PAC-LAN: Mixed-Reality Gaming with RFID-Enabled Mobile Phones

OMER RASHID, WILL BAMFORD, PAUL COULTON, AND REUBEN EDWARDS, Lancaster University, Lancaster, UK, AND JURGEN SCHEIBLE, University of Art and Design, Helsinki, Finland

RFID (Radio frequency identification) is often seen as an enabling technology for mixed-reality experiences where all kinds of objects, even the most mundane and inanimate, can be equipped to provide interaction between the real and virtual worlds. These mixed-reality experiences could occur in all aspects of our lives, but one of the most easily envisaged is that of computer games. As the mobile phone has become the computer carried in the pockets of a third of the population of the planet, it would seem a natural platform for these mixed-reality games. Further, the emergence of mobile phones that incorporate RFID readers gives the opportunity for creating games in which players interact with real physical objects, in real locations, and provides enhanced gameplay and experience. In this article we present details of a novel location- and object-enhanced mixed-reality version of the Namco arcade classic, Pacman. In particular, the article presents a comparison of the game to other mixed-reality versions of Pacman; the rationale behind specific design choices made during game design and its subsequent implementation; and an analysis of the experiences of people who have played the game. Our system highlights the possibilities via use of physical objects and the combination of mobile phones and RFID of yielding new mixed-reality entertainment experiences.

Categories and Subject Descriptors: J.7[**Computer Applications**]: Computers in Other Systems – *Consumer products*

General Terms: Design, Experimentation, Human Factors

Additional Key Words and Phrases: Mobile, mixed reality, RFID, location- based

1. INTRODUCTION

Mixed reality is the merging of real and virtual worlds to produce a new environment where physical and digital objects can co-exist and interact. Radio frequency identification (RFID) is often hailed as one of the enabling technologies that will bring about this vision. RFID tags, a simple microchip and antenna, interact with radio waves from a receiver to transfer the information held on the microchip. RFID tags are classified as either active or passive, with active tags having their own transmitter and associated power supply, while passive tags reflect energy sent from the receiver. Active RFID tags can be read from a range of 20 to 100m; passive RFID tags range from a few centimeters to around 5m (depending on the operating frequency range).

With over two billion users and the emergence of standardized operating systems [Coulton 2005], it is widely forecast that the mobile phone will become the dominant

Authors' addresses: O. Rashid, W. Bamford, P. Coulton, and R. Edwards, Informatics Group, Infolab21, Lancaster University, Lancaster, LA1 4WA, UK; J. Scheible, University of Art and Design, Helsinki, Finland; email addreses: m.rashid@lancaster.ac.uk, w.bamford@lancaster.ac.uk, p.coulton@lancaster.ac.uk, r.edwards@lancaster.ac.uk, jscheib@uiah.fi.

computing device for the majority of the world's population. This is no doubt why mobile games are the subject of much debate within the games industry, particularly as they already account for 14% of the $43 billion total in world gaming revenue [Palmer 2005]. Industry analysts are predicting that the mobile may become the dominant force in games. However, recent reports by Glu Mobile in the UK and NPD in the US indicate that the mobile gamer demographic is very different from the traditional console and PC gamer. This means that the games industry has a tremendous opportunity for creating new gaming genres that will take advantage of the unique nature of the mobile phone and the broad range of users who possess them. One such opportunity is that of mixed-reality games, where players can interact with objects that are either fixed or mobile, which is a practical possibility with the emergence of mobile phones with in-built RFID readers. It has been predicted that as many as 50% of all phones will incorporate RFID by 2009 [RFID Journal 2005], so this is a practical long-term solution that will cover both high- and low- end phone models.

RFID is not the only means of interacting with objects. Alternative approaches include the utilization of other short- range communications such as Bluetooth or WiFi. However, these techniques require a power supply for the object, and so are impractical for wide-scale implementation. Therefore, in the short to medium term, for phone/object interaction, we must consider passive RFID or the various forms of two-dimensional barcodes such as QR codes [IOS 2000] as the best solutions, as neither requires a power supply. All of the two-dimensional barcode systems use a phone with an on-board camera to either decode the code on the phone or through interaction with an online database. RFID and its associated technology of near field communications (NFC) [ECMA 2004] offer an alternative approach:

- that provides faster read times, as the tags can be accessed at rates between 106, 212, or 424 kbits/s, whereas the two-dimensional barcodes require image capture and processing, which we found typically takes a few seconds;
- provides RFID tags that can be written to as well as read from;
- provides a simpler reading method, as the phone and the tag have merely to be placed in close proximity (less than 3cm), whereas the barcodes require the user to take a picture. In fact, the phone and RFID tags used in this project provide round target icons to make positioning intuitive; and
- that is more robust, as errors are more likely to occur when scanning a barcode due to irregular camera orientation.

