an item is seldom, if ever, made by walking through it. We seek to understand if the user finds it intuitive to collect virtual cookies by walking through them just as is done in the original Pacman game
(iv) Please rate, from 1 (lowest) to 7 (highest), the level of excitement of playing as a Pacman in Pac-world (first person experience), in comparison with the arcade Pacman that you can play using a joystick/keyboard (third person experience)?	We want to find out if the immersive experience of Human Pacman makes the game more exciting. Arcade Pacman is used as the baseline for comparison as it is fundamentally similar in game-play
(v) What do you think of displaying "cookies" as virtual objects augmented inside the real world?	From this question, we want to find out how realistic the experience of collecting virtual cookies using AR is
(vi) Does the physical collection of real objects (special cookies) enhance the gaming experiences?	The collection of special cookies is a tangible interaction with a physical object that translates into a digital meaning (i.e., update of Pacman's inventory list). We want to find out if such graspable interaction enhances the game for the user
(vii) What do you think of the "capturing" event implemented in our system (touching the Pacman by Ghost)?	The "capturing" event is a reflection of the naturalistic and physical approach Human Pacman took towards tangible interaction. We seek to find out if the user enjoyed this feature
(viii) Do you like to play the Human Pacman game?	Having reflected on the game by answering the previous questions, the user is quizzed on the overall level of interest she has on Human Pacman

Table 2.2 (continued)

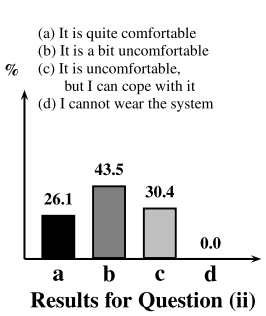
Question	Reason for asking
(ix) Please rate, from 1 (lowest) to 7 (highest), the feeling of "social interaction" in being a Ghost, Pacman, or Helper	We want to find out the level of social interaction experienced by the user in each role
(x) How do you compare this game with other computer games?	As Human Pacman aims to extend and differ itself from conventional human–computer interface used in normal computer games, this question investigates how well Human Pacman achieved its aim
(xi) How do you compare Human Pacman with the traditional "Catch Me" game?	The question looks at how Human Pacman compares with simple, non-computer based games. Traditional "Catch Me" game is used as a basis for comparison due to its similarity with the "capturing" event in Human Pacman. We want to see if adding the fantasy element has any benefit in the user's enjoyment over a normal catch game
(xii) If there is such a game in an amusement park, how much are you willing to pay to play the game?	Currently acquiring the whole Human Pacman system requires high overhead. So a commercially viable version of the system could only be sustained based on a pay-per-use basis, which is a norm in amusement parks. The question investigates the amount of revenue per person the system could bring in if implemented commercially. The question is asked to see if there is a link between such research systems and potential commercial use
(xiii) How often do you play computer games?	The question finds out how frequently the user plays computer games. This enables us to find out if her love for conventional computer games would influence her desire to play Human Pacman
(xiv) Please give us some comments on how we can improve the system and what the current drawbacks of the system are	We seek user's comments on our system to further improve the system in areas we may have neglected

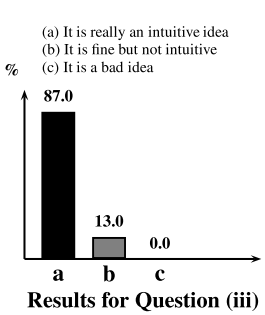
First, we will discuss the set of results from the questions in Table 2.2 focussed on the real world players. Questions (i), (viii), (x), and (xi) examine how well Human Pacman is received by users; and how it compares with respect to other types of game in terms of user preference. As seen from the respective findings given in Fig. 2.13, most of the users are enthusiastic about Human Pacman. However, it is noted that, when compared with the traditional "Catch Me" game, 34.8% of the users gave a neutral stand in their preference. Results from (i) give an average rating of 5.85 (and a variance of 1.46) indicating that Human Pacman is much more favored than normal Pacman in terms of entertainment value. Statistical analysis with the T-test confirms the significance of our inference ($p = 6.72 \times 10^{-7}$).

