Capture the Flag:

Mixed-Reality Social Gaming with Smart Phones

This game uses mobile devices, PCs, and a network to combine real-world and virtual game play.

Adrian David Cheok, Anuroop Sreekumar, Cao Lei, and Le Nam Thang
National University of Singapore

The last decade has seen the proliferation of highly portable devices such as PDAs and cell phones. At the same time, technological developments suggest that the explosive expansion of mobile computing and networking infrastructure will gradually free users from the constraints of stationary desktop computing. With this technological progress in sight, we've developed a mobile, mixed-reality version of capture the flag, a popular genre of computer game.

Our CTF game is novel in three ways. First, the smart phone is the main interface. Using the smart phone, players physically role-play virtual characters who try to capture enemy flags by traversing different landscapes. This approach creates a direct, real-time linkage between the real and virtual worlds.

Second, players can move freely in the real world over a wide area while maintaining seamless real-time networked contact with other players in both the real and virtual worlds. Our implementation of CTF focuses on true mobility with minimal hardware.

Third, CTF explores novel tangible aspects of human physical movement and perception, both in the real-world playing environment and in interaction with the virtual world. Figure 1 illustrates the types of interaction in CTF. The game tracks the real-world players' physical movements and creates a virtual representation of those movements in the virtual-world players' desktop application. In addition, physical and virtual objects embedded throughout the real and virtual worlds enrich the players' experience of interacting with the environment.

Toward more social and mobile interaction

Today's mainstream entertainment revolves around interactivity. Gone are the days when people were satisfied only with the passive entertainment that television and radio provide. Today, people also want entertainment they can control and become fully involved in, a system that interacts intelligently with them and their surroundings. One of the top reasons why people play games is that game playing is a social activity they can enjoy with their family and friends.[1]

In parallel with the increasing desire for interactivity, networking-technology[2] advancements have precipitated networked games' popularity in social settings. Nevertheless, even in networked games, social interaction is still limited because a mental feeling of physical and social presence is lost. So, CTF game play overcomes this limitation by taking physical proximity into account.

A growing trend has been commercial arcade games that require physical movement. For example, in Dance Dance Revolution and ParaPara-Paradise, players dance in sync with a dance tune and animated objects. However, these systems still force players to stand in the same spot and focus on a computer screen in front of them. CTF expands on this trend by moving the game outdoors and encouraging players to move around without constraints.

Published by the IEEE CS and IEEE ComSoc ■ 1536-1268/06/$20.00 © 2006 IEEE

Figure 1. Real-world and virtual-world players interact in Capture the Flag.

CTF

The original capture the flag is a popular outdoor game. Each of two teams chooses an area as its base. In one version, each team has a time period (for example, five minutes) to hide its flag at its base. During this period, spies try to locate the opponents' flag and catch the opponents' spies. After the flags are hidden, each team tries to capture the other team's flag. If a player is caught by an opponent, that player goes to "jail" but can be freed when a teammate touches him or her. The first team that brings the opponents' flag back to its base wins.

Various popular computer games such as Quake and Counter Strike have incorporated this game's basic concept: capturing your opponents' flag at their base and bringing it to your home base. Our CTF game follows similar rules but incorporates pervasive physical and social interaction over a wide area. (For information on some games that are similar to CTF, see table 1.)

Game play

The game employs a medieval theme, with castles representing bases in the virtual world. Real-world players are knights and virtual-world players are guides, on either the red or blue team. Figures 2 through 4 show examples of game play from a knight's and a guide's viewpoints. There are five types of game entities—flags, bombs, traps, magic potions, and castles. The flag is a physical entity (a brown wooden box encasing a Linux-based Bluetooth device) with a virtual representation; the rest are purely virtual entities that are collocated in a physical position in the real world.

First, each team sets its castle in the playing field. Any knight can set a castle

Figure 2. The red guide's game play on the 3D desktop application.

