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A Pervasive Augmented Reality Serious Game

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Abstract—This paper presents a pervasive augmented reality serious game that can be used to enhance entertainment using a multimodal tracking interface. The main objective of the research is to design and implement generic pervasive interfaces that are user-friendly and can be used by a wide range of users including people with disabilities. A pervasive AR racing game has been designed and implemented. The goal of the game is to start the car and move around the track without colliding with either the wall or the objects that exist in the gaming arena. Users can interact using a pinch glove, a Wiimote, through tangible ways as well as through I/O controls of the UMPC. Initial evaluation results showed that multimodal-based interaction games can be beneficial in serious games.

Keywords-serious games; pervasive computing; augmented reality; multi-modal interfaces.

I. INTRODUCTION

Computerised games which have learning or training purposes demonstrate a popular trend in training due to the wide availability and ease of use of virtual worlds. The use of serious games in virtual worlds not only opens up the possibility of defining learning game-based scenarios but also of enabling collaborative or mediated learning activities that could lead to better learning [1]. An added benefit of using serious games in combination with virtual worlds is that learners engage with these in a multimodal fashion (i.e. using different senses) helping learners to fully immerse in a learning situation [2] which might lead to learning gains [3]. The multimodal nature of virtual worlds [4] and the facilities they offer to share resources, spaces and ideas greatly support the development and employment of serious games and virtual worlds for learning and training.

The use of games as learning devices is not new. The popularity of video games among younger people, led to the idea of using them with educational purposes [5]. As a result there has been a tendency to develop more complex serious games which are informed by both pedagogical and game-like, fun elements. One common example of these combinations is the use of agents [6]: The idea behind agents is to provide pedagogical support [7] while providing motivating environments in the form of agents [8]. However, the use of agents is not the only motivating element in serious games as the use metaphors [9] and narratives [10] have been used to support learning and training in game-like scenarios.

It has been only recently that the term serious games has been integrating with concepts borrowed from the Artificial Intelligence in Education (AIED) community, for example using modelling techniques to scaffold learning. As such, efforts are being taken to use games as test beds in combination with sensors to test the sensors' feasibility to inform the models of the students. The use of eye-tracking [11], multimodal elements [12] sensors measuring the person's positions during the interaction [13] and brain computer interfaces [14] are examples of this trend.

On the other hand, there have been some examples of game-based scenarios for learning, training or recruiting. These examples do not use a particular set of sensors but rather make use of agents, modelling and virtual worlds to support gamers. Examples of this trend include the support for the development of cultural and linguistic abilities [15], the use of games to recruit people, i.e. America's Army [4] or the use of Second Life to support the training of paramedics in Stanford Medical School [4]. A tendency for the development of new Serious Games consists of the integration not only of the pedagogical concepts and modelling techniques borrowed from AIED but also of the integration of novel input/output devices and its deployment in virtual worlds to support collaborative, game-based experiences.

Pervasive games can sometimes have an educational aspect. The whole idea of playability in pervasive games is the player's interaction with the physical reality. In addition, the accessibility space that is the key to the oscillation between embedded and tangible information [16]. On the contrary, augmented reality (AR) has existed for quite a few years and numerous prototypes have been proposed mainly from Universities and Research Institutes. AR refers to the seamless integration of virtual information with the real environment in real-time performance. AR interfaces have the potential of enhancing ubiquitous environments by allowing necessary information to be visualized in a number of different ways depending on the user needs. However, only a few applications combined them together with trying to graphically represent sensor information in real-time performance.

This paper presents a pervasive augmented reality serious game that can be used to enhance entertainment using a multimodal tracking interface. The main objective of the research is to design and implement generic pervasive interfaces that are user-friendly and can be used by a wide range of users including people with disabilities. A pervasive AR racing game has been designed and implemented. The goal of the game is to start the car and move around the track without colliding with either the wall or the objects that exist in the gaming arena. Users can interact using a pinch glove, a Wiimote, through tangible ways as well as through I/O controls of the UMPC. Initial evaluation results were promising and showed that multimodal-based interaction games may be beneficial.

The rest of the paper is structured as follows. Section II provides relevant background information and section III, illustrates the architecture of the system. Next, section IV explains how tracking is performed in the AR environment. Section V, presents five different types of interaction that were implemented in the game. Section VI, demonstrates the pervasive game in detail whereas section VII illustrates initial evaluation results. Finally section VIII, presents conclusions and future work.

