TimeWarp: Interactive Time Travel with a Mobile Mixed Reality Game

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ABSTRACT
Mobile location-aware applications have become quite popular across a range of new areas such as pervasive games and mobile edutainment applications. However it is only recently, that approaches have been presented which combine gaming and education with mobile Augmented Reality systems. However they typically lack a close crossmedia integration of the surroundings, and often annotate or extend the environment rather than modifying and altering it.

In this paper we present a mobile outdoor mixed reality game for exploring the history of a city in the spatial and the temporal dimension. We introduce the design and concept of the game and present a universal mechanism to define and setup multi-modal user interfaces for the game challenges. Finally we discuss the results of the user tests.

Categories and Subject Descriptors
H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities - Audio input/output H.5.2 [User Interfaces]: Evaluation/methodology - Graphical user interfaces (GUI) - Input devices and strategies. I.3.1 [Hardware Architecture]: Input devices. I.3.6 [Computer Graphics]: Methodology and Techniques - Interaction Techniques. K.8.0 [Personal Computing]: General - Games.

General Terms
Measurement, Design, Experimentation, Human Factors, Languages.

Keywords
Augmented Reality (AR), Multimodal Interfaces, Pervasive Gaming, Mixed Reality (MR), Presence.

1. INTRODUCTION
There are many differences between traditional and computer games, these include trying to increase the level of player curiosity, the provision of more challenging tasks and the creation of rich fantasy experiences. Many of these elements are considered critical to the success of fun in games [21]. However, most traditional games still provide much easier interaction with the environment or with other users.

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Pervasive games and mobile edutainment applications represent a major advance for game players and developers. Such games use information and communication technology (ICT) to overcome the boundaries of traditional gaming environments by creating new, extended ones, where the real environment of the user becomes an intrinsic component of the overall game. By joining both worlds - the real and the virtual world, they integrate the social quality of traditional games into computer games. Therefore a key aspect is the seamless integration of such games into our everyday situations and public environments.

Pervasive Augmented Reality games further extend location-aware pervasive games through the use of AR technology. The approach extends the players' environment through the use of real and virtual objects, thus altering the users' spatial and temporal presence.

During World War II, bombings destroyed about 90% of Cologne's city: as a result historic buildings, documents of the City's foundation by the Romans, or the remnants of its heyday during medieval times no longer exist. Therefore AR systems which let people walk round the real city as it is today while experiencing its historic past are both interesting and educational. In contrast to conventional forms of electronic city tours, pervasive game-based guides provide a playful way to explore a city. Combining pervasive game play with AR potentially allows for the creation of exciting city based tours.

In this paper, we describe an outdoor edutainment game called *TimeWarp*. The story of the game is based on the legend of the *Heinzelmännchen* of Cologne. These *Heinzelmännchen* were small elves, which worked clandestinely for the citizens during the night. However, legend has it that one day they disappeared. The overall goal of this game is to find and bring back the *Heinzelmännchen*. For that reason the players are equipped with a mobile AR system and a handheld-based information device.

We developed a system that allows for a 4D multimedia experience. Beside the spatial dimension, the user can also explore the environment in the temporal dimension. To superimpose virtual content in the context of real 3D surroundings we use a six degree of freedom (6DOF) hybrid tracking system to detect the player's position and orientation. Whereas former projects do not provide a sense of time but only display the historic scenes to the spectator, we provide interfaces and interaction techniques allowing the player to interact with the city and to experience its temporal changes. Instead of static, timeline-based game play, we provide a non-linear experience of the individual historic time periods. This impression is enforced by rich interactive content placed carefully in certain locations, which is easy to create through the use of our Mixed Reality Interface Modeling Language (MRIML)[4]. MRIML allows us to position multimedia content and to react to events using a universal listener concept (e.g. the system reacts if a player approaches a certain location).

In section 2 of this paper we will review existing work related to our approach. In section 3 the *TimeWarp* approach including the background story and the game concept will be introduced, while section 4 will present the overall system hardware and software architecture. In section 5 we will describe our approach for user interaction and interface techniques. Beside the technical challenges, *TimeWarp* examines presence aspects, such as how the AR game experiences will alter the perception of the city through different epochs. In section 6, we present initial results of ongoing user tests, before concluding and introducing our future work in section 7.