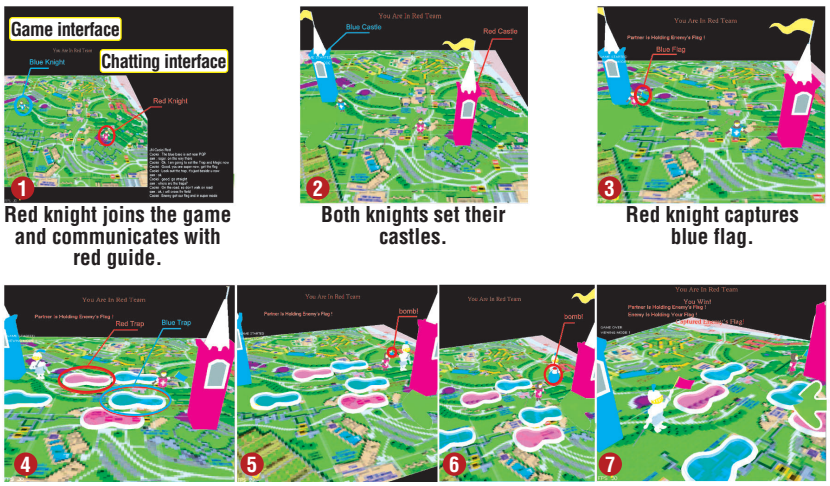


TABLE 1

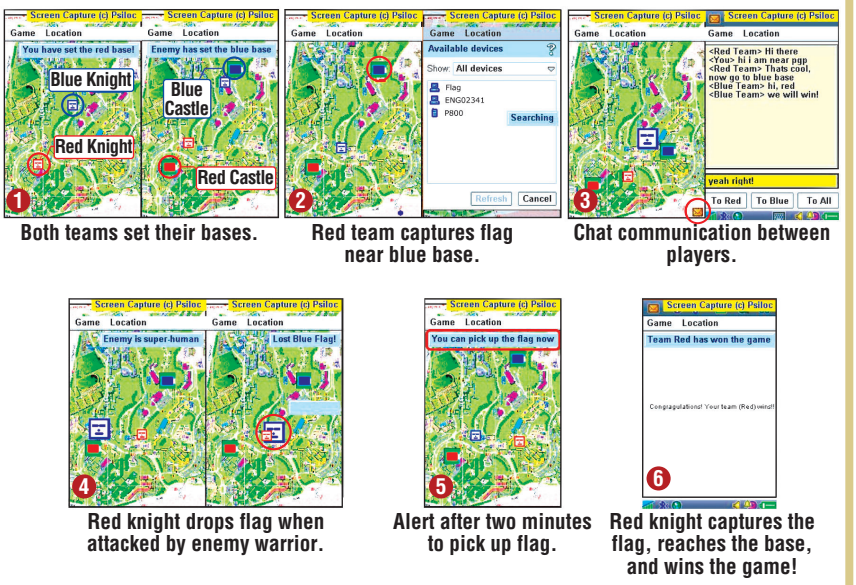
Several games that employ location-based, multiplayer, ubiquitous, or mixed-reality approaches.