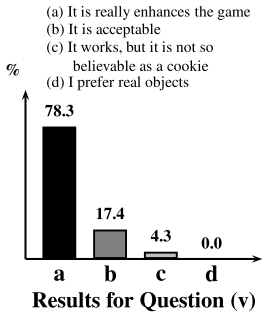
The element of physicality may have been the pushing factor for the preference shown towards Human Pacman over arcade Pacman and conventional computer games. However, this is not so much of a benefit over the traditional "Catch Me"

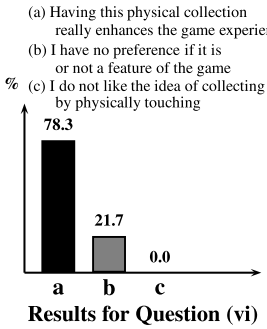
Table 2.3 Questions in the user study focussing on the role of Helper

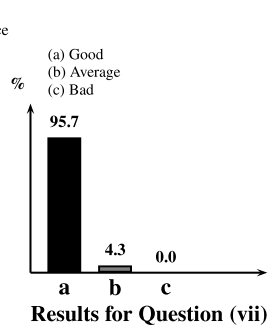
Questions	Reason for asking
(i) Does the VR mode give you a good idea about the game environment?	It is important for Helper to understand the situation her partner is in so as to dispense the appropriate advice. The ability to comprehend the game environment from the VR mode "Gods-view" is essential in helping her access the situation. Thus we wanted to see if this is confirmed in the user's opinion
(ii) Do you think Helper increases the chances of winning?	Helper is an additional feature to the original game. It is introduced to breach the geographical barrier in mixed reality gaming. However, we do not want to add this feature just for this sole purpose. We would like to find out if this enhancement to the game is useful
(iii) Does Helper make the game more enjoyable for Pacman/Ghost?	Helper is supposed to be an enhancement to the original game. Thus, if this new role does not make the game more enjoyable to the original players, there may be a need to reconsider the inclusion of Helper
(iv) How boring/exciting is the game for Helpers? Please rank from the 1 (very boring) to 7 (very exciting)	As the role of Helper is played by another person, we should find out from the point of view of Helper whether he or she is enjoying the game as well
(v) Currently the game is played by one Pacman/Ghost to a Helper. Do you think the game would be more interesting for the Helper if he/she could assist more Pacmen/Ghosts? If yes, what is the optimal number? If not, why?	Human Pacman basically revolves around social and physical interaction among all players. Generally, these interactions will increase with more players, thus making the game more enjoyable, too. However, as number of players increases, confusion will inevitably start to creep in. We would like to find out what is generally the optimal number of players
(vi) Do you think the frequency of conversation will increase when the complexity of the game (in terms of area size and number of Pacmen/Ghosts) is increased?	As Human Pacman is based on virtual and real interactions, we would like to know if complexity of the maze will affect the frequency of communication
(vii) Do you think Pacman needs a Helper?	The main role of Pacman helper is to guide Pacman to all the cookies and avoid the path of Ghost. However, some players may find it more exciting to be able to explore the real world freely and without any reins
(viii) Do you think Ghost needs a Helper?	The main role of Ghost is to track down Pacman. Similar to the above situation, some players may feel that the additional help is redundant and would like to explore the real world freely