Figure 1. Virtual reconstruction of a historic building (referring to medieval time) compared to real world setting (small image)

2. RELATED WORK

In this section we will review existing pervasive or outdoor AR games as well as mobile AR based edutainment applications and systems with a special focus on historical exploration.

The reviewed approaches often share similar technologies (see also [5]): Typically the players are equipped with a wearable PC (e.g. a lightweight back-packed laptop, a UMPC (ultra mobile PC), or a PDA). Those are either used for handheld video-see-through AR (based on the magic lens metaphor) or are combined with head-worn displays (usually monocular, sometimes binocular/stereoscopic). For communication most approaches rely on WiFi and/or phone based services such as GPRS, EDGE, or 3G/HSDPA. Location tracking is usually based on GPS, often combined with orientation sensors and/or fiducial markers (AR Toolkit [14] or ARToolkit+ [29]).

Examples are *ARQuake* [24] and *Human Pacman* [7] - AR versions of the well known games Quake and Pacman.

In *ARQuake* the player is situated in the real world. He has to run around shooting monsters and collecting items. His position is tracked by marker-based computer vision and GPS tracking and for detecting the viewing orientation a digital compass is used.

In *Game-City* [8] the idea of *ARQuake* was developed in to a multi-user game. This was further developed in *Human Pacman,* the AR adaptation of the arcade game Pacman which is played in a real city environment. The story is the same as in the original game, namely that a player which is Pacman has to collect all the cookies in the world while being hunted by ghosts. However, in contrast to the original game, the ghosts are represented by other players, trying to catch Pacman. In contrast to *ARQuake, Human Pacman* supports multiple players. The *Human Pacman* system consists of a client-server architecture which is connected via WiFi. The client and the object, representing a cookie, are connected via Bluetooth. In contrast to our approach, *Human Pacman* situates a game, which has little or no connection to the space in which it takes place. However *TimeWarp* makes specific use of certain locations which are of historical or cultural significance, hence it is more specifically related to the environment in which it takes part. The position and orientation tracking in both systems is realized by GPS and an orientation sensor (inertial tracker).

NetAttack [15] represents a mixed indoor/outdoor AR game using GPS and inertial tacking for localization. This "scavenger hunt"-like game is based on a story of an evil corporation trying to dominate the world through the use of a huge database containing data of every human being. The goal for the players is to find and destroy the central database. *NetAttack* is played by two competing teams, each consisting of one indoor player (at a PC) and one or several outdoor players. Each outdoor player is equipped with a stereoscopic head-mounted display and a back-packed laptop. While GPS-based position accuracy was sufficient for collecting game artifacts, it showed insufficient for measuring the exact distance between the competing outdoor players or aiming at them (an outdoor player could disturb the competing outdoor player if he or she was close enough). Thus the tracked position was refined by using rather large fiducial markers (ARToolkit) carried by the outdoor players. The communication between the individual application components is based on WiFi. In contrast to our approach, the gaming area was not a public space and the game items were not interfering with real world objects.

Epidemic Menace [16][17] is a crossmedia indoor/outdoor game developed as part of the IPerG project[1].The story is about a deadly virus which has been released by an evil scientist and has to be captured by the players from either of the teams. Due to the crossmedia character of the game, the individual players use individual media such as videos, performances, etc. and individual devices including smartphones, PDAs, augmented

[1] IPerG – Integrated Project on Pervasive Gaming: www.pervasive-gaming.org

webcams, and mobile AR systems. Additional display walls are used in team headquarters. The mobile AR systems use head-worn displays, back-packed laptop computers, GPS, hybrid 3-degree of freedom (DOF) orientations sensors, and WiFi communication. The game items (viruses) are only loosely coupled with the real playground, but depend on current weather conditions (i.e. the propagation and the movement of the viruses directly depends on the current temperature and wind speed and direction).

Recent research in AR for historical exploration [28][23] and [26] has primarily focused on digital content issues such as 3D reconstruction or virtual character animation to allow an immersive tour experience on site. Projects making use of this edutainment approach are *REXplorer* [30], *Eduventure* [11] and GEIST [20], but they are primarily related to mobile social software, learning, and digital story telling than to pervasive AR games.

