Pervasive Games Research: A Design Aspects-Based State of the Art Report

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ABSTRACT
Pervasive games represent a radically new game form that extends gaming experiences out into the physical world, weaving ICTs into the fabric of players' real environment. This emerging type of games is rather challenging for developers who are engaged in exploring new technologies and methods to achieve high quality interactive experience for players. This paper follows a systematic approach to explore the landscape of pervasive gaming. First, we present ten representative pervasive game projects, classified in five genres based on their playing environment and features. Then, we present a comparative view of those projects with respect to several design aspects. Last, we shed light on current trends, design principles and future directions for pervasive games development.

Categories and Subject Descriptors
A.1 [Introductory And Survey], H.1.2 [User/Machine Systems], H.4.3 [Communications Applications], H.5.1 [Multimedia Information Systems], H.5.3 [Group and Organization Interfaces], J.4 [Social and Behavioral Sciences], K.8 [Personal Computing]

General Terms
Management, Design, Reliability, Experimentation, Human Factors.

Keywords
Pervasive games, mobile, mixed reality, trans-reality, augmented reality, localization, context-awareness, orchestration.

1. INTRODUCTION
Pervasive computing is a post-desktop model of human-computer interaction in which information processing is thoroughly integrated into users' physical environment (both objects and activities). Pervasive gaming is an emerging field within the context of pervasive computing, defining a major evolutionary step from traditional 'electronic/computer games', i.e. electronic systems that employ some kind of computational machine to create an interactive system with which a player can play [1]. Pervasive games represent an exciting and commercially promising new form of computer games that builds upon a combination of hybrid interfaces, wireless networking, and context-sensing technologies [2]. Through a combination of personal devices, positioning systems and other multimedia sensors, combined with wireless networking, a pervasive game can respond to players' movements and context and enable them to communicate with a game server and with each other [3].

As in classic computer gaming, pervasive games may be classified in sub-genres, mainly based on their playing environment and features:

- *Pure location-based games* support some kind of localization technology, e.g. GPS; the game play somehow evolves and progresses via a player's location to enhance game experience [4].
- *Mobile games* are video games played on a mobile phone, smartphone, PDA, handheld computer or portable media player [5] and incorporate dynamic relative or absolute position into account in the game rules [6-8].
- *Trans-reality games* combine virtual gaming with game experiences staged and played in physical environments [2, 9, 10].
- *Augmented reality games* and *mixed reality games* create game spaces that seek to integrate virtual and physical elements within a coherently experienced perceptual game world [11-14].

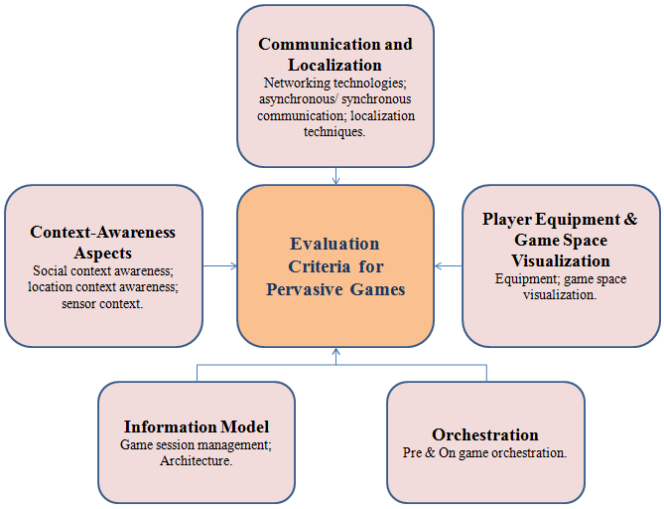


Figure 1. Design and evaluation aspects of pervasive games.

The main objective of this paper is to investigate in detail a number of games from several angles, so as to highlight the trends and challenges in pervasive gaming and extract design principles inherent in pervasive gaming. The surveyed games will be examined with respect to several design aspects (See Figure 1).

- *Communication and localization* refer to communication facilities (either among players or between players and some kind of game management engine) and localization techniques, which represent a fundamental requirement for pervasive games [9].