II. Background

In the past few years, a number of pervasive computing and AR applications have been proposed. A good survey of sensors used in ubiquitous and pervasive computing has been previously proposed [17]. A taxonomy of mobile and pervasive applications was also recently documented [18]. This section presents an overview of the most characteristic applications and prototypes that integrate sensors into AR environments. One of the earliest pervasive AR prototypes is NaviCam [19], which has the ability to recognize the user's situation by detecting color-code IDs in real world environments. The system displays situation sensitive information by superimposing messages on its video see-through screen. Combination of ID-awareness and portable video-see-through display solves several problems with current ubiquitous computers systems and augmented reality systems.

Another early important work refers to the Remembrance Agent [20], a text-based AR wearable system. This prototype allows users to explore over a long period of time augmented representations and provide better ways of managing such information. Through the adaptation of the user's changing environment, the wearable AR prototype can assist them more intelligently, consistently and continuously compared to desktop systems. EMMIE [21] is a hybrid user interface to a collaborative augmented environment which combines a variety of different technologies and techniques, including virtual elements such as 3D widgets, and physical objects such as tracked displays and input devices. Users share a 3D virtual space and manipulate virtual objects that can be moved among displays (including across dimensionalities) through drag and drop.

A more recent prototype is DWARF [22] which includes user interface concepts, such as multimedia, multimodal, wearable, ubiquitous, tangible, or augmented reality-based interfaces. DWARF covers different approaches that are all needed to support complex human-computer interactions. Higher level functionality can be achieved allowing users to manage any complex, inter-related processes, using a number of physical objects in their surroundings. The framework can be used for single-user as well as multi-user applications. In another prototype, the combination of AR and ubiquitous computing can lead to more complex requirements for geometric models are appearing [23]. For such models a number of new requirements appear concerning cost, ease of reuse, inter-operability between providers of data, and finally use in the individual application.

Moreover, simulation-based AR was used to enhance development on physical hardware by seamlessly integrating a running simulated network with a physical deployment in a way that is transparent to each [24]. The advantages of such an augmented network include the ability to study a large sensor network with limited hardware and the convenience of studying a part of the physical network with simulation's debugging, profiling and tracing capabilities. To enable seamless fusion of simulation and a live sensor network, the design of AR was based on a distributed simulator. The suitability of Jini networking technology as an enabling and integrating technology used by pervasive environments has also been examined in the past [25]. Jini has several features necessary to provide the fundamental infrastructure required to integrate disparate smart components.

III. Architecture

In the past, a few pervasive games have been proposed and a good overview of similar systems has been previously documented [26], [27]. The architecture of our system has been based on an earlier prototype [28]. However, there are many differences with the previous prototype. Firstly, interaction is performed using a pinch glove and Wiimote. Secondly, visualization is enhanced through the use of a head-mounted display (HMD) which includes a three degrees-of-freedom orientation tracker. Also, visual tracking is based on multiple markers which provide better robustness.

It was of high importance that the hardware used within the architecture is wearable (or mobile) and thus the Sony VAIO UMPC was ideal for AR applications. The UMPC essentially turned a regular computer into a piece of mobile technology with its high processing speeds and large storage capacity (1.3 GHz, two 1.3 mega-pixel cameras, VGA port, Wi-Fi, USB ports, Bluetooth and keyboard/mouse). The rest of the hardware devices used and integrated to the UMPC included a pinch glove (5DT Data glove), a Wii Remote and an HMD (eMagin Z800). An overview of the major hardware components is shown in Figure 1.