Eduventure plays in the medieval Marksburg castle from the 12th century, situated in the Middle-Rhine valley in Germany. The plot is about a scientist travelling back into the time of the 30 Years' War to find a captive in this period. The position and orientation detection is completely realized by using marker-based computer-vision. The game will be played in constrained environments, as the castle has to have ARToolKitPlus markers placed around it. These markers have to be found by the player using a Tablet PC equipped with a USB webcam.

REXplorer takes place in Regensburg. In this tourist guide, the user explores the city in a playful manner. Virtual magical spirits and treasures are locked in two landmark buildings. The player can unleash and interact with these items by doing specific movements using a sensing device. This gesture recognition is realized by the camera of a mobile phone. Applying optical flow image processing, the mobile phone is used like an optical mouse. The position is detected with a GPS tracker. Augmentations are only provided in acoustical form. The player gets furthermore an animation on the screen of the mobile phone as feedback for successful interaction.

While the work mentioned earlier focussed on spatial augmentation, Güven et al. [12] present interaction techniques for temporal augmentation browsing through several time periods. In their system the user wears a backpack AR system similar to [10] using a wireless trackball as an interaction device. A point of interest in the world is denoted as a virtual 3D object. When clicking on that object, an associated image or 3D model is shown. There are two different timelines to choose the age of each model or image. Furthermore, location-independent and location-dependent representations are distinguished, the latter one referring to a correct registration with the real world. This is realized by markerless computer vision.

The work presented in this paper which forms part of the *TimeWarp* system combines several aspects of the earlier approaches presented above, but additionally aims for

- a closer integration or fusion of the real environment and the virtual artifacts,
- the creation of a richer and more complex gaming experience through support for non-linear game play,
- the provision of a modular, flexible, and expandable approach based on a high-level user interface description, and
- the achievement of a high degree of spatial/physical, social, and temporal presence (by addressing multiple senses).

3. THE TIMEWARP APPROACH

TimeWarp explores the idea of creating temporal MR games both from a technical and theoretical perspective by specifically exploring new methodologies as well as issues related to presence.

3.1 Design Objectives

Traditional definitions of presence are often drawn from research into virtual environments, which tend to assume the user is in a real or virtual experience where the objective is to substitute the real sensory elements with virtual equivalents. In contrast, TimeWarp creates an environment where the real and virtual elements are combined to create a unified experience in which the user feels present. Thus, it is the relationship between the real and the virtual which is key. In many ways this is related more to the idea of "perceptual illusion of non-mediation" [18], which emphasizes that sense of presence depends on the users inability to distinguish real from virtual – although it is acknowledged that this view is drawn from a more classic VR perspective.

There is currently considerable debate within the presence community on firstly defining presence and secondly how to measure it. Both of these issues are particularly relevant to *TimeWarp* as traditional laboratory experiments are not as suitable within a city-based MR context. We chose initially to base our work two classic types of presence, for example social (the feeling of being with others) and physical presence (being in the mediated environment) [13]. In the case of the sense of physical presence our definition was extended to be the unified experience of feeling present in the overall MR experience. We were also interested in exploring how the user's sense of presence and place changed when they moved between time periods. Place being defined as a combination of the physical properties, activities and meanings within an environment [25].

The game story of TimeWarp reflects the design objectives and decisions made during conception:

- make the game play take place within the city,
- develop rich mixed reality experiences exploring the full potential of 3D animation and spatial AR sound,
- allow the player to determine the duration of the game, and
- make the game foster temporal, physical and social presence.

Consequently the game includes a game element (time portals) that allows time travelling and small, self-contained challenges permitting non-linear game play.

3.2 Story and Structure of TimeWarp

3.2.1 Background Story

The background of *TimeWarp* is the tale of the Heinzelmännchen of Cologne. The tale is about these small elves, which helped (although they were actually never observed) the citizens of Cologne during the night, until they suddenly disappeared to an unknown location. Rumor has it that they disappeared because they were trapped by a nosy tailor's wife.