- *Context-awareness* criteria deal with gaming environmental aspects captured by the games as a means of linking changes in the environment with computer systems, which are otherwise static.
- *Information model* criteria aims at examining the informational and architectural models adopted in these games to assist users in satisfying their needs.
- *Player equipment and Game space visualization* criteria aims at evaluating the devices used by players and the means that the games use for the visualization of the game space.
- *Orchestration* refers to techniques and devices used by developers to manage live game action behind the scenes [2].

Our survey is based on the review and comparison of ten (10) pervasive games: TimeWarp [14], Human PacMan [12], Epidemic Menace II (EM II) [15], Urban Defender [4], Parallel Kingdom Age of Emergence (P.K AoE) [7], Hot Potato [6], Capture The Flag (CTF) [13], Can You See Me Now? (CYSMN?) [9], Uncle Roy All Around You (URAAU) [16] and Age Invaders [11]. While several other pervasive game prototypes currently exist (e.g. [17, 18]) we have chosen the abovementioned projects as a compromise between having a fairly sized games' sample and achieving a balanced representation of prototypes with respect to their generation, genre and utilized technologies.

The remainder of this paper is organized as follows: Section 2 classifies and briefly presents the set of examined pervasive game projects and summarizes their main features. Section **Error! Reference source not found.** evaluates the projects with respect to the above listed design aspects, while Section 4 discusses design considerations and highlights trends in the field.

2. CLASSIFICATION AND PRESENTATION OF PERVASIVE GAMES

To ensure a methodological presentation we have classified the ten representative pervasive gaming projects based on their genre, i.e. in augmented/mixed reality, pure location-based, mobile, and trans–reality games.

2.1 Augmented

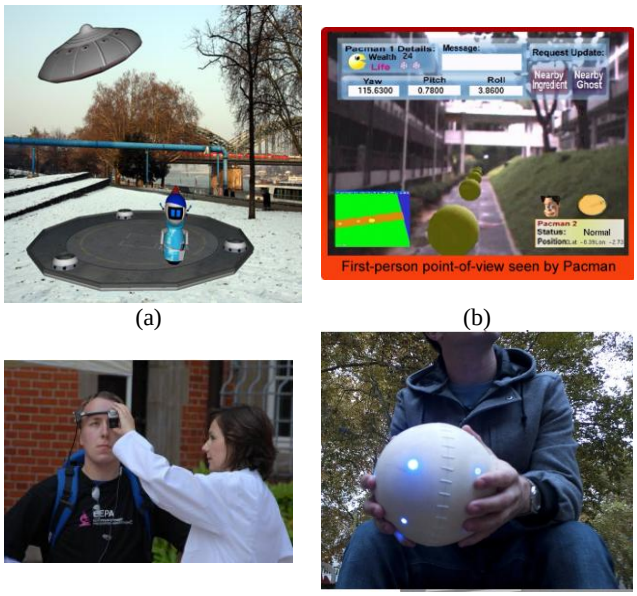
In this category we examine three games. TimeWarp (see Figure a) is a mobile mixed reality game played in the old town of Cologne by two players who are so-called Chrononauts and try to stabilize the time space continuum that is endangered by little robots by travelling into different time periods in the history of Cologne [14].

Human PacMan (see Figure b) is a real-world-physical, social and wide area mobile entertainment system built upon the concepts of ubiquitous computing, tangible human-computer interaction and wide-area entertainment networks, which enables a real time link between the wide-area physical world and the virtual Pac-World [12]. Players either play the role of PacMan or that of the ghosts, resembling the original arcade game.

EM II (see Figure c) is a cross media multiplayer social adventure game which includes indoors "stationary play" as well as outdoors "mobile play" including strategy and action elements. In EM II users try to eliminate a humankind-threatening virus epidemic fighting against 3D viruses roaming around in the real world using augmented-reality technology [15].

2.2 Pure Location-Aware Games

Urban Defender (see Figure d) is a location-aware game acted in the real world using a ball as the main interface. Targeting children and young adults, the goal and main rule of the game is: try to conquer as many quarters as possible (throwing the ball against a wall), reinforce these quarters and defend them against other players [4].



