Brain-controlled serious games for cultural heritage

Vourvopoulos, A. , Liarokapis, F. and Petridis, P.

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Athanasios Vourvopoulos
Interactive Worlds Applied Research Group (iWARG)
Coventry University
Coventry, UK
vourvopa@uni.coventry.ac.uk

Fotis Liarokapis
Interactive Worlds Applied Research Group (iWARG)
Coventry University
Coventry, UK
F.Liarokapis@coventry.ac.uk

Panagiotis Petridis
The Serious Games Institute (SGI)
Coventry University
Coventry, UK
ppetridis@cad.coventry.ac.uk

Abstract— This paper proposes a prototype system for cultural heritage based on brain computer interfaces for navigating and interacting with serious games. By analyzing traditional human-computer interaction methods and paradigms with brain-controlled games it is possible to investigate novel methods for interacting and perceiving virtual heritage worlds. An interactive serious cultural heritage game was developed based on commercial BCI headsets controlling virtual aggents in the ancient city of Rome. Initial results indicate that brain computer technologies can be very useful for the creation of interactive serious games.

***Keywords** – serious games; cultural heritage; brain computer interfaces.*

I. INTRODUCTION

Computer games and virtual environments for entertainment have enjoyed a widespread use nowadays, especially amongst the younger generation. This has been demonstrated by the recent advances in software and hardware technologies. As a result, the quality of real-time computer graphics, increased realism and immersion has been greatly improved in computer games. However, although the widespread use of gaming for leisure purposes has been well documented, the use of games to support cultural heritage purposes, such as historical teaching and learning, or for enhancing museum visits, has been less considered [1]. The potential use of serious games technologies on cultural heritage education has been recently addressed in the literature [2], [3], [4].

The successes of games that cross over into educational gaming – or serious gaming, as well as games and virtual worlds that are specifically developed for educational purposes, all of which exist within a cultural heritage context, reveal the potential of these technologies to engage and motivate beyond leisure time activities [1]. A broad definition refers to serious games as computer games that have an educational and learning aspect and are not used just for entertainment purposes. Serious games are currently being used in a range of different contexts and two survey papers regarding of serious games have been well documented [1], [5].

Moreover, different learners will have different preferential learning styles, so a serious game cannot automatically guarantee success, and there is some evidence of the learner's gender playing a role in this [6]. However the available evidence generally suggests that the visual medium that serious games employ has a positive effect [7]. Another factor for the success of serious games is the actual presentation of the subject matter in the form of computer games, which have been found to improve the players' concentration and attention levels [8]. This not only benefits the retention of information as such, but also increases the learners' motivation, thereby improving the learning experience.

Although research on Brain-Computer Interfaces (BCIs) started during the 1970's only the last few years it became possible to introduce brain-computer interfacing as an alternative controller to simple users through commercial non-invasive EEG headsets. BCI technology is a rapidly growing field of research with various applications in computer games [9], prosthetics and control systems [10] through to medical diagnostics. Advances in medical imaging technology have presented a variety of alternative means for bio-recording, such as functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), and positron emission tomography (PET). A fundamental difference between bio-recording technologies used for diagnostic imaging, and those used for BCI applications, is a typical requirement for real or quasi-real time performance in order to translate user input into interactive responses.

This paper proposes a prototype system for cultural heritage based on brain computer interfaces for navigating and interacting with serious games. By analyzing traditional human-computer interaction methods and paradigms with brain-controlled games it is possible to investigate novel methods for interacting and perceiving virtual heritage worlds. An interactive serious cultural heritage game was developed based on commercial BCI headsets controlling virtual aggents in the ancient city of Rome. Initial results indicate that brain computer technologies can be very useful for the creation of interactive serious games.

The rest of the paper is structured as follows. Section II provides relevant research done in BCIs.

Section III presents the architecture of our system. Section IV describes the serious game called Roma Nova. Section IV provides an overview of how brain computer interactions are performed in the game. Finally, section VI illustrates initial evaluation results and section VII presents conclusions and future work.