We extend this legend by spreading the rumor that the elves actually never left Cologne, but fell into time holes. Thus, they are still in the city, but they are captured in different time periods. The goal of the game for each player is to find the Heinzelmännchen within the individual epochs by the means of time travel and bring them back into the present. Therefore, each player is equipped with a "magic technical" system, which enables her to see the elves and to visit different time periods – roman, medieval, new age and even the future. To rescue the so much missed small helpers, the player has to solve challenges presented by the elves.

3.2.2 Game Content

The game is staged in the old part of Cologne, within an area of about 1.5 square miles. As the players walk around they have to locate game relevant locations so that they can interact with the various elements. Three different types of game locations are implemented: time portals (leading to other time periods), markets (to buy items that are required to solve challenges), and the challenges itself. The main virtual characters in the game are the Heinzelmännchen, but other characters support the feeling of being in different time periods. In addition to graphical augmentation *TimeWarp* features spatial sound. The purpose of sound is firstly to support the sense of temporal presence, and secondly to guide the user through the non-linear game play.

Figure 2. Sample challenge: identifying the correct coat of arms

4. System Concept

TimeWarp is a distributed system: the game server retains game resources the players compete for, whereas the player system is a thick client. In single player mode, it is also possible to play *TimeWarp* without connection to the server. As *TimeWarp* is location-driven, synchronization of game status is only necessary if game play changes available resources like tools or solved challenges.

Software components running on the client include: the local game control logic, user tracking (provided by MORGAN [22]), the MRIML renderer and the user interfaces for the AR system and the PDA. In case of a multi-player game, the client is connected to the *TimeWarp* game server.

Each player is equipped with two systems: a mobile AR system which augments the real environment, and a handheld-based information device. This information system uses a Dell Axim x51v running Windows Mobile 2005. The device communicates with the AR system via a Bluetooth connection. It provides several services supporting the player during the game (see Figure 3): on an overall information page the game state is provided including the currently owned tools, the current budget and the time left to finish the game. An interactive map showing the current position of the player in satellite or map mode (similar to services such as Google maps) allows for easy player guidance within the city. The player may navigate and zoom in or out. Additionally, depending on the current game state, important game related locations are represented within the map. Moreover, specific information such as historical knowledge of the city or technical help is provided to the user by this application.

Figure 3Information device with the overall information page (above) and the interaction map (below)

Each personal AR system either uses a Notebook with onboard graphics running Windows XP Professional, or an UMPC with the same onboard graphics and OS. We use a monocular SVGA head-worn optical see-through display, tracked by a GPS receiver for positioning tracking and an inertial sensor for orientation tracking attached to the display. For spatial 3D audio we installed a special sound card. The lightweight hardware is packed into a back pocket of a vest. The total weight is less than 4.4 lbs, or 2.9 lbs respectively. Interaction devices are either a standard Bluetooth mouse or a gyroscopic mouse.

The TimeWarp AR application is based on our AR/VR framework MORGAN [22] and uses our AR/VR viewer Marvin for 3D visualization.

5. User Interface Design and Interaction

5.1 Mixed Reality Interface Modeling Language

One of the objectives when designing TimeWarp was to provide an easy way to specify the content and interaction scheme for both systems (PDA based and mobile AR). One reason for this was that the map content on the PDA had to be synchronized with the location of time portals and markets (see Figure 3) which in turn had to result in virtual objects being displayed at the correct time (see Figure 1). Instead of creating application and platform specific interfaces, we extended MRIML [4] to specify the interface. MRIML is based on XML and comes with a large number of existing high-quality tools for editing and validating. Many and open source XML/XPath/XSLT implementations exist. Moreover, the format is self-documenting, human- and machine-readable, and elements can be addressed using methods such as XPath. In contrast to WIMP based user interface description languages MRIML fully supports three-dimensional content. UI elements are located in 3D space and can be of arbitrary media types. Element binding types allow us to place them relative to another element or view-stabilized (i.e. similar to a head-up display). Possible binding types are:

- element related, i.e. the position is relative to its parent's position
- world related, i.e. an absolute position in the real world
- view related, i.e. the element is always in the field of view independent of the current player's position and viewing direction

The connection between game engine events or user input with the user interface is described with the MRIML element *Listener*. *Listeners* describe conditional signal-slot mechanisms, allowing for the specification of the game logic as well as the user interface logic. *Listeners* can react on game engine events such as proximity, data changes, or timeouts, and on user input events triggered by the individual input devices. The signals result in an action provided by the back-end (game engine or UI renderer) if the specified conditions are matched. In *TimeWarp*, the game engine triggers:

- proximity events, if the player is close to a game-relevant location
- a time travel event, when entering a time portal, and
- an event to notify about data changes.