(a) (b) (c) (d)

Figure 2. (a) TimeWarp; (b) Human PacMan; (c) EM II; (d) Urban Defender.

2.3 Mobile Games

The P.K AoE (see Figure 3a) is a medieval themed, massively multiplayer GPS-based online role-playing game for Google Android and iPhone devices, wherein the user creates and evolves an in game character. P.K AoE uses Google Maps on the background and puts a whole new virtual world upon it [7].

Hot Potato (see Figure 3b) is played by a group of players gathered at a specific place. Each player holds a device that has the potential of generating a "Hot Potato" after the game begins. Each hot potato has a per-second decreasing counter that ticks for a certain period of time until it goes "boom". The players try to pass the potato to another player using a device (sensor node) through gesturing, when in proximity to the co-player. A player is disqualified when a potato 'blows' while carrying it [6].

2.4 Trans-Reality Games

CTF is based in the original 'Capture The Flag', a popular outdoor game. Each of two teams chooses an area as its base to hide its flag. Having hidden the flags, each team tries to capture the other team's flag. In CTF, real and virtual-world players are called 'knights' and 'guides', respectively [13]. The game employs a medieval theme, with castles representing bases in the virtual world. Any knight can occupy a castle by dropping his/her team's physical flag at a selected place, while guides use traps and potions to help knights; the game terminates when a team successfully captures its enemy's flag and carries it to its base.

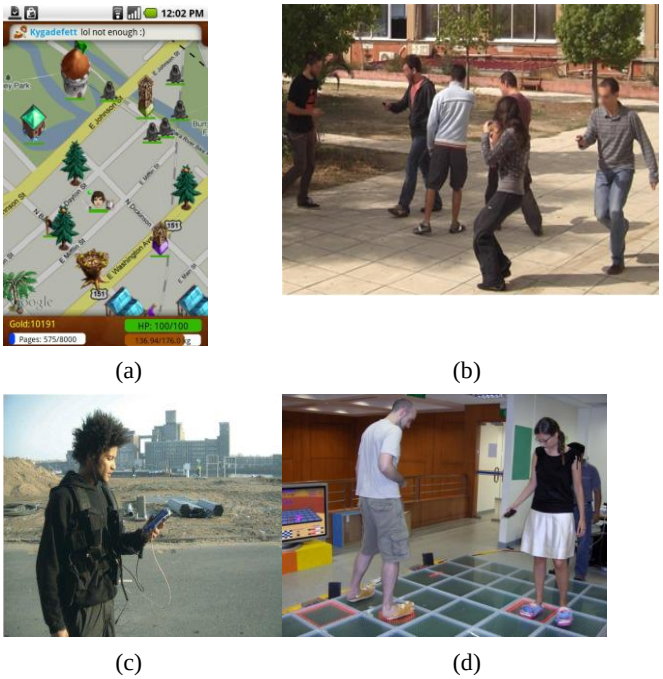
In CYSMN? (see Figure 3c) runners, equipped with a handheld PDA with WiFi radio, a GPS receiver and a walkie-talkie, run around real city streets to catch the online players who use a PC and move through the virtual street representations. The online

players can move through the virtual model of the city at a fixed maximum speed, can access various views of the city streets, can see the positions of other players and the runners and can exchange text messages with one another. As the runners move through the city streets, they can view the positions of the online players and other runners on a handheld map, read the players' text messages, and can communicate with one another using walkie-talkies [9,19].

URAAY is a mixed reality game that mixes online and street participants, physical and virtual worlds. It employs programmed game-play with live performance wherein the players search of an elusive character named Uncle Roy. Street players join the game by purchasing a ticket for an experience that will last for a maximum of one hour. They journey through the city following clues on a PDA in search of Uncle Roy, while online players connected to the game over the Internet journey through a parallel 3D model of the game space and follow street players progress trying to help them [16].

2.5 Mixed Reality Games

Age Invaders (see Figure 3d) involves two children playing with two grandparents in an interactive physical media space, while two parents can join into the game via the Internet as virtual players, thus enhancing inter-generational interaction. Age Invaders is based on the popular traditional Space Invader arcade game and the players physically act the characters of Invaders and Defenders. [11].