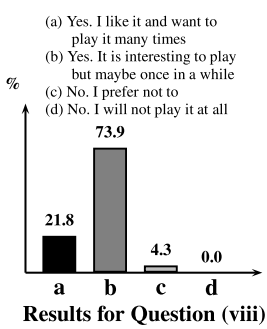


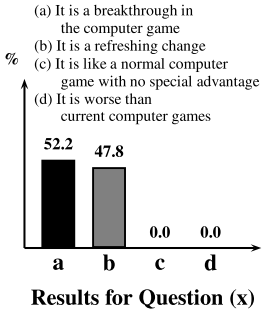


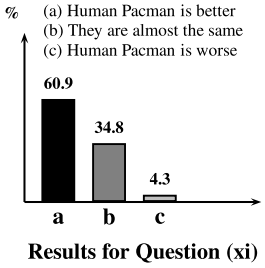


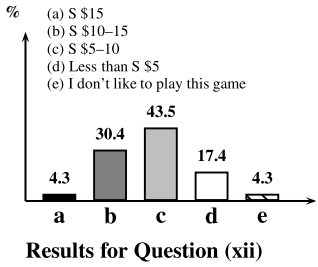












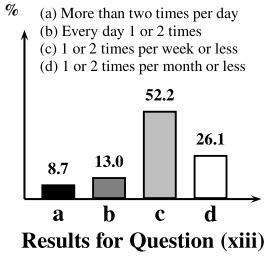


Fig. 2.13 Graph results for all multiple choice questions focussed on the real world players (some questions have no graphs and are described in the main text only)

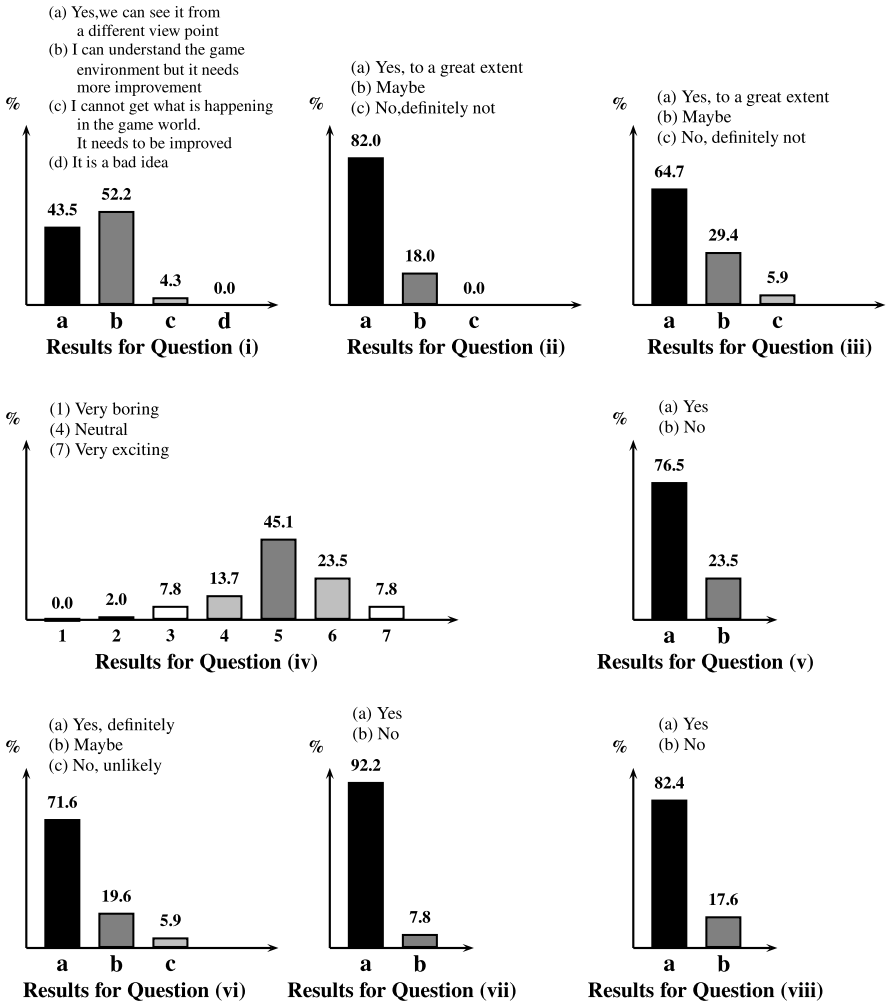


Fig. 2.14 Graph of the results for questions related to the virtual Helper players

game (which by itself is a game that involves a high level of physical participation). A number of users commented that they like the idea of "physical involvement" and "physical movement" in Human Pacman. Some said that such movement is a good form of exercise. Note that 60.9% of the users still prefer Human Pacman over the "Catch Me" game. This indicates that the element of physical involvement in Human Pacman is not its sole attraction. The immersive experience in the role playing of Pacman could be another element that users enjoyed over arcade Pacman and conventional computer games. Findings from Question (iv) give the average level of excitement rated by the subjects as 6.0 (and a variance of 0.182) for the first person experience in Pac-world and 3.33 (variance of 0.97) for the third person experience in arcade Pacman, indicating a higher level of excitement

in the former. The non-parametric two conditions Wilcoxon statistical test confirms the significant difference in the feeling of excitement by the players at the level of $p = 4.88 \times 10^{-4}$.