Modeling generic user input events is quite difficult as mobile outdoor AR applications lack a standard input device. In TimeWarp pointers and buttons are supported. The device abstraction layer of MORGAN allows for the easy exchange of the actual device.

Conditions may be expressed using XSLT/XQuery statements. When modifying the overall game state by user interaction, e.g. buying a tool at a market or picking up an item, this first results in a change of the local player data, which will then modify the displayed content of the local systems (e.g. highlighting of an item or playing a sound file).

MRIML files are interpreted by an MRIML renderer written in C++. For XML parsing and validation we use Xerces/C++[2]. A plug-in mechanism allows hooking in back-end methods.

5.2 User Controls

Being in public, uncontrolled and unrestricted space sets up limitations to the possible user interaction due to the fact that the hardware to realize user control has to be carried by the user. Furthermore user control should contribute to the game experience. Consequentially, controller functionalities were restricted to a core set avoiding 2D control widgets such as menus or sliders, taking advantage of prior design experiences with other games and game-like applications.

5.2.1 *Physical Proximity*

Core interaction control is realized through proximity in the real world. Being location-aware, the system reacts on the proximity of the player to a location: in our approach, we have three proximity ranges: outside, near, and at a game location. For most of the game area there is no augmentation (neither visual nor spatial audio), and thus the GPS signal is sufficient to track the player's path, display his current position on the PDA, and play ambient sound. Entering the range of a game location (time portal, market, or challenge), precise tracking is required to register graphical and audio augmentation. As the field of view of the head-mounted display (HMD) is rather limited, a sound icon informs the players when they are getting close to a game location. To avoid unintentional use of the AR interaction device, input is only enabled while the player is at a game location. Another specific sound icon informs the player about the activation and deactivation. Additionally, particular actions may be executed immediately.

The interaction with time portals is an example for this type of control: as the player approaches the game location of a time portal, he hears a mysterious sound of wind chimes. If he gets closer to the portal and finally enters it, traveling in time is carried out automatically and immediately. A roll of thunder accompanies this interaction and a view related label denotes the changed time period. Another example are virtual characters, which start talking depending on a player's proximity.

5.2.2 *Focus, action and feedback*

The second core interaction control is based on focus and click events. Focus either is controlled with a gaze-based view pointer, a view related crosshair, or by stepping through selectable items in predefined order using the mouse wheel. The view pointer is controlled by the viewing position and orientation, thus the view pointer makes advantage of the user tracking which is anyway required for registration. If a game item is in focus, in this first version of the game, its bounding box is drawn around it. The next version will implement more advanced game-like altering of the items to provide feedback on focus selection.

Actions and feedback associated with a click can be manifold:

- Items appear on the PDA interface (e.g. the player buys an item)

[2] Xerces-C++: http://xerces.apache.org/xerces-c/

- Items disappear in the MR augmentation (e.g. he player buys an item)
- Sound icons may be associated with a click (e.g. dropping coins)
- Response from the virtual characters (e.g. speech and animation)
- View related labels

5.2.3 Placing a virtual item

The third core interaction control was inspired by the Wii remote controller. Movements with a gyroscopic mouse in mid air control the orientation of an item, whereas translation speed is controlled by the mouse wheel. The interface designer specifies a target sphere the item has to hit to finish the interaction task. Actions and feedback associated with a click can be manifold as well (see above), depending on the individual needs of the designed challenge.

5.2.4 Addressing technical issues

Test runs with an early prototype have shown that the user needs some kind of feedback that the system is still working properly even if she is not at a game location. These needs arise from the sparse virtual content and inaccurate tracking. We address this issue by providing visual feedback: a graphical element displayed in the head-mounted display (HMD) represents the reception of tracking updates (GPS position updates). Another issue is the pretty low accuracy of GPS: virtual content is floating around rather than stable aligned with the real world. In our first prototype, the players may freeze their position at a challenge or market avoiding floating virtual elements. This however, is rather considered a work-around than a final solution. Previous work (see section 2) often used fiducial markers to overcome this problem. This however, is not feasible in a public city environment, where it usually will not be possible to place such markers on public buildings or at other points of interest. Thus, in our future versions we plan to incorporate markerless computer vision-based tracking mechanisms for this purpose.