Game	Description	Comparison to Capture the Flag
Can You See Me Now[3] (www.blasttheory.co.uk/cysmn/cardiff/en/intro.php)	Three street runners chase up to 20 online players across a city. Players use handheld computers over a wireless LAN; the game uses GPS to track their positions. Real-time audio communication channels connect runners and online players. Online players can also talk to each other or runners using a text channel.	CTF uses smart phones on a GSM network instead of handheld computers. CYSMN's reliance on WLAN access points restricts its playing field to several hundred square meters; CTF's playing field is much larger, owing to the GSM network. In addition, CYSMN doesn't involve as much interaction and team spirit because real-world and virtual-world players don't collaborate to achieve a common objective.
Pirates![4]	Virtual ship captains explore islands, trade goods, or engage in combat. Pirates! runs on PDAs over a WLAN, with short-range-radio proximity-sensing technology. It incorporates a player's contextual information (such as physical colocation of players and objects in the world) into the game context as important elements. Communication takes the form of trading or combat between captains.	CTF works in a wider playing field with no complicated setup of tracking equipment. Moreover, CTF involves both collaboration among team members and competition between rival teams; only the latter is true of Pirates!
Uncle Roy All around You (www.uncleroyallaroundyou.co.uk)	Online players must search for a postcard in a virtual city and guide street players to collect this postcard in the real city. Street players use a handheld computer connected to a WLAN. Street players declare their physical location either explicitly through short audio messages or implicitly by sending information about the area of the map they're looking at on the PDA to remote online players.	CTF combines a smart GSM phone with GPS tracking, thus providing a reliable, simpler way to locate players. In addition to tangible interaction with real objects, CTF lets players interact with virtual objects, which doesn't happen in Uncle Roy All around You.
Botfighters (www.botfighters.com) and Gunslingers (http://guns.mikoishi.com/gunsSingTel/gameplay.html)	These two commercial location-based phone games have been implemented in several countries. They exploit GSM location technology—namely, Cell ID Network Positioning technology—to determine the phone user's position. They're like a GSM version of Pirates! implemented on a larger playing field. The GSM location system's accuracy depends on the various techniques each game applies. Currently, GSM-network-based positioning usually has an accuracy of up to 100 meters;[5] Cell ID Network Positioning increases the accuracy to 50 m.	CTF uses GPS tracking with an accuracy of 20 to 50 meters and is freely accessible. Furthermore, CTF doesn't rely on the service provider for extra services such as GSM positioning technology.
ARQuake[6] (http://wearables.unisa.edu.au/projects/ARQuake/www/index.html) and Human Pacman[7] (http://155.69.54.110/RESEARCH/HP/HP_webpage/research-HP-infor.htm)	These two games, examples of previous research in mixed-reality gaming, are adaptations of the popular Quake and Pac-Man games that incorporate the real world. ARQuake is a single-player game with practically no social interaction that uses a heavy head-mounted display that immobilizes the player. Human Pacman requires a high level of player social interaction but uses complicated wearable-computer equipment.	Unlike ARQuake and Human Pacman, CTF minimizes the hardware requirement down to a single smart phone, giving players more mobility. Also, CTF allows multiple players, unlike ARQuake.

by dropping his or her team's physical flag at a selected place. Once the knight does this, a virtual castle and flag appear at the corresponding location in the guides' 3D map (view 2 in figure 2). Icons in the smart phone interface indicate the castles' locations (view 1 in figure 3). The base can't be moved, but an opponent knight can move the flag. So, players should choose places that opponents can't easily access.

Knights capture a flag by physically picking it up (view 3 in figure 4). Tangible interaction with a real object to obtain a virtual entity (the virtual flag) offers yet another unique experience for the players in mixed-reality gaming. As soon as the knight acquires the physical flag using his or her mobile toolkit (which we describe in the next section), the communication framework ensures

Figure 3. The red knight's game play on the smart phone interface.



that the guides' computers are updated to show the knight's new status.

Guides can place one magic potion and up to three traps in playing field. In the virtual world, when a knight touches his or her team's magic potion, that knight becomes a warrior for two minutes. Moving warriors and stationary traps can catch an opponent knight who has their team's flag by being in the same physical location as that knight. If they catch that knight, the flag becomes a bomb in the virtual world (view 6 in figure 2). To survive, the opponent knight must "drop" the bomb (place the physical flag quickly on the ground) and run 15 meters away immediately. The bomb turns back into a flag after two minutes. Possession of the flag can alternate between teams throughout the game.

Throughout the game, players communicate through text messaging. They can chat publicly with all players or send private messages to their own team. Communication between the knights and guides is the key to winning the game because only the guides know where the magic potions and opponents' traps are. So, it's imperative to pass on this information at the right time to the right player.

The game ends when a team successfully captures its enemy's flag and takes the flag to its base. The game could also end if one team's knights all fail to escape from an opponent trap or warrior. If neither team captures the flag in one hour, the game is a draw.

System design

The guides use a normal Internet-connected PC running a 3D virtual-client application. Each knight's mobile toolkit consists of a Sony Ericsson P900 smart phone running Symbian OS v7.0, a Bluetooth-based GPS receiver, and a Linux-based Bluetooth device. We use the same type of Bluetooth device for the flag.

All this hardware is readily available on the consumer market except the Bluetooth device in the wooden box. This device comprises a single-board computer, a serial Bluetooth dongle, touch sensor circuitry, a controller module, and a power supply. A knight acquires the real-world flag by connecting to it through the mobile toolkit's Bluetooth communication system, activating its touch sensor, and then physically holding it.

The system's core is the Active Game Server, which stores persistent game information in a local database. The AGS simultaneously communicates with multiple disparate clients—at least two smart phones and two PCs. In addition, each smart phone communicates with its player's GPS receiver and Bluetooth device.