Mixed-reality games on mobile phones are not new, and a number of them have been reported [Rashid 2006], although as yet none have used RFID, and only ConQwest (semacode.org) has used two-dimensional barcodes. In this article we do not wish to compare RFID technology against two- dimensional barcodes, as the majority of the findings would likely merely confirm the technical analysis previously discussed. Instead, we seek to identify what RFID mixed-reality mobile phone games have to offer in terms of user experience and gameplay. Therefore, the objectives of this project were to create a readily deployable game in which we can ascertain the following:

- if the use of physical objects enhances the user experience;
- whether RFID produces effective user interaction with those objects;

- the effectiveness of RFID as an implied location- positioning scheme when the game players are moving quickly; and
- how tactics develop over subsequent participation in the game.

As the game utilizes RFID to suggest the position of players as they interact with fixed game objects, it is also a location-based mobile game.

In the following section we highlight the design and development of such a game platform, providing the rationale for the design choices at each stage, based upon both system and environmental limitations and initial user experience.

2. SYSTEM OVERVIEW

2.1 Gameplay

PAC-LAN is a novel version of the video game Pacman, in which human players use the Alexandra Park accommodation complex at Lancaster University as the game maze. The player who takes the role of the main PAC-LAN character collects game pills (using a Nokia 5140 mobile phone equipped with a Nokia Xpress-on™ RFID reader shell), in the form of yellow plastic discs fitted with stick-on RFID tags. These tags are placed around the maze as shown in Figure 1.

Four other players take the role of the "ghosts" who attempt to hunt down the PAC-LAN player. The mobile phone game client is implemented on the Java 2 micro edition (J2ME) platform which is connected to a central server using a general packet radio service (GPRS) connection. The server relays to the PAC-LAN character his/her current position along with position of all ghosts based on the pills collected. The game pills are used by the ghosts to obtain the PAC-LAN characters last known position and to reset their kill timer which, if expired, will prevent them from "killing" PAC-LAN. In this way the ghosts must regularly interact with the server which is then able to relay their position to the PAC-LAN.

PAC-LAN sees a display with his own position highlighted by a red square around his animated icon, while the ghosts see both a white square highlighting their animated icon and the red flashing square around PAC-LAN. These character highlights were added after pre-trials revealed that players found it difficult to quickly identify important information.

Fig. 1. PAC-LAN player tagging a game pill with his phone and Mr. Pink in full flow.

Fig. 2. PAC-LAN phone user interface.

Fig. 3. Ghost (Mr. Orange) phone user interface.

The ghosts can kill the PAC-LAN character by detecting him/her via an RFID tag fitted to their costume (assuming their kill timer has not run out). Once PAC-LAN is killed, the game is over and the points for the game are determined by calculating the number of game pills collected and time taken to do so. When PAC-LAN tags one of the red power pills, indicated by all ghost icons changing to white on the screen, he/she is then able to kill the ghosts, and thus gain extra points, using the same RFID detection process. Dead ghosts must return to the central point of the game maze where they can be reactivated into the game. Figure 2 shows a number of typical screens that the PAC-LAN character will experience during the course of the game.

Figure 3 highlights a simple game scenario for a ghost player where he/she enters the game after a controlled delay. The ghost player then attempts to kill PAC-LAN, but his kill timer has expired and he/she then falls victim to PAC-LAN who has subsequently obtained a power pill.

The game's scoring mechanism is simple for all participants. The PAC-LAN character obtains 50 points for a normal pill; 150 points for a power pill; 1000 points for collecting all the pills; and 500 points for a ghost kill. The ghosts obtain 30 points per pill (this is linked to the length of the kill timer) and 1000 points for killing PAC-LAN. All players lose 1 point per second to ensure they keep tagging.

2.2 Design Decisions

In this section we highlight significant design decisions made during the development of the game and the rationale for each.

2.2.1 *Why Pacman?* We used Pacman as the basis for our game design for a number of reasons:

- it is widely recognized, with simple but compelling game play. Therefore, players can quickly ascertain the game's overall concept without the need for a complex and lengthy explanation of the rules;
- the virtual game maze premise transfers readily to a physical location; and
- the Pacman character (PAC-LAN) interacts with game elements (the game pills) which can be considered as physical objects at specific locations. This type of interaction is one of the principal elements we wish to investigate.

This is not the first time Pacman has inspired the development of a location-based game. The most famous other example is probably Pac-Manhattan (www.pacmanhattan.com). However, Pac-Manhattan differs significantly from PAC-LAN in that:

- it does not incorporate actual physical objects;
- it uses mobile phones simply to provide a voice link (effectively a walkie-talkie arrangement);
- the developers chose not to implement a means of estimating location because the game was played around the streets of Manhattan, which would have acted as urban canyons for systems such as GPS; and
- the gameplay of each player was controlled by a human central operator.

We have specifically chosen to avoid incorporating voice calls or SMS, and hence human game controllers, as we wanted to keep the gameplay as fast as possible and more akin to the arcade classic. Although human controllers introduce interesting aspects of trust and acceptance, as explored by games such as Uncle Roy All Around You [Magerkurth 2005], we felt that there would be a greater possibility for the emergence of spontaneous tactics without a controller.