(a) (b)

(c) (d)

Figure 3. (a) P.K AoE; (b) Hot Potato; (c) CYSMN?; (d) Age Invaders.

Table 1 summarizes the main features of surveyed games.

Table 1. Main features of the reviewed pervasive games.

Game	Concept	Shipping date/Creator	Single/Multi Player	Genre	Game space	Unique Features
TimeWarp [14]	Item hunt/ Puzzle	2007/iPcity	Multi/Single player	Augmented reality	City streets	
Human PacMan [12]	Chase	2003/Mixed Reality Laboratory	Multiplayer	Augmented reality	City streets	
EM II [15]	Item hunt/ Puzzle/LARP	2006/ Fraunhofer FIT, University of Tampere	Multiplayer	Augmented reality	Indoors/ Outdoors (in a predefined area)	
Urban Defender [4]	Chase	2009/Zurich University of Arts Department of Interaction Design	Multiplayer	Pure location-Based	City streets	
P.K AoE [7]	Item hunt/ /role playing	2010/PerBlue	Multiplayer	Mobile game	Outdoors/ indoors	Supports massive number of players; persistent game world
Hot Potato [6]	Chase	2010/University of Patras	Multiplayer	Mobile game	Outdoors/indoors	Allows operation in connected/disconnected mode; persistent game world
CTF [13]	Chase	2006/National University of Singapore	Multiplayer	Trans-Reality	Indoors/City streets	
CYSMN? [9]	Chase	2003/, University of Nottingham	Multiplayer	Trans-Reality	Indoors/ Outdoors (in predefined area)	
URAAY [16]	Item hunt/ Puzzle/LARP	2003/ University of Nottingham	Single Player	Trans-Reality	Indoors/ City streets	Encourages players to cross boundaries between physical and virtual worlds (e.g. getting into a limousine with a stranger)
Age invaders [11]	Chase/puzzle	2006/ Mixed Reality Lab	Multiplayer	Mixed reality	Indoors/Floor Board	Compensation for elderly players' disadvantages

3. DESIGN ASPECTS-BASED EVALUATION OF PERVASIVE GAMES

3.1 Communication and localization

The use of networking technologies is a fundamental requirement for pervasive games as they enable the communication among players or between a player and a centralized game management facility. Bluetooth has been a common networking choice among many games [11-15], to enable short-range connectivity. In most cases, Bluetooth has been supplemented by GPRS [13, 15], and Wireless LANs [12]. Other games opted to use 3G [7] and ZigBee technologies [4, 6]. However, developers and users reported connection and latency problems when using WLAN or GPRS technology [12, 13, 15, 16, 19] in many game projects.

Evidently, connections exist among the games' generation (i.e. shipping date) and adopted networking technologies, depicting the evolution path of wireless technologies. Another selection criteria has been the intention to support small or large-scale playscape and indoors or outdoors coverage. In that respect, in the near future we shall expect increased use of 3G/4G as well as emerging, standardized short/medium-range technologies such as ZigBee, UWB and WiMAX.

A major challenge for almost all types of pervasive games is to track players' position, as content and action typically depend on the absolute or relative players' position (e.g. for real-time navigation, location-based information provision, co-players positions visualization, etc). GPS technology has been a reasonable choice for outdoor user positioning in most projects [4, 13, 14, 19]. However, in practice many users reported frustration due to GPS serious coverage and accuracy problems, especially in urban landscapes which accentuate GPS uncertainty. The coverage problems of GPS motivated the use of supplementary positioning technologies like computer vision [14], DRM III modules [12] or combination of GPS and Wi-Fi cell identification [7] or even ask for the players to declare their position like in URAAY [16]. Only a few games make no use of GPS technology and opted to use ZigBee [6] and RFID [11].

3.2 Context awareness aspects

Players location is a contextual parameter captured by all surveyed game projects. All the games also take into account some short of social context. Many of them are aware of co-players activity in addition to their location [4, 7, 11-14]. In CYSMN? online and street players are only aware of other players' position, while Hot Potato involves gesturing identification and communication among nearby user devices. Several games capture additional contextual parameters such as orientation and acceleration [4, 12-15] as well as human touch (pressure) [12, 13].