II. BACKGROUND

While there has been extensive research in BCI's for communication and control of prosthetics and robotic devices [11] only the last few years with the launch of commercial BCI headsets as an alternative gaming controller Brain-Computer Interfaces appeared in the computer gaming and virtual reality domain. This gave the opportunity to researchers to get involved with BCI research for various applications by using relatively low cost non-invasive EEG equipment and software development kits (SDK's). This technology boosted the BCI's in games research with main target medical applications and brain rehabilitation through serious games and virtual worlds. In addition, this has been also assisted by mixed reality systems like Virtual and Augmented Reality (VR and AR respectively), making hybrid BCI systems capable of enhancing the user experience [12], [13].

Currently, non-invasive BCI research methods (recording the brain activity from the scalp with EEG sensors) in serious games development are usually oriented in the medical domain rather than entertainment. A relatively early study dealt with an internet game linked to a brain-computer interface (BCI) system. This system translated real-time brain activities from prefrontal cortex (PFC) or hippocampus of a rat into external device control commands and used them to drive an internet game [14]. Another BCI based 3D game measured the user's attention level to control a virtual hand's movement, based on 3D animation technique. This system has been developed for training those who suffering from Attention Deficit Hyperactivity Disorder (ADHD) [15]. Moreover, researchers are focused on the design and implementation of games capable of moving an avatar to simple a tennis games using only brain activity [16]. This can assist people with diseases involving movement difficulties for controlling a computer. To achieve this, studies using the mu (μ) rhythm of brain activity have been conducted for BCI applications [17].

The concept of identifying users from the EEG patterns of their brain and adapting the system without training has become an issue for many research teams. An EEG pattern recognition system to adapt a serious game has been designed for comparing recognition rates for experimental serious games without any traditional controllers. Their proposed Support Vector Machine (SVM) algorithm for classification is compared with other algorithms, improving the recognition rate [18]. A Quantitative and Qualitative Study in Self-Paced Brain-Computer Interaction with Virtual Worlds showed that, without training, roughly half of the subjects were able to control the application by using real foot movements and a quarter were able to control it by using imagined foot movements. The application consisted of an interaction with a virtual world inspired by the "Star Wars" movie. Users were asked to control the take-off and height of a virtual spaceship by using their motor-related brain activity [19].

In the last few years research in BCI with serious games and virtual worlds grew exponentially. All these attempts for BCI controlled games target in neurofeedback and in measuring users' different brain states. Previous work in BCI game design with the BCI equipment to be considered as a possible input controller of games is rare. This is mainly because BCI and EEG are traditionally considered medical techniques hence the research is mostly medical oriented. A similar approach just started to emerge in discussing current BCI research from the viewpoint of games and game design [20].

On a recent study the development of practical and inexpensive non-invasive brain-computer interface systems was investigated by comparing different low-cost EEG systems by price and functionality [21]. In their findings, the Emotiv Epoc headset scored high in terms of usability. Lowering the cost of BCI equipment allowed Gamers to focus their interest to BCI headsets as a new game device as they're often the first to adopt any new technology, willing to put the effort into learning and work with it [22]. Brain-Computer interaction at this stage is slower and less accurate than traditional interfaces that are currently available. This makes healthy users to be more demanding while interacting with the game. In addition, BCI's often require a lot of training for successful interaction which weakens the overall user experience. Current Brain-Controlled games are just proof-of-concepts with simple BCI paradigms, such as moving a paddle (left or right) in the game Pong with imaginary movement of the hand [23]. Overall, BCIs can uniquely provide information to the gaming environment that no other traditional game controller can provide. Like thoughts, computer games are not constrained, enhancing the possibilities of the human-machine interaction. Therefore, connecting the user directly with the virtual world gives a more natural way of control and communication.