As reflected by many users, the backpack holding the wearable computer system is bulky and heavy, and the HMD is cumbersome to wear. As seen from the results obtained for Question (ii), 73.9% of the users found the wearable computer to be uncomfortable. This could be the deterring factor for 77% of those who indicated that they like to play Human Pacman but would refrain from playing it frequently. The absence of equipment weighing down the user could also make traditional "Catch Me" game more attractive as one is unencumbered physically.

Despite not being a normal day-to-day experience, collecting virtual cookies by walking through them is deemed to be intuitive by 87% of the users (as seen in Fig. 2.13(iii)). The rest found the experience to be acceptable, though not intuitive. Findings for Question (v) show that 78.3% found that the use of virtual cookies enhances the game, whereas 17.4% feel that the cookies are acceptable as virtual objects but they fail to enhance the game.

A shift in alignment of virtual cookies from their supposed absolute position in the real space (caused by sensing drifts), mentioned by some users, could be the reason why virtual cookies to some users seem lacking realism, and thus being unable to enhance the game. As the view of virtual cookies is calculated with respect to the user's location, any discrepancies of her exact position may lead to the "shifting" of the absolute position of the virtual cookies in the real space. Since the system uses DRM-III and the dead-reckoning method to estimate displacement of the user, an inaccurate estimation of her stride (which varies with individual) or the wrong count for the number of steps taken will introduce error in the estimate. The location of the user thus computed is an estimate and may not reflect her true position in the physical space. Some users have reflected that the DRM-III module failed to sense all the footsteps taken by the user.

Users also found the visual cue of the cookies collection (i.e., cookies disappearing from AR world when collected) to be weak and insufficient in providing a "better feel" of collection. A number of users suggested using sound, for example, a "beep", to indicate collection of each virtual cookie. A lack of realistic affordance of virtual cookies makes reliance on other cues more important to indicate collection.

On the issue of tangible interaction element in Human Pacman, 78.3% (as seen in Fig. 2.13(vi)) found that the graspable interaction offered by the collection of real objects enhances the game. The other 21.7% gave a neutral response towards having this collection as part of the game. Almost all the users indicated in Question (vii) that they like the "capturing" event. Despite being both naturalistic interaction with the physical world, users seemed to like the "capturing" event more. This suggests the physical human-to-human interaction in the process of "capturing" makes the event more enjoyable.

Results obtained for Question (ix) show that the feeling of having social interaction have rated means of 5.67, 5.41 and 4.17 with variances of 0.97, 1.17 and

0.88 while playing as Pacman, Ghost and Helper, respectively. The non-parametric Wilcoxon test shows insignificant difference in the level of social interaction between Pacman and Ghost ($p = 0.5$), while the difference of between being Ghost and Helper is significant with $p = 0.0039$. Helper role is perceived to have lesser social interaction as compared to the other roles. We feel this is related to further questions discussed below about Helper's role, and that the role is less enjoyable. As this is an entertainment system, the fact that Helper has more limited modes of interaction than the physical players seems to lead to less enjoyment and a feeling of social interaction.

Based on the results from Question (xii), the average amount the users are willing to spend to play Human Pacman in amusement parks is S $8.15 with a variance of 16.5. This is in the typical price range of amusement rides available locally. It is noted that the 17.4% who would pay less than S $5 to play Human Pacman also indicated in Question (xiii) that they seldom play computer games. Perhaps they do not enjoy playing games as much as the average person, and are therefore less willing to spend on it.

We now discuss the results from the questions focussed on the experience of the virtual Helper player in Table 2.3.

As reflected by the response to Question (i), almost all users were able to comprehend the game environment from the VR mode. It is noted in the feedback comments that more than half of the users felt that more improvement still needs to be made for the VR mode. Users would like to see better 3D graphics and more variety of virtual objects in the VR world. Perhaps the lack of visually appealing 3D interface as compared to those found in commercial computer games makes Helper's role less attractive (our 3D models are non-commercial and designed in the laboratory by students).