The other significant implementation has been Human Pacman [Cheok 2004], which uses an innovative combination of virtual reality goggles, GPS receivers, and portable

Fig. 4. Campus map and typical buildings.

computers with Bluetooth and WiFi access to recreate the game. This differs from PAC-LAN in that

- it is played over a much smaller area, approximately 70 meters squared, compared to 300 meters squared;.
- only one real object is used for interaction;
- the game is played at a slower pace due to the large amounts of equipment being carried; and
- each player is controlled by a human central operator.

Obviously this is a highly specialized and expensive technology; in November 2004, its creator, Dr Adrian Cheok, predicted that "Within two years we'll be able to see full commercial Pacman-type games on mobile phones."

With the commercial technology presented in this article this will became a reality in less than a year, with an equipment outlay of less than $1500. Hence, the system can be tested with large numbers of people, without concern over equipment costs or the practicalities of running while wearing virtual reality goggles.

2.2.2 *Why Alexandra Park?* Alexandra Park has a number of physical attributes that make it particularly desirable for this type of game. The most obvious can be viewed in Figure 4, in that it exhibits a maze-like structure of tall buildings spread over an area of approximately 300 m^2. This means there is both sufficient space to allow players to extend the gameplay over a reasonable length of time and avoid the situation where players can be sighted from a long distance.

Additionally, the area is entirely pedestrian with wide pathways, which means that our desire to keep the game action as fast as possible would not place the contestants in danger from vehicles or produce too much interference to the general populous. As our game includes a large number of people, safety is a serious issue that we feel all designers of location-based games should consider seriously; especially when children are among the game players.

2.2.3 *Why this Mobile Phone Model?* Although this model phone, with limited display size (128 x 128 pixels) would not be many developers first choice in terms of features, it was the only one that incorporated an RFID shell at the time of development. However, during testing we found that the small form factor and rubberized case made is easier to run with and much more resilient when dropped. In fact, these features are why it is a very popular model among people engaged in outdoor activities who may well represent a more likely target audience than traditional video game players. Further, due to the current trend for “retro” phones with limited features, developers cannot assume that everyone will carry an elaborate “smart” phone.

2.2.4 *Why use RFID to Provide Location?* Many location technologies have varying degrees of accuracy [Rashid 2006], and RFID is effectively independent of terrain. In our case, a GPS survey of the site revealed that the buildings created a large number of urban canyons, as highlighted in Figure 2, where the signal was lost resulting in reacquisition times that were sometimes as long as 60 seconds. It also allowed us to place some of the pill locations undercover, which would be impossible with GPS.

2.2.5 *Why Use Plastic Discs?* The discs were a cheap and effective way of keeping the action very fast-paced, in that the RFID tag location can be seen easily by the players, as shown in Figure 5. In the game, the discs were generally attached to lamp posts by a Velcro strap at about 1.5m from the base to make them easily visible and accessible. At a couple of points around the maze, we had to attach them to a low fence (< 0.5 m), although it did not appear to cause the players any problems.

2.2.6 *Why Use GPRS?* There are a number of reasons for choosing GPRS over other wireless technologies such as WiFi. First, it does not require the installation of additional infrastructure to support a game; second,, as Figure 6 shows, the coverage of the game maze is excellent, never dropping below 70%. Third, it is specifically designed to be resilient to Doppler shift and frequency selective fading, which, if a player is running, can significantly degrade communication performance.

Fig. 5. Normal yellow game pill and red power pill.

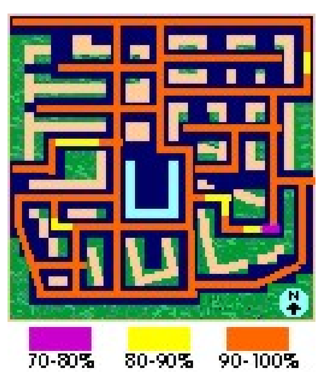

Fig. 6. GPRS coverage over the game maze.

Fig. 7. Ghost (MR. Blue) kill tag.

2.2.7 *Why Use an RFID Tag as the Kill Mechanism?* Our original idea was to use Bluetooth as the 'kill' method, to allow the player to kill the opponent once they were in range without the necessity for physical contact, which we felt could cause problems. However, we came up with an RFID tag on a foam disk attached to the characters' costumes by Velcro, as shown in Figure 7, which worked well during gameplay.

3. SYSTEM IMPLEMENTATION

The system architecture consists of a central server communicating via a GPRS to the PAC-LAN and ghost client applications running on the phones. The client applications are programmed in J2ME and utilize the contactless communications API.