Figure 4. The red knight's game play in the real world.

A user study

To explore and analyze the game experience, we conducted eight trial runs of the game. The playing field was the National University of Singapore campus, which covers 800,000 square meters. The players were NUS students and staff. Of the 32 players, 29 (91 percent) were between 18 and 24 years old, and 21 (66 percent) were male.

Our approach

Our study had four phases. In the *introduction phase*, we introduced the participants to the CTF system and briefed them on how to play the game and use the equipment. In the *pregame-expectations phase*, the participants answered questions about the perceived level of challenges and interactivity the game offered. This phase also explored the participants' demographics and their computer- and outdoor-gaming interests. In the *user trial phase*, participants played the game for approximately half an hour. In the *postgame-feedback phase*, the players answered more questions aimed to measure their experiences playing the game and compare this with their expectations. Some questions were for all players; others were just for the knights or guides.

Findings

The game's pace was fast in most trial runs. Knights dropped and reacquired the flag an average of six times per game, meaning that they used some of the special features (traps, bombs, and magic potions) six times each game. Each team consisted of two players: one knight and one guide (logistical constraints limited the number of knights in a team to one). So, the knights' responses regarding interactivity and communication were likely to be skewed because guides are most effective when they manage two or more knights.

Communication. Although players could see the location of bases and enemy players, some of them liked to check with teammates. One knight explained, "I can see the base on my phone's screen, but I don't know if my guide notices it. It's not that I don't trust the system, but perhaps what the guide sees is different from here." Sometimes players also wanted to remind their teammates of new events.

As we expected, knights usually listened more intently to their guides when deciding strategy owing to the guides' view of entire playing field.

This phenomenon happened more frequently with the knights and has been captured in these two conversations:

Knight: base set, c it?
Guide: Yar, near E3 entrance. Enemy's at sci fac.
Knight: on the way.
Knight: I've picked the flag
Guide: Yar, well done! Look out enemy, he's Warrior now.

When composing text messages, knights usually used abbreviations such as "c" for "see" and "u" for "you" to save time and effort because keying messages on the phone isn't convenient. This could mislead the guides. One guide complained that he thought his teammate was asking "why" when he saw a "y," but his teammate was actually saying "yes."

Communication between teams was poor; such chatting was limited to greetings or some nonsense arguing. Many players felt that they didn't have anything to say to the other team. We can improve interteam communication by introducing common missions that require both teams initially to coordinate so that the main competition can start properly.

Team play. Players carried out team discussions on strategic playing. They discussed mostly where to set their castle and their traps. They usually used magic potions as an emergency backup when their opponents might win. One team decided to use just two of three traps, reserving the third for an emergency.

The following conversation occurred between red team members during the two-minute wait after a red knight was caught by a blue trap but successfully dropped the bomb.

Guide: Catch knight 1st. I'll put potion on ur way.
Knight: Still got trap?
Guide: Yar, no worry. I'll block other tracks.
Knight: on the way

Knights usually listened more intently to their guides when deciding strategy owing to the guides' view of entire playing field, as we expected. To reach a destination, knights had considerable freedom. Some of them caught a bus passing by; others chose a shortcut.

Trust issues existed between team members. For example, when a knight took a bus or went through a building, the GPS signal became distorted or inaccessible. So, the guide couldn't see the knight's actual position. Most guides who experienced this problem chose to trust their teammate and provide guidance based on what the knight told them, not on what their screen showed them.