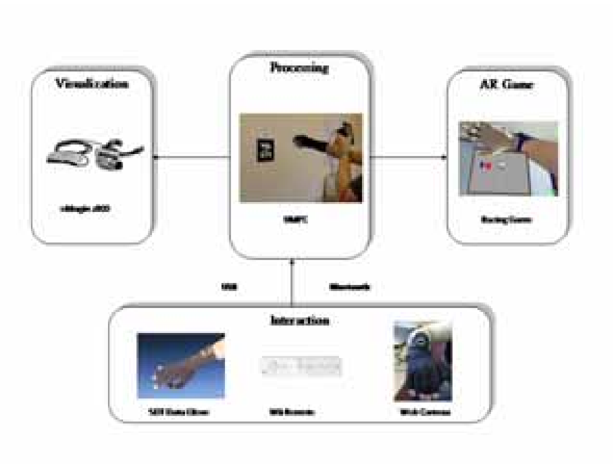

Figure 1 Multimodal Interaction Techniques

The software development was very much created around the hardware, as new devices were added to the system; the code was updated to include integration of the new devices. The basic AR tracking capabilities came from the ARToolKit [29] and ARTag [30] libraries. This provided the tools needed to display the video, detect markers, and calculate their position relative to a web camera. To retrieve multimodal tracking data in real-time, a socket was created which was constantly waiting for input. The input comes in a structured form so data structures were set up in order to grab and store this information for the visualisation. This socket server function was placed inside a thread of its own to stop it affecting the whole process while it waits for data to be retrieved. Once the data are received, its values can be assigned to a particular marker or to multiple markers (see the racing application in section VI). When that marker comes into sight of the camera and the visualiser recognizes that the current marker has further data attached to it.

Integrating the Wiimote was initially a daunting task until the Wiiuse libraries were found. These libraries provide everything needed to establish an active connection to the Wiimote through Bluetooth and allows it to be treated by the computer as a regular human interface device. This was implemented into the application giving access to data sent by the Wiimote. The data glove is connected by USB and is in a sense a plug and play device. The glove comes with an SDK which comes with some sample code, it was this sample code to retrieve values from the glove; again, this was implemented into the main application making the data available to the rest of the visualiser. The HMD was simply an extension to the display of the laptop or UMPC and included an orientation sensor. The hardware was now all connected and communicating with the main application.

IV. TRACKING

An issue that arose early on with using the player's hand to interact with virtual objects in an AR environment were occlusions. Once the hand moves to interact with the AR scene, it obscures a real-world visual marker. As a result, the on-screen objects disappeared; the AR system relies on the markers to accurately register the virtual information on screen. This being the case, one of the objectives early on was to create a system that would use multiple markers to represent a single object or set of objects. This would mean that even if one or several markers were blocked by a user's hand, for example, the objects would still be displayed based on where the visible markers were placed.

The game uses a method of detecting which marker of the available markers on a sheet of paper is currently the most visible, based on a confidence rating assigned to it by a class in ARToolKit. This marker becomes the origin from which all other objects are drawn on the game board. If this marker becomes obscured, the program automatically switches to the next highest confidence rated marker. The confidence is based on a comparison between the marker pattern stored in memory and what is detected by the camera in the current frame.

An additional problem was that the superimposed computer graphics would be drawn over the camera feed, regardless of the real world objects and their position. This meant that even if a user's hand was supposed to be above a virtual object, the virtual object would be drawn on top of the hand. Given that the user relies on the screen and camera feed to see what is happening in the scene and how they are interacting with objects, this presents a significant issue. To rectify this problem, the game uses a 3D model of a hand and places it over the known position of the user's hand, based on the marker position. This 3D model could then have standard depth test algorithms applied to it to check if it was closer to the camera than the other models in the scene. From a user's perspective it means that their hand is always visible, even when interacting with computer-generated objects.

A potentially better solution that will be tested in the future on this system is to use a model for the hand that has separate sections for each finger, the position of which would be determined by the current readings on each of the finger sensors on the glove. This model could then use an alpha colour value of 1.0, meaning that it is entirely transparent in the scene. As a result the model would become an alpha mask for the live video of the users hand; the real world hand would then appear to be above any virtual objects that the depth testing determined were further away from the camera.

V. MULTIMODAL INTERACTION

The main objective of this work was to allow for seamlessly interaction between the users and the superimposed environmental information. To achieve this, a number of custom interaction devices have been researched such as the PS3 controller, 3D mousse, etc. However, since usability and mobility were crucial, only a few interaction devices were finally integrated to the final architecture as illustrated in Figure 2.

Figure 2 Multimodal Interaction Techniques

In particular, five different types of interaction were implemented including: *hand position and orientation*, *pinch glove interaction*, *head orientation*, *Wii interaction* and *UMPC I/O manipulation*. A brief overview of these techniques is presented below.

A. Hand Tracking

Detecting the orientation of the user's hand plays a large part in this project. The intention is to move around environments with ease. A separate measurement is needed from the player's body position due to the hand being free to move in a different orientation to the player's body. The tracking data were obtained by attaching a small USB web camera into the pinch glove. Based on ARTag tracking libraries hand's pose was combined with the data of the player's position and orientation in the environment and then used to compute where the hand is located in the real environment. Based on those readings, it is easy to define different functionalities that may be used for different configurations. As an exemplar, a 'firing' function was implemented based on localization of the hand (see section VI). Another function that was experimentally implemented is multiple camera viewports (one originating from the UMPC camera and a second from the mounted web camera) to provide a more immersive view to the user.