3.3 Players equipment and game space visualization

Pervasive game players commonly use more than one device as player equipment. In many cases players use mobile phones as part of their equipment [7, 13, 15] and occasionally wearable computers [12], sensor nodes [6], UMPCs and PDAs [9, 12, 14-16] and PCs [9, 11-13, 15, 16]. Custom devices (e.g. sensor nodes [6], Led block floor [11], ball devices [4], sugar cans [13] and toy guns with embedded Bluetooth transceivers [11]) has also been operated as game equipment.

Regarding the utilized means of game space visualization, virtual reality is a popular visualization instrument. Augmented reality appears to claim increased share [12, 14, 15], while Urban Defender is the only game that uses vibration (combined with audio) as a means of game space visualization [4]. The majority of the games visualize content through 2D and 3D graphics/maps [9, 11-16]. The use of audio has not been common among surveyed games.

3.4 Information model and architecture

Most of the games only support maintenance of basic, explicitly stated profile information, like name and gender [4, 7, 9, 11, 16]. Some provide simple personalized services based on user profile (e.g. adjustment of players' anticipated reaction time based on user age [11] or avatar selection based on user gender [7]. Many of the games maintain game history records, typically fed as implicit input to the game engine; for instance player statistics or credits earned [7, 9, 16], player trajectories [14] and game state information (allowing to pause/resume the game) [6, 7].

Many of the games are based on a centralized model, wherein a single server facility maintains game session state information, with players' devices communicating asynchronously through it [4, 7, 9, 11, 15, 16]. Others enable direct communication between players without necessarily requiring interaction with a remote server, hence their hybrid adhoc/centralized organization model [6, 12, 13]. In contrast, TimeWarp uses a distributed game engine model, wherein user devices maintain and exchange game session information through P2P interaction.

3.5 Orchestration and assigned roles

The actions and techniques used by developers to manage the live game behind the scenes and ensure a game flow with minimum interruptions and errors can be summarized under the term "orchestration" distinguished in pre-game orchestration (actions taken before the game session starts) and to on-game orchestration (actions taken during the game session, at real-time) [2].

In some of them the main pre-game orchestration action is the registration of the game area into real world coordinates [4, 7, 12-16]. Human PacMan and EM II also exercise team formation [12, 15]. Interestingly though, only a few games incorporate on-game orchestration actions. In particular, some games employ individuals or teams charged with the orchestration responsibility and/or technical assistance [9, 15, 16], while Hot Potato involves automated monitoring of game rules by the game engine.

In addition to the role of street player, the examined games also cater for online player roles [9, 11, 12, 16]. A few games let players choose among street and station player roles. Age Invaders also defines a role similar to street player that may play indoors on a Led block system.

4. DESIGN CONSIDERATIONS AND TRENDS IN PERVASIVE GAMING

The proliferation of mobile platforms, the fast evolution pace of wireless networking and the increasing availability of sensing devices have shaped a favorable technology landscape for the adoption of pervasive gaming. The advent of mobile games (at the beginning, practically mobile versions of full-fledged desktop video games) has been the first major step towards the vision of pervasive gaming. Soon after, several games specifically designed for mobile platforms appeared [15]. Such games take advantage of the mobile features like network connectivity, portability and

game context, enabled by the emergence and commercial availability of pervasive computing technologies. Coupled with the augmented reality technology, which allowed the mix of physical and virtual playscape and enabled the participation of online and 'street' players, pervasive games succeed in creating innovative and exciting game experiences.