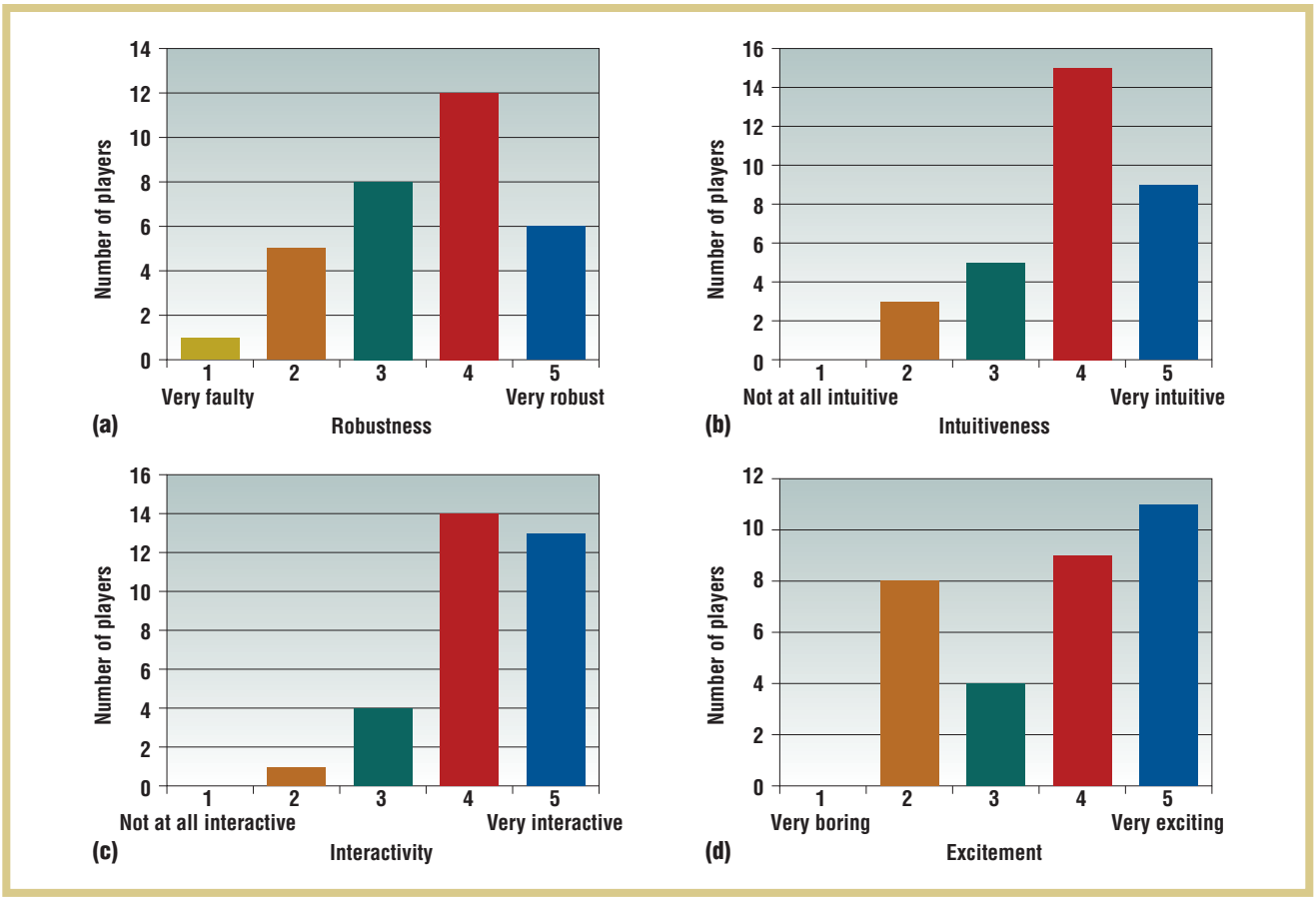


Figure 5. Players' opinions of CTF's (a) robustness, (b) intuitiveness, (c) interactivity, and (d) excitement.

User responses

The players all felt that game play was highly innovative. They felt that the social interaction between the real-world players and virtual-world players was unique and thought-stimulating. They were also pleased by the playing devices' user-friendly interfaces.

We asked all the players to rate CTF on its robustness, intuitiveness, excitement, and interactivity on a scale of 1 to 5 (see figure 5). Most players were pleased with the game's robustness and intuitiveness (see figures 5a and 5b). Although sometimes GPRS (General Packet Radio Service) lag caused network problems and the mobile application didn't give desirable results (for example, it crashed at times), the game performed well overall.

We defined interactivity as the extent to which communication with the system and fellow players contributed to game play. Twenty-seven players (84 percent) felt that game play was highly interactive (a ranking of 4 or 5—see figure 5c), although many suggested that the game should use sounds and vibrations to indicate completed acts. This finding confirmed the effectiveness of our user interface, which we implemented to be interactive and intuitive.