The subsequent three questions (Questions (ii), (iii) and (iv)) focus on the experience of Helper in the game. Nearly 4 in every 5 participants' responses to Question (ii) agreed on the fact that Helper increases the chances of winning, while the rest thought maybe, and none disagreed on the role of Helper in winning the game. From Question (iii), a lesser 64.7% reflected that the role of Helper made the game more enjoyable for Pacman and Ghost, and 5.9% felt otherwise. The remaining 29.4% hesitated and thought it probably did so. Question (iv) sought to examine from the perspective of users who played as Helpers on how enjoyable they felt toward the role. Using a scale of 1 (very boring) to 7 (very exciting), a mean rating of 4.96 with a variance of 1.93 was obtained. Evidently, these numbers illustrate the fact that while Helpers are definitely beneficial to the game, the issue of fun and thrill has not been addressed well, since the user (Helper role) did not enjoy it as much as they understood its strategic importance. This may be due to the fact that Helper's interactions are limited only to text-based messaging. To improve this, perhaps Helper could be assigned to more interesting tasks. For example, Helpers could be granted abilities to temporary make the virtual cookies invisible to the enemies or to make their assisted player immune from being captured, as was suggested by some users.

Question (v) explores the other possibilities and options to be expanded on the interactions between the real physical and virtual online players. More than two-

thirds of the users revealed that the game will be more interesting if a Helper can assist more than one Pacman or Ghost at the same time, so that they can collaborate and form strategies to win the game. According to the feedback, the average optimal number of Pacman or Ghost per Helper is three, as most users commented that it would be too confusing if there were too many players involved.

Regarding the issue of interaction in terms of textual conversation versus complexity of the game, we found out from Question (vi) that 70.6% felt that the communication will definitely be more active as the complexity of the game is increased in terms of the area size and the number of players. It can be hypothesized that when more physical players are introduced, Helpers have to put in more effort to coordinate the players who are roaming in the real world. The physical players would also need more information too if the game area becomes wider and harder to explore physically.

A correlation test was done on those who answered Question (iii) and Question (v) to find out the relationship between users who enjoy (and those who do not) the game and their attitudes toward the issue of higher communication with increasing the complexity of the game. A high degree of correlation coefficient of 0.876 was derived. This suggests that those who enjoyed the game initially would most likely choose to participate and contribute actively to their teammates when the complexity of the game is increased. On the other hand, the remaining who did not find the game interesting in the first place (Question (iii)) do not feel communication would increase with increasing complexity (Question (v)). In other words, it could be hypothesized from these results that a higher enjoyment can promote a positive increase in communicative interactions.

The two remaining questions (Questions (vii) and (viii)) seek conclusions from the users' point of view on the necessity of Helper's role for both Pacman and Ghost. Surprisingly, the results vary slightly instead of being close to each other: 92.3% believed that Pacman needs a Helper, while slightly fewer 82.4% thought Ghosts required such support. While majority agreed on the essential existence of Helpers, a small group commented that it might be better to let the physical players explore on their own as there could be more fun in self exploration, especially for Ghost whose sole job is simply to eliminate Pacman. Nonetheless, the fact that a large majority agreed on the necessity of Helper indicated that it is not something added for the sake of adding; it serves a purpose in completing the whole framework of the game.

2.4.3 Analysis of Message Logs

In this section, we will analyze some excerpts from the text messages that contain the conversation which was logged during the user study. Some interesting and unexpected results have been obtained and should be useful to in order to gain more knowledge in the context of real-to-virtual interaction which we are studying here.

One significant result from the user study is illustrated by the fact that the players often assumed beforehand what their team member would like to know or ask. A typical message log often looks like this:

Pacman's Helper: Carry on.
Pacman's Helper: Go right.
Pacman's Helper: Go straight.
Pacman's Helper: Left.
Pacman's Helper: Go left!!!
Pacman's Helper: Run!!!