5.3 Spatial and Temporal Augmentation

The core aspects of presence and place noted earlier provided a starting point. However, it is acknowledged the traditional laboratory based view of presence may not be appropriate for real life situations such as those experienced with MR. Therefore as the work continues it will specifically explore the impact of the blends created by MR experiences such as spatiality (e.g. altering sense of place and space through changing dimensions such as size), materiality (e.g. the use of real materials within the locations to enhance presence), temporality (which cues from reality and the game can alter the sense of time), as well as ambient and social aspects.

We use the term *spatial and temporal augmentation* to refer to multimedia content that is embedded in the spatial and temporal dimension of the environment. In our approach *spatial augmentation* is extended to all kinds of mobile devices: content provided on the mobile AR system or the hand-held system is location-depending. *Temporal augmentation* refers to the user's experience of being in a certain time period. Visiting the same place in different time periods allows witnessing its change over time; the game concept of time travel through time portals instead of a timeline-based widget control for selecting the current time period additionally contributes to this experience. Furthermore temporal changes and augmentations are reflected across the range of devices. An example of temporal change is a piece of

Figure 4. A market place displayed in different time periods (medieval – left, roman – right)

land close to the Rhine, which once was an island, then became a market place (during the Medieval period) and is now a promenade. Another example of temporal augmentation in *TimeWarp* is the representation of the markets depending on the currently selected time period: the appearance of stalls, the goods offered, and the change of the parlance of virtual characters (see Figure 6). In addition to the graphical augmentation, ambient sounds are used to intensify the reception of the temporal shift of the surrounding.

6. User Tests

In order to address our objectives a range of measurement techniques were used including questionnaires, video analysis and interviews. The questionnaire was based on MEC [27], and was adapted so that questions measured if the user felt present in the real, virtual or overall experience. This included changing the rating scale for some elements and adding questions relating to temporal presence, and interacting with the real and virtual elements. For example in the attention allocation section they we asked to indicate whether they attended more to the real or virtual elements, of if the experience was balanced. Some questions were also added to address issues relating to sense of place; these questions were based upon The Place Probe [3]. Additional questions relating to social presence were added from or based no the work of Bailenson [2]. As a result the changes questionnaire consisted of the following elements: attention allocation, presence (spatial situation model, possible actions, temporal presence, higher cognitive involvement, suspension of disbelief, domain specific interest), social presence (with real and virtual people), usability, general questions and sense of place. The questionnaires were given to the participants immediately after their experience of the game. A total of 24 participants (16 male and 8 female) took part, they ranged in age and background from students to city tour guides.

6.1 Results

"Difficulty reading due to GPS jitter.. I know GPS has trouble with buildings so I tried to stay away from buildings." (TT, Male)

"I think the problem was that the virtual objects did not fit into reality… it was flying about. "(JC, Female)

While GPS provides approximate information on user position, usually within a few meters, this is not sufficient in situations where users must interact with objects or wants to observe items at a particular location. Tracking problems also resulted in people altering their game playing behavior, either as interaction was difficult or they knew that they would experience problems at certain locations. The GPS tracking issues combined with the graphical realism of the objects also caused problems for the users; in particular they were very aware that such objects were not real.

Figure 5. User playing the TimeWarp game in the city of Cologne

Although the level of content and functionality changed across the various iterations of the system, many users reported paying more attention and focusing more on experiences in the virtual dimension – although on further examination their attention was often focused on dealing with technological aspects rather than the game. However conversely they felt more present in the real environment than in the game, this may be reflective of the feeling that there was not much game content and hence they were going from point-to-point rather than constantly being within a mixed reality environment. The behavior observed from videos also pointed to people feeling more engaged with the virtual than real elements, typically they would walk towards an object, and then if it moved chase it until either the position stabilized or they were able to interact with it. Other behaviors included people walking towards then away from virtual objects, often repeating this motion several times. This behavior may have been symptomatic of general problems with the system – an issue highlighted by some responses to how people felt towards errors. For example some noted that they concentrated on the errors and problems.