However, eight players (25 percent) felt the game wasn't as exciting as other computer games (see figure 5d). Seven of these eight players were guides who felt their role wasn't integral to the game. We can tackle this problem by adding special features that would immerse the guides more into the game. For example, we're thinking of adding ghosts who appear only in the virtual world; these ghosts can attack knights, but only the guides can see them. So, the guide needs to deal with both virtual and human players. Another reason for these players' dissatisfaction might be that the game's graphics weren't as visually appealing as those of commercial games. However, most guides felt that the special features enhanced game play.

Both before and after the game, we asked all the players if they thought that communication with their partner was necessary to win the game. This question produced the most important results. After the game, the number of respondents who felt that communication was important increased from 16 to 26, a significant 31 percent increase (see figure 6). This again confirms that we implemented a system through which we could explore interaction between the real and virtual worlds. The messages that the guides and knights exchanged also verified communication's importance. Approximately 70

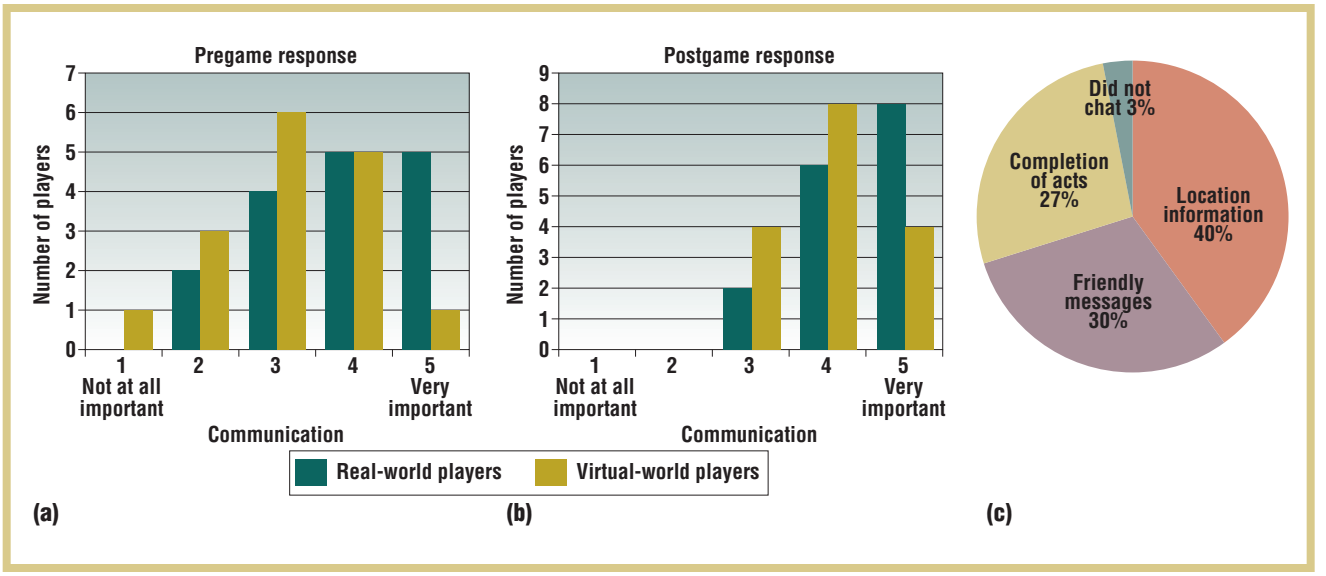
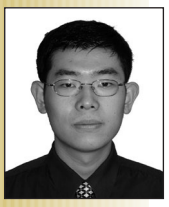


Figure 6. Players' opinions of communication's importance to CTF (a) before and (b) after playing, and (c) the types of messages that players exchanged.

the AUTHORS

Adrian David Cheok is the director of Nanyang Technological University's Interaction and Entertainment Research Center, which incorporates the Mixed Reality Lab. He's also an associate professor in the university's School of Computer Engineering and the School of Art, Design, and Media. He has been working on research covering mixed reality, human-computer interaction, wearable computers and smart spaces, fuzzy systems, embedded systems, power electronics, and multimodal recognition. He's the ACM SIGCHI chapter president and the chair of the Singapore Computer Society Special Interest Group on Entertainment Computing. Contact him at the Nat'l Univ. of Singapore, 10 Kent Ridge Crescent, Singapore; adriancheok@mixedrealitylab.org.