Wireless communication represents a fundamental requirement for pervasive game design. Among others, latency, transfer speed, coverage, user capacity, cost and ease of deployment are the most important factors for choosing a networking technology. Of course, those need to be examined in connection with the particular game scenario and user requirements. For instance, WLANs offer low user cost, low latency and high transfer speeds, which are necessary in fast action-paced games with rich player-to-player interaction as it ensures smooth gameplay. In pervasive games with occasional player-to-player interaction, the above requirements are not that strict. On the other hand, WLANs cannot satisfy requirements for wide coverage and may be expensive and difficult to deploy in large scale. While 3G communication appears an obvious solution for outdoor games, it may considerably increase the cost for mobile players, unless billing policies change radically. To this end, middle-range networking technologies like WiMAX may offer an attractive alternative in the near future, especially for urban-scale playscapes.

When direct player-to-player communication is required, Bluetooth has been so far the obvious choice. However, mainly due to its limited range, Bluetooth is inappropriate for large-scale adhoc networking. Emerging short-range solutions such as UWB and ZigBee overcome many of the Bluetooth technical restrictions and could serve as an effective substitute, especially as these standards become adopted by smartphones.

As for localization techniques, GPS is the definite choice for outdoor game developers, although in some urban environments it is known to have connectivity, latency and accuracy problems. WiFi/3G cell ID techniques may also be considered in cases that high localization accuracy is not important, while Bluetooth (or alternative short-range communication technologies) may act as a proximity measurement tool, e.g. in chasing games. In games that use augmented reality content, developers may use additional localization technologies in conjunction with GPS (like DRM III or CV) to ensure improved precision so as to allow the projection of AR content at the right display position, and eliminate game flow interruptions due to GPS unavailability. For indoor games, developers may choose among available indoor localization systems [20]. RFID and NFC technologies may also act as supplementary tools for indoors/outdoors location tracking, especially since smartphones shipped with RFID and NFC readers become commercially available.

In most games scenarios position visualization is a necessity, using 2D/3D maps, while additional visual information may be conveyed through 2D/3D graphics. The use of 3D maps/graphics is expected to prevail, as they are supported by popular mobile application platforms as Java ME, iPhone and Android [21]. Google Maps will likely dominate among alternative map representation tools due to specialized API support in all major mobile platforms.

Simulation modalities (including virtual and augmented reality) represent a key feature in most games scenarios to enhance game experiences. As mobile devices evolve they become smaller and more flexible than the equipment players used in many of the surveyed games. Popular commercial products like iPhone 4 and Nokia N97 fulfill the hardware and software requirements for supporting satisfactory augmented reality content, acting as a driver for developers to incorporate these technologies that fuse physical and virtual content, in pervasive games.

As for contextual features, most game scenarios should benefit by incorporating the location and social context of players (e.g. ongoing activity and location of co-players). Additional context parameters (such as acceleration, orientation, proximity, gesturing, time, light intensity, temperature, weather conditions) may be useful to be taken into account and comprise alternative modes of implicit input in future game projects scenarios. For instance, user orientation tracking may be critical for the game engine when supporting augmented reality simulation modality. Some of the abovementioned contextual parameters may be captured by dedicated wireless sensor network installations [6]; the emergence of robust, programmable, low-cost 802.15.4-compliant sensor node platforms will likely influence the design decisions of pervasive game developers as those could reliably feed a multitude of environmental, social and activity context data. Even more so, smartphones and PDAs that commonly integrate GPS receivers, sensors, compasses and RFID readers are expected to play a significant role in providing contextual input in future game developments. Context parameters may also be provided by publicly available web services (e.g. weather status and forecast, public transportation schedules, etc).

As for the game engine model the centralized client/server architectures is currently the prevalent organization model. However, the mobile adhoc model is likely to spread among future pervasive games as it could be applicable in a variety of game scenarios that feature direct interaction among peers (players), i.e. highly localized and adhoc game play during encounters on the streets. In this context, the use of WiFi-compliant equipment, configured in the 802.11 adhoc mode, is likely to become increasingly common.

Another critical design guideline for developers is to carefully pre-orchestrate the game, e.g. register the game world into real world coordinates, prepare virtual representations of real world objects, position the game items, assemble the teams, etc. It is essential that individual game sessions have a strong relation to the physical game environment, otherwise the game scenario may appear arbitrary to the players, dramatically decreasing the quality of gaming experience. On-game orchestration actions should also be carefully provided for, in order to enhance players' engagement and ensure adherence to the game rules.

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