Here Pacman remained silent and her Helper dominated the conversation. As a matter of fact, Pacman was preoccupied with her physical activities of moving and searching that she could find no time to reply. Moreover, probably all that she needed (and did not need) to know was already answered by her Helper. The conversation had, in fact, turned into a monologue and interaction has lost its meaning here.

However, for users who are more proactive, we can still observe some two-way traffic of interactions taking place even in trivial cases of guiding the way:

Pacman: What do you mean?
Pacman's Helper: Try going backwards.
Pacman's Helper: Stop!
Pacman: What's next?
Pacman's Helper: Turn right!

Therefore, despite the same settings, we recognize that the degree of interactions that take place might vary for different individuals. Encouraging the players to collaborate in reaching the common goal is essential to promote more interactions.

The importance of collaborations often becomes obvious in the face of difficult problems that arise during critical moments, for instance, toward the near end of the game. The role of Helpers in the following scenarios contributes significantly to the eventual outcome:

Pacman: Where's the last cookie?
Pacman's Helper: I suggest you try killing Ghost first.
Pacman: Why?
Pacman's Helper: Coz he is still guarding the last cookie!
Pacman: What shall I do!?

While the element of surprise seemed to be spoiled by having a Pacman's Helper informing Pacman what has actually happened, it in fact did not spoil the game or caused a stalemate. The next scenario followed from the previous scenario, and Ghost decided on a strategy after she obtained the information from Helper.

Ghost's Helper: 1 cookie left for Pacman.
Ghost: This one??
Ghost: Tell me when he's coming.
Ghost: I'm gonna camp here.
Ghost's Helper: Incoming! But- she's a Super Pacman now!

Through Helpers on both sides, each had devised its own strategy. Ghost, after being informed by her Helper that only one last cookie remains for Pacman, decided that it would be a wise idea to lay ambush near the cookie. Upon learning that Ghost is idling around the last cookie, Pacman's Helper passed this information to Pacman. To outwit Ghost, Pacman found the Super Cookie with the aid of Helper, and became a Super Pacman. Subsequently she eliminated Ghost by surprise, finished collecting the last cookie and won the game.

Pacman's Helper: Cool, we won!
Pacman: Yeah, cool stuff, great job!
Pacman's Helper: Same to you.

Through simple text messaging, ideas and emotions are channeled mutually between real physical and virtual online players, resulting in a unique interplay of social behaviors across different platforms.

2.4.4 Summary Findings

Through the user study survey, we evaluated how the Human Pacman system model fits into the interaction theme we started out with. We believe that from the findings we can say that users like the idea of Human Pacman as a whole. This is seen from their attitude towards playing the game, their willingness to pay to play the game, and their preference of Human Pacman over other types of games. It is promising that users were positive about the physical interaction aspects of the game such as the first person point of view and the tangible interactive elements. However, it is clear that improvements should be made to reduce the size and weight of the wearable computer.

On the individual elements of Human Pacman, the collection of virtual cookies is well accepted though improvements can be made to make the whole experience of moving towards virtual cookies and collecting them more realistic. Sound could be added as a cue to the collection. More accurate and precise tracking device could also be developed to minimize error in location tracking, which was a factor of disapproval from the users.

Though both the "capturing" event and collection of physical objects in the game add value to the game, it is found that the former is better liked. This could be because during the "capturing" of Pacman, physical human-to-human interaction is involved, along with other forms of human interaction that comes into play (e.g., shrieking). The study also shows that immersive experience is valued by users. Users like to be "physically involved" in this first-person gaming experience. This positive

reception is important to note, as the tangible and physical aspects introduced into Human Pacman are some of its major strengths.

Nonetheless, the mean rating of 4.96 out of 7 received for the Helper role in terms of enjoyment level indicated that perhaps more features should be added to enhance the role. Interaction in the form of text messaging alone may not be sufficient to encourage Helpers to stay engaged or maintain their level of interest. Consequently, some users reflected that even if the overall game complexity is increased, the level of interaction might not increase proportionally. This would mainly be due to the fact that they will still be primarily guiding the physical players through text messaging. Besides, some might have rejected the game as boring in the first place, no matter what the complexity.