"I did not notice any difference in time periods….. there are very few virtual objects." (JH, Male)

Feeling towards temporal presence were mixed, although those taking part in the last version of the system used in the trials (and also the most developed) did not note any substantial differences in temporal presence. There appeared to be little in the way of feeling present with other users (social presence). This is almost certainly due to the sparse nature of the content. This is in part due to the game not including support for between player communication. With respect to in-game characters the users felt they were not real and subsequently did not feel present with them. The lack of temporal and spatial presence experienced during the game was also noted to have been caused by the lack of content.

The future was noted as the users most favorite time period or location. This may have been due to the slightly odd nature of the objects, with the effect that it probably felt like a more unique time period. With respect to places, both real and virtual there was little interaction with users in aspects of many of the real locations. For example they would not pick up real objects or interact with passers-by – this may explain the seeming lack of feeling towards and places. Both actions, and sense of others (and their behaviors, type etc) are strong factors in sense of place.

"I felt like an Alien… Sometimes you were involved in the game so much you did not notice them…." (LC, Female)

"A great help would be to have more audio guidance… a great help would be some audio feedback from the Heinzelmänchen." (TT, Male)

"You feel kind of special" (CX, Male)

Users also commented on the need to add sound queues to aid in navigation and interaction, and the strange behaviour from non-game participants e.g. staring or asking questions. There were also issues with becoming so focussed on game elements that they were unaware of safety issues, for example cars or trees.

One of the main problems with the system related to the weather conditions, in particular high levels of sunshine. On very bright days during the trail the mixed reality elements were often invisible of difficult for users to see without the aid a sun block. A number of different sun block techniques were tried, however the final one was quite bulky and resulted in strange responses from members of the public. Where people did not use a sun block they often reverted to using their hands to block out the sun. The problems caused by the sun and the need to frequently adjust the position of the visor appeared to distract the users on a number of occasions and had a negative impact on the experience. Despite its appearance there were no noted problems with the MR vest.

Interaction with virtual game elements was problematic, especially during earlier versions of the system. This was in part due to the confusing interaction techniques used and the lack of any former of user familiarization with the technologies. In later versions users were given a brief training scenario and the interaction techniques were simplified. This resulted in a more positive experience for most users, however some problems remain.

The PDA was used to present navigation information as well as information about various game locations etc. However users found the navigation system difficult to use, and would use the photographs of the locations to orientate themselves. In earlier versions their position was not presented on the map, in later versions this problem was resolved however many indicated they would prefer the PDA display to more accurate reflect issues such as the current time period etc. The PDA often presented too much information early on, in particular stories of the various locations. As a result users were unsure what was relevant to what they were doing. They were also unsure as to where they could obtain content to let them complete the game challenges.

"I tried to find the places that were shown in the pictures, just the same point of view. Like the take of the photographs. " (TT, Male)

6.2 Discussion

Although there are many conclusions which are specific to TimeWarp, from a scientific perspective the study proved invaluable in identifying areas of mixed reality experiences which are essential to altering the users' sense of place and presence. By this we mean the desire to ascertain exactly where users feel they are present, e.g. in a different place or time period and how game play elements (given it is not possible to augment an entire city) can play a part in this. Key aspects include placing greater emphasis on where the action takes place and understanding and therefore using the real locale more effectively. Typical examples include using aspects such as paths through the environment and real people and objects more effectively. Additionally understanding how real and virtual objects impact on the experience, in particular the almost implicit problem of people focusing more on the virtual than real elements, thus to some extent negating the purpose of mixed reality.

As this was the first in depth study of TimeWarp it provided an ideal opportunity to develop, adapt and test the evaluation techniques. Based on the experience we now have a better idea of what aspects to improve in future versions. Moreover, the evaluation provided us with a method of identifying common themes and patterns which the users were engaging in and thus question strategies during interviews.