Anuroop Sreekumar is an undergraduate Final Year Project student under the supervision of Adrian David Cheok in the National University of Singapore's Department of Electrical and Computer Engineering. His research interests include communications and networks. Contact him at the Nat'l Univ. of Singapore, 10 Kent Ridge Crescent, Singapore; anuroop@mixedrealitylab.org.



Cao Lei is an undergraduate Final Year Project student under the supervision of Adrian David Cheok in the National University of Singapore's Department of Electrical and Computer Engineering. He's also pursuing a master's degree in business. Contact him at the Nat'l Univ. of Singapore, 10 Kent Ridge Crescent, Singapore; caolei@mixedrealitylab.org.

Le Nam Thang is a M.Eng. candidate (research scholar) under the supervision of Adrian David Cheok in the National University of Singapore's Department of Electrical and Computer Engineering. His research interests include multimedia, computer vision, and human-computer interaction. He received his B.Eng. from the Department of Information Technology at the Ho Chi Minh City University of Technology. He's a student member of ACM SIGCHI Singapore. Contact him at the Nat'l Univ. of Singapore, 10 Kent Ridge Crescent, Singapore; thang@mixedrealitylab.org.

percent of the messages were game-related information, whereas the remaining messages were friendly chat.

We asked the knights how challenging the game play was. Their postgame responses emphasized the game's physical aspects. Most of them felt that the game was physically challenging because they often had to make abrupt physical movements to save the game (such as dropping a bomb and running). The element of physicality might have been why the knights gave more positive responses than the guides.

Finally, we asked the knights to rate the game's mobility. Twelve of them (75 percent) felt the light equipment made the game highly mobile; however, they had more difficulty playing when they were carrying the flag. This reveals the need for a smaller Bluetooth device to replace the wood-encased Bluetooth device. We could also eliminate the GPS receiver by using new phone models with a built-in GPS module.

Also, 13 of the knights (81 percent) felt that physical interaction with real objects enhanced the game. This confirms the importance of CTF's tangible interaction.

The continual propagation of digital communication and entertainment in recent years is forcing many changes in the societal psyche and lifestyle—that is, how we think, work, and play. With physical and mobile gaming gaining popularity, entertainment paradigms will irrevocably shake free from the stale television-set inertia. We believe that CTF heralds the conjuration and growth of a new genre of computer game that's built on mobility, physical actions, and the real world as a playground. Elements of social gaming in CTF symbolize 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 evolving. In conclusion, we believe CTF is a novel system in the new hybrid field of physical, social, and mobile gaming that's built on ubiquitous computing and networking technology. The players can experience seamless links between the real and virtual world and therefore obtain a higher-than-ever level of sensory gratification. P

ACKNOWLEDGMENTS

Special thanks to Li Yu for helping out in all graphic designs.

REFERENCES

1. Z. Zhang and Y. Shan, *State of the Industry Report*, Entertainment Software Assoc., 2001.
2. *2005 Essential Facts about the Computer and Video Game Industry*, Entertainment Software Assoc., 2002, www.theesa.com/files/2005EssentialFacts.pdf.
3. M. Flintham et al., "Where On-Line Meets on the Streets: Experiences with Mobile Mixed Reality Games," *Proc. 2003 Conf. Human Factors in Computing Systems* (CHI 03), ACM Press, 2003, pp. 569–576.
4. S. Björk et al., "Pirates!—Using the Physical World as a Game Board," *Human-Computer Interaction—INTERACT'01*, IOS Press, 2001, pp. 423–430.
5. T. Poropudas, "GSM Networks Are Failing the Location Test," Mobile CommerceNet, www.seitti.com/story.php?story_id=2362.
6. B.H. Thomas et al., "First Person Indoor/Outdoor Augmented Reality Application: ARQuake," *Personal and Ubiquitous Computing*, vol. 6, no. 1, 2002, pp. 75–86.
7. A.D. Cheok et al., "Human Pacman: A Mobile, Wide-Area Entertainment System Based on Physical, Social, and Ubiquitous Computing," *Personal and Ubiquitous Computing*, vol. 8, no. 2, 2004, pp. 71–81; http://dx.doi.org/10.1007/s00779-004-0267-x.