B. Head Orientation

Head orientation was achieved through the capabilities of the HMD since it included a three degrees-of-freedom orientation tracker. The advantage of using head orientation is that it can illuminate the use of computer vision methods for head tracking. However, when used with monitor-based AR it can provide a distracting effect. Another problem that occurred after experimentation is that if it is used with conjunction with the rest of the sensors (Wiimote and pinch glove) it can confuse the user. For this reason the tracking capabilities of the HMD were not used in the application scenarios.

C. Wiimote Interaction

It was decided to implement the Wii remote as a device to obtain positional data of the user's hand for an alternative to mouse controls. Implementation was based on an extensive library written to manage the actual communication with the Wiimote, called Wiiuse. This takes care of all of the Bluetooth communication between the Wiimote and the computer. It also recognizes events and data received from the Wiimote accelerometers giving orientation information. When the Wiimote was implemented into SensAR another thread was added to continuously retrieve data without affecting the rest of the application. If directional or action buttons where pushed, then we could any function desired.

The Wiimote was also found to be very useful, since it is a very 'mobile' piece of equipment. It is battery powered and can work for roughly 35 hours without needing a replacement and it emits data via Bluetooth. The only disadvantage of the Wiimote is that it provides two degrees-of-freedom tracking so it is not a complete orientation device. However, for a number of table-top games (i.e. puzzles, racing, etc) it is a very useful device since only the yaw rotation is useful.

D. Pinch Glove

The pinch glove has internal sensors that give the system data on each fingers position. If a user was placed their index finger into a curled up position, any event could be triggered. In some circumstances this is an ideal choice for user input, however if the user has to hold any other piece of hardware then it would become hard to make use of the glove's data because their hand position would be set by whatever is in their hand. The pich glove allows up to 15 different combinations. However, only 5 have been implemented at this stage as shown in Table 1.

Gesture Number	Flexure
1	Translate X-axis
2	Translate Y-axis
3	Translate Z-axis
4	Rotate (clockwise)
5	Scale

Table 1 Pinch Glove Interactions

In terms of operation, the glove is initialized and then a thread is created for the constant monitoring of the glove, this thread is responsible for grabbing the data for each finger and assigning it to a variable which can be used throughout the application.

E. UMPC Interaction

The UMPC I/O interaction (mouse/keyboard) is adequate only when the HMD was not used. However, it allows users to perform more accurate manipulations of the superimposed information and thus it was explored only as backup option. On the other hand, the camera mounted on the rear could be used for marker detection and as the hand is holding the camera, the value returned from the ARToolKit would be a position and orientation of the hand.

VI. PERVASIVE RACING GAME

To illustrate the effectiveness of the multimodal interface, the interaction techniques presented above have been combined with a table-top AR car gaming application. It was decided to use a simple gaming scenario and focus more on the reaction of the players during interaction. The goal of the game is to start the car and move around the track without colliding with either the wall or the objects that exist in the gaming arena. In addition, the objects can be re-arranged in real-time by picking and dropping them anywhere in the arena. A screenshot of the starting stage of the car game is shown in Figure 3.

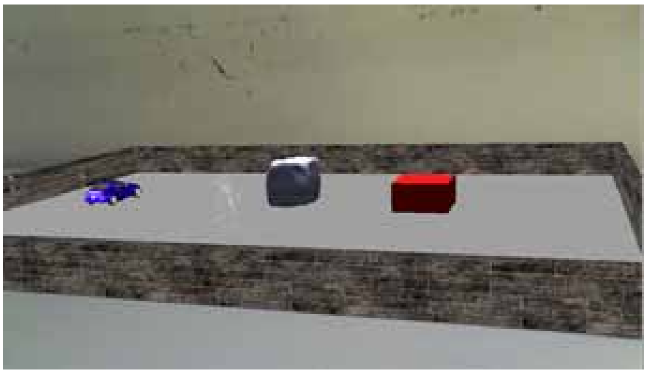

Figure 3 Pervasive Racing Game

The main aim of the game is to move the car around the scene using the Wimote without colliding with the other objects or the fountain. However, alternative interactions techniques may be used such as picking using the pinch glove. Players can interactively change the sound levels (of the car engine as well as the collisions), the speed of the simulation, and finally the colour and the size of the car. In addition they can interact with the whole gaming arena in a tangible manner by just physically manipulating the multi-markers. In the next sub-sections an overview of the main functionality of the game is presented.