Finally, we came up with some concepts which are relevant to the design of MR experiences. They are intended to highlight the importance of considering reality, in particular how to make use of real spaces, people and objects in order to create a unified game experience. Although they share a number of aspects with the mobile game design patterns by Davidsson et al [9] their approach and focus are different.

(1) Understand Attention Allocation
People are easily drawn to objects which engage them in some way, for example animations or those which appear out of place. Consider the impact on the users attention when introducing objects, in particular when you want attention focused more on virtual elements than real elements, also when to balance the two.

(2) Simplify the Interaction Scheme
Avoid using too many types of interaction devices or behaviors. In common with standard usability practice the interactions should be intuitive, for example, where appropriate be comparable to real world behaviours and should not be overly complex. Some of these issues can be overcome by providing training scenarios, however such scenarios should be an integral part of the game play and not separate.

(3) User Safety
Users often become so involved in the game experience that they fail to take into account roads and traffic. Avoid placing key or primarily virtual experiences near roads or other places likely to result in an accident.

(4) Design appropriate paths through the environment
Paths play a crucial role in shaping our perception of space, they can be used to pass-by and pass through spaces. Select routes through the environment which are interesting and terminate game aspects at interesting locations.

(5) Understand the Locale
Alexander [1] provides a summary of common layouts used within environments e.g. Cafes and their uses. Locations can also play a part in creating game ambience.

(6) Interaction with Others
Where appropriate integrate non-game participants into the game. For example the player could ask a passerby for advice.

(7) Seamful Design
Make use of environmental features within the game to overcome technical problems. As noted by Chalmers [6] certain technologies for example GPS may not work at all given locations, hence when this is not the case use the problems to enhance the game experience.

(8) Use a combination of real and virtual objects
Use real objects within the game experience where they (1) provide a more intuitive form of interaction (2) can play a key part in the game play.

(9) Provide a continuous experience
It is important that game play is constant, for example people should not suddenly have to interact with virtual elements in one space then face a long walk to the next experience. Therefore the game should make regular use of real and virtual objects so as to maintain the user's interest.

7. Conclusion and Future Work

In this paper we have presented *TimeWarp* - a novel pervasive augmented reality game which lets people experience the City of Cologne during different time periods. We described the theoretical background to the *Timewarp* experience, for example how the game aims to fuse real and virtual elements to create the illusion that people are present in different time periods. Furthermore the paper described the design and development process, in particular the range of devices used, story telling approach and the flexible nature of the Mixed Reality Interface Modelling Language. The paper concluded with a user study which explored various iterations of the game from the perspective of usability, place and presence and number of concepts were presented which are useful in the development of such games.

The results of the study point to a range of classic usability issues, for example the need for accurate position and object tracking and the simplification of the interaction scheme; namely the need to reduce the amount of devices and level of content presented to the user at any given time. At a higher level we identified a number of issues relating to sense of place and presence which require more in depth consideration, in particular the disjointed nature of many mixed reality experiences. Critical aspects include how to create a foster a continuous game experience, so that users feel constantly present in the desired time period (or being clearly aware when there is a change), this is of course a challenge as not all objects or locations can be augmented. However it is our view that by making better use of the real space, in particular using paths to create a sense of heightened experience (e.g. as the user walks towards the destination), through to understanding the range of people and actions afforded by the real environment and carefully linking these to virtual elements many of the problems with sparse content can be at least partially overcome.

In our future work we intend to significantly enhance the registration of the virtual objects in the real setting by using markerless computer vision based tracking in addition to GPS localization. We further plan to provide richer multimedia content including information points where players may collect hints or pieces of historical information. An example could be a talking gargoyle or statue. Another area for further improvement is the multimodality of the user interface. While currently restricted to spatial navigation, (mouse) button input, gaze related selection, and gyroscopic directional pointing, we intend to incorporate speech commands, mouse gestures, tangible interfaces (i.e. interaction with real items located throughout the city), and intuitive 2D content manipulation devices – in particular the CityWall (http://citywall.org/) also developed within the IPCity project. Part of our future user tests will also be the comparison and evaluation of different interaction styles and modalities. Finally we intend to provide more advanced authoring support, including a more high-level game description language as well as graphical editing and orchestration tools to allow for an easier and faster setup of this kind of pervasive AR games as well as an easier adaptation to alternate locations (further cities).

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