Once a particular RFID tag has been scanned (indicated by an audible alert), the tag ID is sent to the central server. While the application is communicating, a red communications icon is displayed to the user, instead of the compass symbol on the game maze as shown on Figure 8. The server uses PHP to process the tag information, depending upon its type; and, depending on the game logic, updates the database running on MySQL. The server then returns the current location of all the ghosts and PAC-LAN to the client device. Figure 9 shows the average round-trip time for the server to respond to the application, based on all the tag locations. We found this delay averaged approximately 2.7s, which we found more than sufficient to avoid interfering with the gameplay. Note that the first reading always takes longer (around 8s), irrespective of position, as the server connection is initiated; but this has no effect on the gameplay.

The way the client software on the phones handles the tag information and communicates with the server differs between the ghosts and PAC-LAN. In Figure 10 we highlight the application flow-diagram for the PAC-LAN client software.

The application uses J2ME's persistent storage functionality to maintain information about tags as they are scanned during the course of a particular game. If a tag has already been scanned, that is, a game pill that has already been collected, the application first alerts the PAC-LAN player and then checks with the server for any updates on player positions. If the tag has not been used before, its information is checked in the record store to find out its type (game pill, power pill, or kill pill) and the actions necessary are

Fig. 8. Update verification icon on Mr. Pink's phone screen.

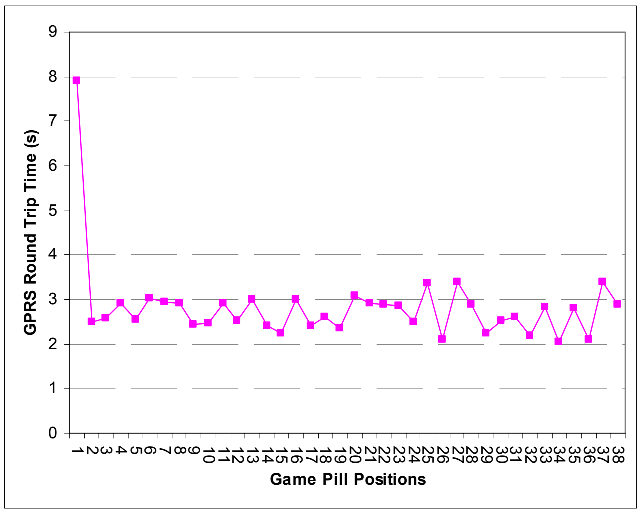

Fig. 9. Average GPRS round-trip communication.

then taken, such as updating points, initializing timers, and so on. For newly scanned tags, the unique ID, along with timer information, is sent to the central server over GPRS. This is represented by dotted lines in Figure 10.

There are several differences between the software architecture of the ghost and PAC-LAN client. One of the major ones is the way RFID tag data is handled. The ghost application sends the tag ID to the server to obtain updates on the state of the game and then reinitializes its kill timer. In the case of a game pill, the server returns the current location of the PAC-LAN character, and if PAC-LAN has initiated a power pill, changes the color of the PAC-LAN sprite on the display. The time out for the power pill is only shown to the ghosts when they read the RFID tag on a power pill. This implementation has been devised to ensure that ghosts have to read the RFID tags often, and prevents them from trying to hide their actual location from PAC-LAN player. At the start of the game, or when the ghosts have been killed, the ghost application is only initialized when released by the server. This ensures that the ghosts are released into the game gradually and that dead ghosts cannot re-enter the game illegally.