We also found that interactions might always not take place readily as what the designers had intended in the early stage, whereby the game was actually customized to promote two-way communication between the physical players and the virtual online players. However, the a priori knowledge of users on their partner's requirement often led to pre-assumptions, which in turn led to one-way communication – Helper giving commands on where to go, while Pacman/Helper just following the instructions. Nonetheless, as the users approach critical stages (collecting the final cookie or capturing the Pacman) collaborations become inevitable as the users interact with each other to achieve their ultimate goal of winning the game.

Based on the user study, we did a qualitative analysis on users' perceptions toward the different form of interactions and produced a color interactive matrix as shown in Fig. 2.15. We assigned different levels of importance, in terms of high, medium and low, to each interaction. The levels of importance are obtained based on the user study results of the general effectiveness (useful, intuitive, enjoyable) of each form of interaction. Evidently, Pacman experiences most of the important interactions compared to other users, as the game design is initially revolved around the Pacman character to a larger extent. Interactions between users of any roles are also higher than to those between users and objects, implying the importance of social interactions in mixed reality gaming environment.

2.5 Mobile Service and Ubicomp Issues

In recent years, we have witnessed phenomenal growth of mobile devices. Together with current trends in embedded systems and software, real-time interaction and omnipresent wireless networking, these devices fertilize the formation of a ubicomp landscape, in which digital environments are aware of the presence of users, and communicate with the user via natural interaction means. Human Pacman attempts to incorporate a number of mobile and ubicomp elements into the game play, for instance, mobility, ubiquity, awareness, intelligence, and natural interaction. In this section, we will examine the various repercussions in the system by studying the three principle features of mobile computing: wireless communication, mobility and

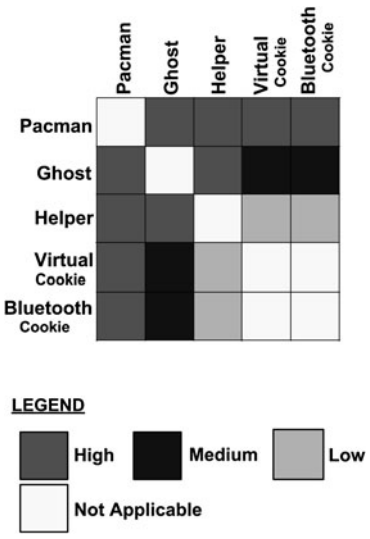


Fig. 2.15 Interactive matrix

portability [13]; following which we will examine two of the interaction themes in ubicomp, that is, tangible interfaces and context-awareness in the context of Human Pacman.

2.5.1 Mobile Computing

From a broader perspective, the game of Human Pacman is a type of user adaptive application that is built upon the infrastructure of wearable and mobile computing, as well as the wireless multimedia communication. It aims to utilize the mentioned technology to provide nomadic players with personalized location based entertainment. However, there are numerous problems associated with the actualization of these concepts.

2.5.1.1 Wireless Communication

We have identified three main problems in deploying the wireless communication network, in this case, the wireless LAN of IEEE 802.11b. Firstly, disconnections in communication often interrupt the flow of the game. Secondly, limitation in bandwidth sets constraints on the type of multimedia data that can be sent between players and between the players and the server. For example, we have to limit ourselves to simple text files for the frequent location, perspective, and status updates between the player's wearable computer and the server; and forego with the initial intention of sending live video streams between players. Thirdly, unstable outdoor conditions often result in high error rate of the network. These three factors, in turn, increase communication latency which is due to retransmission, retransmission on time-out

delays, error control processing, and short disconnections. Therefore, it is rather difficult to maintain Quality of Service (QoS), especially when players accidentally move beyond the coverage of the network, or move into areas of high interference. We try to minimize the problems by carefully selecting the area for game play in the vicinity of the University campus in Singapore where network connectivity is good. Also, when designing the software for the game, we have embedded components that enable continual processing based on local data on the wearable computer so that when short disconnections occur, the game can still proceed without many disruptions. Lastly, the client/server communication between the server and wearable computers occurs in an asynchronous manner in order to reduce the problem of latency.