A. *Picking*

Once it has been established that a user is interacting with a particular object, the program checks the state of the sensors on the glove. If it is detected that the user is bending all five sensors over a certain threshold, then the object adopts the same position and orientation as the user's hand. This gives the impression that the object has been picked up and is now held by the user. If the sensors running along the glove's fingers are detected to straighten, then the item is dropped and falls to the plane representing the virtual ground. In the game, this interaction means that objects on the course can be manipulated in a far more instinctive and tangible way than is possible using a convention control system (for example, keyboard and mouse or a video game controller). The pinch glove was used to move objects in the scene by grabbing them as illustrated in Figure 4.

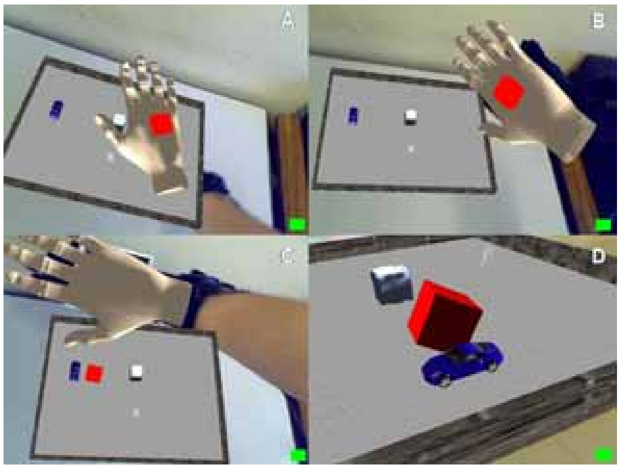

Figure 4 Pinch glove interaction scenarios

In Figure 4 (a), the user is picking up a 3D object (in this case a 3D cube) that exists in the AR game. Figure 4 (b) shows how the user can manipulate the 3D object in three-dimensions. In Figure 4 (c) the user is dropping the 3D object in the gaming arena. Finally, in Figure 4 (d), the object is placed in the gaming arena in a random position. It is worth-mentioning that the game can be played in a collaborative environment by eliminating the use of the HMD. One player can be in charge of the Wiimote interaction and another for the pinch glove manipulation.

B. *Firing*

One method of interaction that was not fully integrated into the game, but the framework was created, is a way of firing from the virtual hand. Figure 5 provides an overview of how firing is performed.

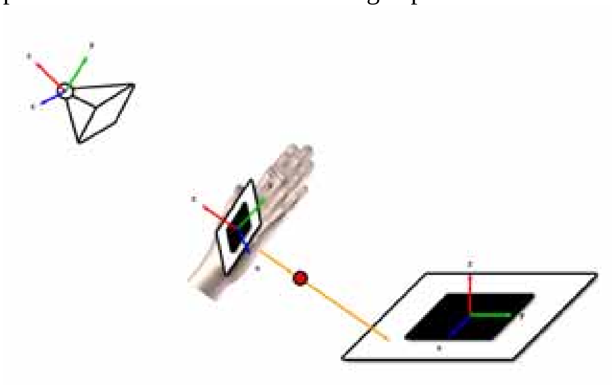

Figure 5 Firing

By making a predetermined gesture, detected by the glove, a user is able to fire a virtual projectile into the scene. From the marker on the user's hand, we can apply a transformation from its orientation to that of the virtual world and thereby determine the direction a projectile would travel from the hand and whether it would intersect with other objects in the scene. Once integrated into the game, this would allow a user to destroy obstacles or non-player characters (NPCs).

C. Colision Detection

Using bounding boxes around each of the items in the scene and one to encompass the user's hand, intersection testing was used as a simple method of collision detection. Much as in any game, collision detection plays a vital role in gameplay; here, the car is not able to cross the boundaries of the game board and its progress is impeded by the other obstacles. Importantly for this particular application, the collision detection also enables the program to determine when the user's hand in the real world is intersecting with an object in the virtual scene.