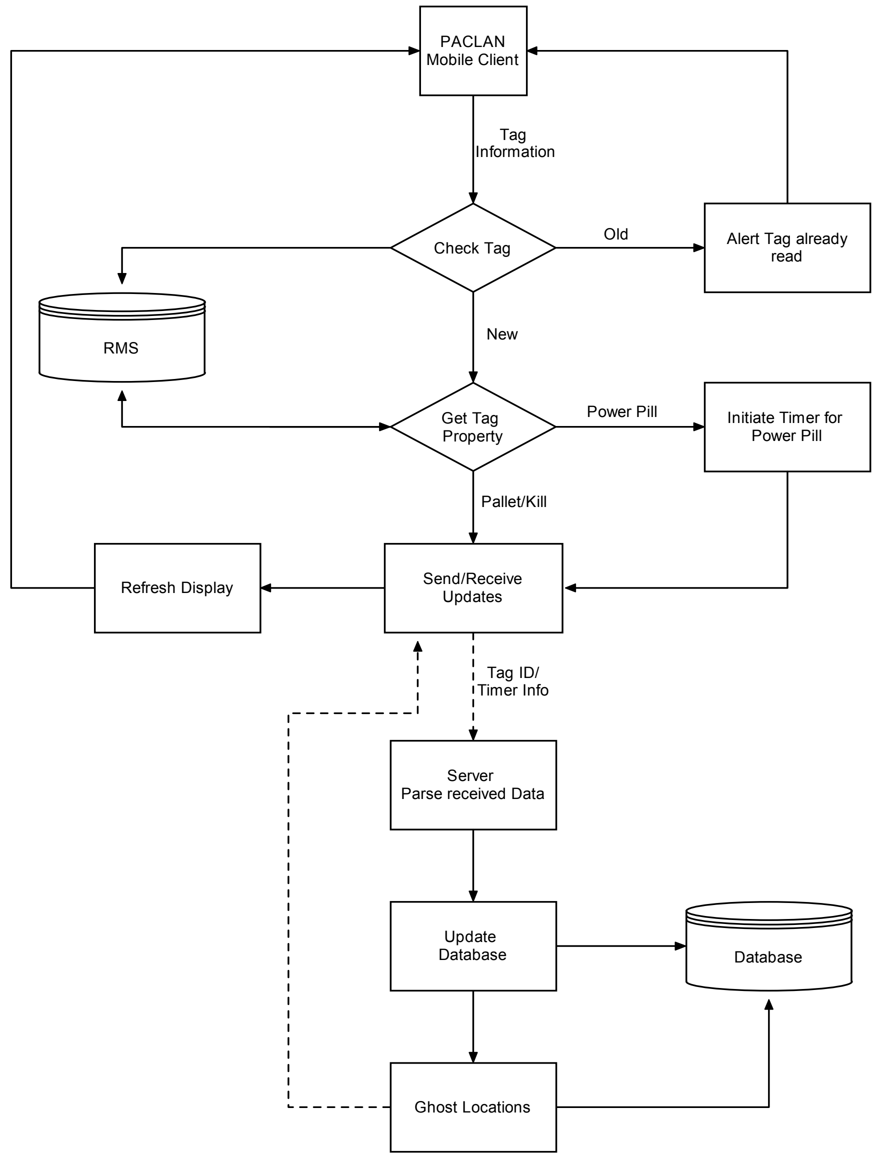

Fig. 10. PAC-LAN mobile client.

As neither PAC-LAN nor ghost mobile clients connect to the server periodically to check their activation status, it is essential that we ensure that status information is made available form the server at each tag read. For example, consider one of our test scenarios: PAC-LAN kills a ghost (Mr. Orange)--this information is sent to the server immediately, but will not be available to the ghost client (Mr. Orange) until he reads the next tag, which could result in the ghost then being able to kill PAC-LAN. This problem was overcome by sending the status of all players (dead or alive) along with position

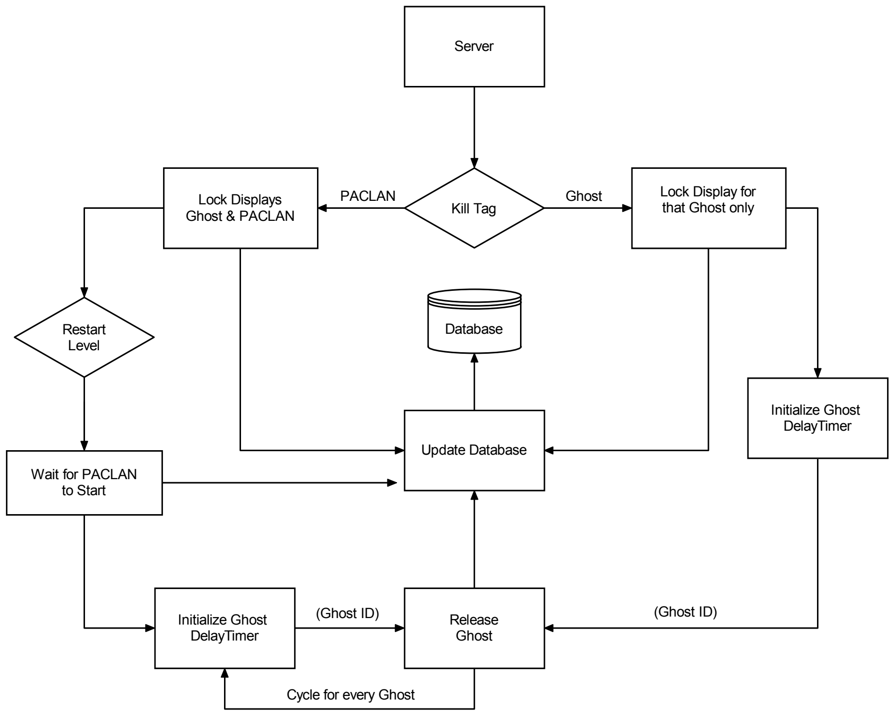

Fig. 11. Server "kill" handling.

updates. Therefore, in this test scenario, PAC-LAN is credited with killing a ghost (Mr.Orange) and the server updates this information in the database along with Mr. Orange's new position to spawn point. When Mr. Orange reads the next tag the ghost mobile client recognizes that Mr. Orange is dead and locks his/her display until spawn tag is touched. The other ghosts in the game simply see that Mr. Orange is at the spawn points, which implies that he/she has been killed.

Having discussed the mobile clients, we now turn our attention to the server. Although most of the scenarios are straightforward tag updates to the database and the provision of information is through a query from the clients, there is one particular scenario that requires the server to control the execution of mobile applications, that is, handling a kill by PAC-LAN or a ghost; illustrated in Figure 11.