2.5.1.2 Mobility

The combination of networking and mobility engender this new form of entertainment system where support for collaborative environment for impromptu communication between mobile players is essential. The dynamism of data, including location and context information from trackers and sensors, contributes much to the volatility of data in the whole system. This creates a grave problem when the wearable computer is dozing because of inactivity of players or power failure. Also, with the players moving around in an outdoor physical area in this type of wide area mobile gaming, they might move across multiple heterogeneous wireless networks and therefore suffer from address migration interruption between the networks. However, in Human Pacman, we try to avoid these difficulties by limiting the size of the game play area and using single centralized server network architecture.

2.5.1.3 Portability

Wireless networking with mobile computing has greatly enhanced the utility of carrying a computing device, in this case, a wearable computer. However, unencumbered portability is very important for the enjoyability of the game. Conventional portable computing devices like netbooks and handphones often suffer from the lack of raw processing power and storage size when running multimedia entertainment programs. With the use of custom-built wearable computer, we managed to secure high computing power together with large storage volume for our application (for details on wearable computer, please, see the previous section on system design). Another important portability issue is the power for the computing device. Since Human Pacman is a game with short duration of play (recommended 10 minutes), the wearable computer that is powered by two Sony InfoLithium batteries lasting about three hours can adequately manage the task. The last issue in portability is the user interface. Duchamp and Feiner have investigated the use of head-mounted virtual reality displays for portable computers [10]. They concluded with

several disadvantages of using the display, including the hassle of the head gear, low-resolution, eye fatigue, and the requirement for dim lighting conditions. These problems also exist in Human Pacman since we are also using head mounted display for Augmented Reality outdoor gaming. Nevertheless, as mentioned previously, due to the short duration of play in Human Pacman, the problem is bearable to the players.

2.5.2 Ubicomp

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 [37], 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, in fact, two of the interaction themes in ubicomp. Tangible interfaces and context-awareness, which are integral components in the game play of Human Pacman, are discussed in the following subsections. Since the game is played in a wide outdoor area, context-awareness issues are studied with the focus on outdoor settings.

2.5.2.1 Tangible Interface

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 the literature in the early 1990s with the introduction of Computer-Augmented Environments [8] that have envisioned 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 [32] that has made a compelling demonstration of passive marbles as "containers" for voice messages; "Brick" by [12] that is essentially a new input device 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 [15] that allow 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, initiating communication with the tangible objects, and confined only between virtual objects and humans.

However, in Human Pacman, with the use of embedded Bluetooth devices and capacitive sensors, we explore active communication between computers and human players instantiated by Bluetooth devices, as well as graspable interaction between humans and computers, and between human players themselves. Therefore, 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 providing 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. On the other hand, tangible interaction between the Bluetooth embedded object and the player is made possible by using a 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 in computer gaming.

2.5.2.2 Context Awareness in Outdoor Environment

Researchers at Olivetti Research Ltd. (ORL) and Xerox PARC Laboratory pioneered the context-aware computing area with the introduction of Active Badge System and PARCTab [30, 35]. 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. With the introduction of GPS and emergence of cheap but accurate sensors, a number of context-aware systems for outdoor applications were built.

One notable system was the Georgia Tech Cyberguide project [17] 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 [29], a giraffe observation tool [27], and a rhino identification tool [26] 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 [38], 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 [34] as mentioned in the 'Background' section. 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.

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 experiments 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.

2.5.3 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 number of issues encountered have exceeded the scope of this paper. Therefore, we will concentrate on

Table 2.4 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 the computer. The existence of a 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 is more than one player 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 has picked up Bluetooth embedded object. Also, since this graphical information is provided in the HMD directly in the zone of the user's attention, such objects 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 the physical space where interaction is intuitive. According to Norman's Theory of Action [23], 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-clicks on virtual ingredient in order to dump the ingredient

discussing sensor-tracking issues with respect to human–computer interface design. According to Bellotti [1], there are five questions posing human–computer communication challenges for interaction design. In Table 2.4, we summarize the sensing approaches to interaction in Human Pacman with respect to the five questions raised.

2.6 Conclusion

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'.

The 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". Students are immersed in a 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 the real and virtual world, and therefore a higher than ever level of sensory gratification is obtained.

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