D. Spatial Sound

To enhance the level of immersion of the application, features from the OpenAL and AL utility toolkit (ALUT) APIs were added. These APIs dynamically affect the level of sound in each of the audio output channels of the computer based on the distance of a virtual listener from the sound source. In this program, the camera is defined as the listener, making the levels of all sounds in the augmented part of the environment relative to the camera's position and orientation.

Examples of sound sources defined by the game include 'engine' and 'collision' sounds. The 'engine' sound is assigned in the virtual car whereas the 'collision' sound represents the noise created when the car collides with other virtual objects in the scene, such as the moveable cubes. As the car is started and directed away from the centre of the camera's view, the sound of its engine gradually reduces in volume and, depending on the direction of movement taken; the balance of stereo sound is altered accordingly. Collisions between the car and virtual objects on-screen will trigger the playback of a .wav file. The volume of this file in each audio channel will again be relative to the positions of both the camera and the collision.

This functionality creates a base upon which a more complex system of sound could be developed. For example, the speed of the car could affect the sound of the engine, by using different samples depending on the current velocity. Also, given the vehicle's velocity and the perceived material of another object in the scene, different sound files could be used to represent varying levels of collision. A fast impact into a hard surface could sound completely different than a slight glance against a soft, malleable object. However, these potential additions are made possible and would be more realistic to a player with the 3D sound in place.

VII. INITIAL EVALUATION

Up to now the game has only been qualitatively evaluated in two demonstrations at 'Cogent Computing Applied Research Centre' [31] and 'Serious Games Institute' (SGI) [32]. At Cogent the basic functionality of the game was tested based on 'think aloud' evaluation technique [33]. Think aloud is a form of observation that involves participants talking through the actions they are performing, and what they believe to be happening, whilst interacting with a system. Overall the feedback received was encouraging but certain aspects need to be improved in the future. The three tasks that were examined include: *Wiimote interaction* and *pinch glove interaction*.

For the first task, a virtual sword was superimposed with a Wiimote placed next to it as shown in Figure 6. It must be mentioned that Yaw detection can't be detected as the motion sensor chip used in the Wiimote is sensitive to gravity, but rotation around the yaw axis is parallel to the earth.

Figure 6 Wiimote interaction test

Users were asked to angle the sword upwards as if to point to an object in the sky. The feedback received was positive from four users. However, one user stated that although it is possible to detect the yaw rotation against one area, it is impossible to identify different IR sensors placed around the whole environment. As a result, interaction using the Wiimote would get confused as one IR sensor went out of site. For the second task, users were presented with the data glove placed on their right hand as illustrated in Figure 7. Then they were asked to manipulate in 3D the virtual information in this case the virtual sword used in the previous task. Virtual manipulation included scaling, rotations and translations using the fingers of the pinch glove.

Figure 7 Data glove interaction test

All users managed to interact with the pinch glove without any problems as soon as they were briefed with its operations. Four users agreed that it is very intuitive to perform the pre-programmed operations. Two users mentioned that they would like to have more combinations such as change or color and activate/de-active the textual augmentations. One user stated that it can be tiring to control the UMPC with one hand only.

At the SGI the game was demonstrated in an internal event with 20 visitors. Initial feedback received stated that the game is very realistic in terms of interactions and enjoyable to play. Especially the idea of picking virtual objects and placing them in arbitral positions was very enthusiastic. Most visitors felt that tangible games presented potential for the next generation of gaming. On the negative side, they preferred to experience a more complete gaming scenario including a score indicating successful achievements. In addition, some users requested more objects in the scene (i.e. obstacles), multi-player capabilities (i.e. more racing cars) and more tracks with different levels of difficulty.

VIII. Conclusions and Future Work

Pervasive computing has the potential to change a number of applications that we perform in our day-to-day activities. This paper has presented a generic pervasive AR gaming system. Users can interact using a pinch glove, a Wiimote, through tangible ways as well as through I/O controls of the UMPC. Initial evaluation results were very encouraging and provided us with useful recommendations for future work. A formal evaluation with 30 users is currently underway and results will be used to refine the architecture.

From the research proposed many potential gaming applications could be produced such as strategy, puzzles and action games. Future development will include integration of more interaction sensors such as a three-degrees-of-freedom tracking device like the Honeywell digital compass. In terms of software development, more work will be performed in the graphical user interface to make it more user-friendly. Finally, speech recognition is considered as an alternative option to enhance the usability of interactions.

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