Once the server receives the tag information, it parses the data to check which client has scored the kill and the identity of the "victim." If PAC-LAN has been killed, the server updates the database with a display lock on all ghosts and PAC-LAN clients; the players must then return to the central maze point and the game can restart. The server initializes the level restart once PAC-LAN reads a random tag. Once PAC-LAN has joined the game, the server releases the ghosts at specific intervals. In the alternative scenario, where PAC-LAN kills one of the ghosts, the server updates the database, and once again this information is passed onto other ghosts when they connect to the server. The "dead" ghost player must return to the central maze point where he/she can join the game, after an enforced delay by the server, by reading the central maze tag.

Fig. 12. PAC-LAN monitor, demonstrating player tracking and server control.

During the development of the game, we created another mobile client designed for monitoring and server administration while in the field. The application periodically connects to the back-end server to get positional updates for all the players. The server administration allows the organizers to reset the game at the end of play. The application performs a system check before the reset to ensure that the option was not selected by accident. This is done by checking the game status for two possible game-ending scenarios, namely; PAC-LAN being killed or PAC-LAN having collected all the pills. If either scenario is valid, the system is reset; otherwise the server prompts the mobile monitor application, and hence the user, for a confirmation to avoid an accidental reset of the game server

The application is designed for any J2ME-capable phone, and as such does not require the device to have RFID reading capabilities. Figure 13 shows a PAC-LAN monitor in action during various stages in the game. The monitor gives the textual description of every player's position while holding the "move down" key on the phone.

The monitor application could be modified to provide a spectator client, which would allow nonplayers to follow the game on their own mobile phones as well as physically within the maze. As the application gives the positions of all players during the game, spectators can then use it to ascertain the best position in the maze to enable them to follow the action. As spectators are not often considered in mixed reality games, this might provide some interesting experiences.

4. USER EXPERIENCE

In this section we present the feedback collected from 8 games of PAC-LAN played by 45 players (5 per game), taken after their first experience of the game. The average time for the games was 26 minutes, and in all cases the games ended with the PAC-LAN player being killed; there was an average of 1.5 ghost kills per game. The players were students from Lancaster University who answered an advert distributed via the university email system. The player groups were selected by the research team, who took care to select groups from the various faculties across the campus to ensure we did not have a technophile-biased sample. Of the 45 players, 7 were female; the players were aged

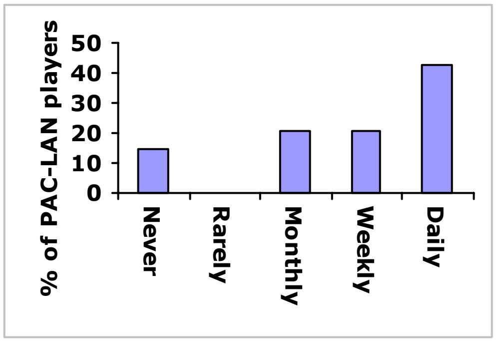

Fig. 13. Frequency playing mobile games.

Table I. User Feedback on Interface Design

UI Feature	Average Score	Standard Deviation
Reading RFID tags	3.71	1.14
Sounds	4.07	1.14
Vibrations	4.29	0.83
Visual Alerts	3.64	0.93
Overall Usability	4.21	0.80

between 18 and 24, except for 6 males aged between 25 and 35. As no discernable difference was evident in the experience of the PAC-LAN players to the ghost players, the following tables and statistics were taken from questionnaires completed by all 45 players. Of the players, 93% expressed no knowledge of RFID prior to playing the game, although at the end the same proportion expressed a willingness to use an RFID-enabled mobile phone to access other services, which is encouraging for the proponents of this technology. One of the surprising results was the mobile games-playing habits of the players shown in Figure 13. The graph indicates that the highest proportion of people play a mobile game almost daily, although 70% of people who played games only played preinstalled games. This is likely due to the fact that all the players were students in the predominantly 18-24 age group, which might account for the bias.

In Table I we provide the feedback concerning the UI of the application's relation to reading RFID tags, sounds, vibrations, visual alerts, and overall usability. A scale of 1 to 5 was used, with 1 being difficult and 5 being easy for tag reading and overall usability; and 1 being not useful and 5 being very useful for the rest.

From this, we can see that in general the application was seen as easy to use, although the RFID reading and visual alerts were perceived slightly less favorably. Having interviewed a number of players after these findings the general perception was that at first they had difficulty aligning the phone correctly with the tag for RFID reading, so

Table II. User Feedback on Game Playability

Game Feature	Average Score	Standard Deviation
Maze Layout	4.29	0.73
Pill Visibility	4.14	0.53
Ease of Kill	3.71	0.91
Overall Playability	4.21	0.58
Overall Enjoyment	4.36	0.63

that more guidance at the start of the game would have helped. In respect of the visual alerts, players felt the sound and vibrations worked best when running. This is useful observation, as few location-based games have made extensive use of sound or vibration.

We also obtained feedback relating to the playability of the game in terms of the phone map, compared to the actual physical layout, visibility of the game pills, ease of killing an opposing player, overall playability, and enjoyment. Once again, players were asked to rate each of these elements on a scale of 1 to 5, with 1 being poor and 5 being excellent.

As one of are objectives was to see if physical objects enhanced gameplay, it is encouraging to note that pills were scored highly and the game map seen as very effective. In terms of playability and enjoyment, the game fulfilled all our expectations, and indeed the majority of players expressed a great desire to play again. We were particularly pleased that the kill mechanism seemed to strike a good compromise between being too hard and too easy, as we had to compromise from our original design due to the capabilities of the phone model.

By analyzing the logged date at the server we were able to identify tactics that became apparent during gameplay. The first concerned PAC-LAN players who deliberately went long periods without tagging a pill, despite losing a point for every second they went without doing so. This occurred on a couple of occasions, which did not seem to prolong the game much above the average. In both cases the PAC-LAN character failed to get close to the two highest scorers, who, interestingly, were players who tagged most regularly. This phenomenon was not as noticeable in the ghost players who generally tagged regularly, as they had to keep their kill timer charged; those who didn't invariably finished with a negative score. We considered making the points' deduction for the PAC-LAN player exponential, based on the time between tags, but delayed doing so until we had exposed more players to multiple games. The second tactic is related to whether the ghosts appeared to act as a group or were truly independent. Some ghosts quickly grasped the concept of adjusting their movements in relation to the other ghosts as well as to the PAC-LAN character, enabling the ghosts to cut off his/her means of escape. When they came into close proximity to each other, we often observed ghosts either calling directions to each other to try and catch the PAC-LAN character in a pincer movement, or warning each other that the PAC-LAN character had a power pill. These kinds of ghosts most often achieved a kill, while those who became fixated on the PAC-LAN character were more likely to be killed, as they often failed to spot that the PAC-LAN character was approaching a power pill. We are currently developing an enhancement that will adapt the monitor/spectator application to create a ghost master who will be able to send messages to the individual ghosts to instigate a greater degree of collaborative play. Our intention is to make the ghost master "invisible" to the PAC-LAN player, in that he does not wear a costume or know the players prior to the game. The textual descriptions are created in such a way that the ghost master has to have an understanding of the game maze. The descriptions could vary from the straightforward, such as giving a building number, to something less direct like "having a pint." From the latter description, the ghost master has to infer that the player is near to one of the college bars in Alexandra Park.

Further improvements could be to dynamically change the allocated points, or provide special "power moves" (a power move allows a ghost to kill PAC-LAN, even if he/she has a power pill) or provide a longer kill time to the ghosts as the game progresses. The changes can be deduced from the real-time data received at the server to ascertain the effectiveness of the time the ghosts have spent in the game. To see how this can be obtained consider Figure 14, which shows a space-time plot [Bamford 2006] for data obtained during a trial and shows PAC-LAN being hunted down by a ghost.

From this space-time analysis, this particular ghost, despite a delayed start, was often very close to PAC-LAN, and therefore very active in the game. This can be measured

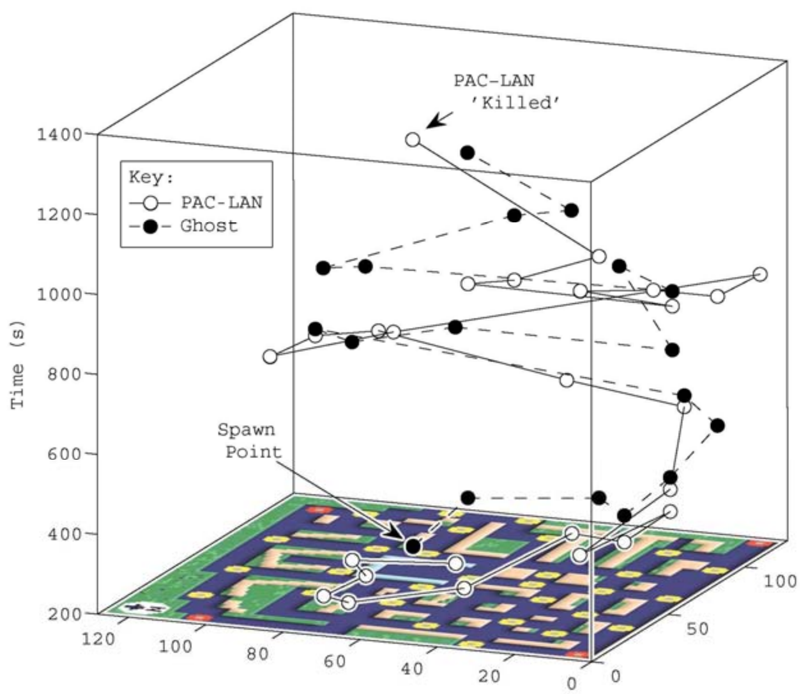

Fig. 14. Space-time analysis of PAC-LAN and ghost during a game.

dynamically within the game by performing a real-time cumulative correlation calculation between the path of the PAC-LAN player and each ghost. At some point in the game, the server can trigger a power move for the most active ghost. The points or power move benefits will not only encourage ghosts to be more active in the game, but could also result in more collaborative play, e.g., two ghosts lure PAC-LAN into an area where a third ghost is hiding with a power move.

Overall, we concluded from the user experiences that the game is a great success, perceived as fun to play and easy to use. The following are quotes taken from the feedback questionnaires, given at the end of each game.

"A unique experience! Great Fun!"
"Very good idea and very good fun (but exhausting!)"
"This is a very simple game but effective and enjoyable to play. It seems well thought out and would be popular with gamers and nongamers. Top game!!"
"Amazing game! Would definitely play again!"
"Thanks for the chance to play. Enjoyed it and got very tired!"

5. DISCUSSION AND FURTHER WORK

In terms of meeting our four objectives for the game, we have indeed seen that physical objects do aid in playing an augmented reality game and that RFID can produce an effective interaction. The use of RFID certainly means the game could be played at high speed, as attested to by the comments from the players. In terms of tactics, we have already seen emergence of such, but we will continue this analysis over the coming months when we intend to run weekly trials of the game and develop a maze map to allow similar trials in Helsinki. Further, we intend to run some games with the ghost master in play to see whether this enhances the overall collaborative game play.

In terms of future work, we are currently developing a game based on the Sega Megadrive classic, Toejam and Earl, but utilizing NFC-enabled phones will allow players to interact directly with each other by simply touching their phones. Although some games have seen collaborative efforts between online and mobile games [Licoppe 2006] and some mediated encounters were observed in some mobile location-based games, we feel that direct interaction as part of the game may produce a greater collaborative gaming experience. Indeed, whereas PAC-LAN fits most readily into Jane McGonigal's definition of pervasive gaming, our hope is that the implementation of Toejam and Earl will produce an immersive experience or, as described in McGonigal [2003], a "perversive game."

We also intend to make extensive use of sounds to expand the findings of the PAC-LAN user trials. To this end, with the kind permission Greg Johnson, one of the original game developers, we are incorporating sounds from the original game.

6. CONCLUSIONS

RFID is already having significant impact on the business sector, and has the potential to make an equally significant impact on the consumer market. We have seen a small number of examples of RFID games, such as SEGA's "Major War," but they have all been based on a static location scenario and have not incorporated a mobile phone.

The synergy of the RFID and NFC with a mobile phone will enable a greater level of innovation, as it will allow users to readily interact with real objects in real locations, outside the traditional games arcade.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of Nokia by its provision of RFID phones and access to the LI server to the Mobile Radicals research group at Lancaster University for the development of this project.

REFERENCES

BAMFORD, W., COULTON, P., AND EDWARDS, R. 2006. Location based mobile blogging. In *Proceedings of the International Conference on Information & Communication Technologies: From Theory to Applications* (Damascus, Syria, April 24-28). IEEE.

CHEOK, A. D., GOH, K. H., LIU, W., FARBIZ, F., FONG, S. W., TEO, S. L., LI, Y., AND YANG, X. B. 2004. Human Pacman: A mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. *Personal Ubiquitous Computing 8*, 71-81.

COULTON, P., RASHID, O., EDWARDS, R., AND THOMPSON, R. 2005. Creating entertainment applications for cellular phones. *ACM Computers in Entertainment 3*, 3 (July).

ECMA. 2004. Near field communication: White paper. Ecma/TC32-TG19/2004/1.

INTERNATIONAL STANDARDS ORGANIZATION. 2000. Information technology – Automatic iIdentification and data capture techniques – Bar code symbology – QR code. ISO/IE 18004.

LICOPPE, C. AND INADA, Y. 2006. Emergent uses of a multiplayer location-aware mobile game: The interactional consequences of mediated encounters. *Mobilities Journal 1*, 1 (March), 39-61.

MAGERKURTH, C., CHEOK, A.D., MANDRYK, R.L., AND NILSEN, T. 2005. Pervasive games: Bringing computer entertainment back to the real world. *ACM Computers in Entertainment 3*, 3 (July).

MCGONIGAL, J. 2003. A real little game: The performance of belief in pervasive play. In *Proceedings of the Digital Games Research Association (DiGRA) "Level Up" Conference* (Nov).

PALMER, S. 2005. Mobile phone makers eye booming games market. http://news.ft.com. Aug.

RASHID, O., MULLINS, I., COULTON, P., AND EDWARDS, R. 2006. Extending cyberspace: Location based games using cellular phones. *ACM Computers in Entertainment 4*, 1.

RFID JOURNAL. 2004. Developing RFID-enabled phones. http://www.rfidjournal.com/article/articleview/1020/1/1/. July.

Received March 2006; revised May 2006; accepted June 2006.