Moreover, a significant volume of literature exists around the study of projects aiming to populate a virtual environment with a crowd of characters. Crowds are used in virtual worlds for varios purporses such as bringing life and immersiveness into a historical reconstruction/world, or for sumulating the behaviour of human people for various scenarios such as emergency evacuation. Crowds are desirable for a range of purposes, such as bringing life and immersiveness to a historical place, accurately simulating the behaviour of human people, or application-driven scenarios, such as emergency evacuations [24]. The Pennsylvania station project aims to populate the historical reconstruction of the famous New York City railroad station [25]. Although an emphasis is placed on the characters' diversity, similar to the Pompeii project, Shao and

Terzopoulos focused upon emulating the rich variety in behaviour of the characters.

Other projects consider the role of the human viewer in more detail when synthesising virtual crowds. The Metropolis project investigates visual and auditory perception of crowds in city environments [26]. Commercial games are worthy of interest as well, since the interactions between the user and the 'non-player' characters (NPCs) have a critical impact on the game-play and the overall experience of the player. However in the commercial games the player is not meant to interact with all the NPCs of the games. There is a distiction between the NPCs that the interaction is crucial for the progression in the game, and the NPCs that are mainly used to bring life to the virtual environment.

III. System Architecture

An abstract way that this prototype works with the Emotiv Epoc headset is illustrated in Figure 1, where the user controls brain-generated events in a closed neuro-feedback loop. The user is visually stimulated by controlling an avatar in the serious game (see section IV). The raw data is calculated on the headset's chip and sent to the dedicated computer. Afterwards EmoKey generates the keystroke events moving the player based on the users' brain-activity and facial expressions on the virtual world.

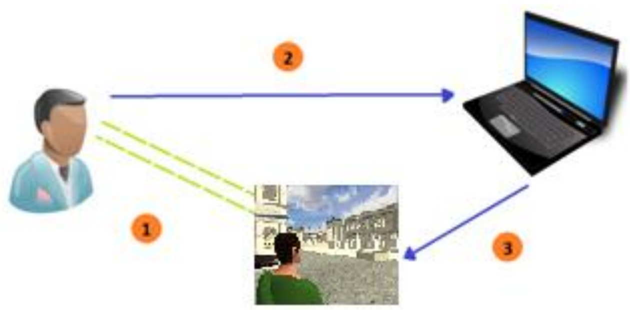

Figure 1 System Architecture

EmoKey translates the detection results of the headset to predefined sequences of keystrokes according to logical rules defined by the user through the EmoKey user interface. A set of rules, known as an 'EmoKey Mapping', can be saved for later reuse. EmoKey communicates with Emotiv EmoEngine in the same manner a third-party application would do (i.e. by using the Emotiv API exposed by edk.dll). EmoKey emulates a Windows-compatible keyboard and sends keyboard input to the Windows operating system's input queue. The application with the input focus will receive the emulated keystrokes.

The Emotiv EmoEngine refers to the logical abstraction of the functionality that Emotiv provides (in edk.dll). The EmoEngine communicates with the Emotiv headset, receives preprocessed EEG and gyroscope data, manages user-specific or application-specific settings, performs post-processing, and translates the Emotiv detection results into an easy-to-use structure called an EmoState. An EmoState is an opaque data structure that contains the current state of the Emotiv detections, which, in turn, reflect the user's facial, emotional and cognitive state. EmoState data is retrieved by Emotiv API functions as illustrated in Figure 2.

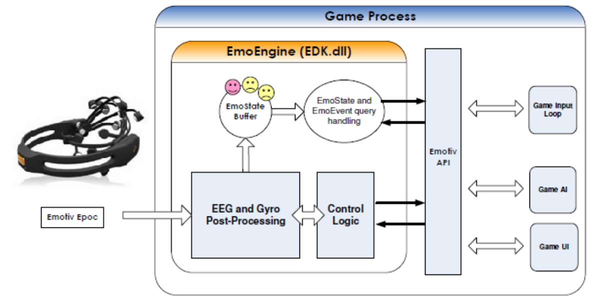

Figure 2 Integrating the EmoEngine and Emotiv EPOC with the Game

Moreover, the 16 sensors (14 plus 2 reference sensors) are based on the international 10-20 system [27]. This is an internationally recognized method which describes in detail the electrode placement on the scalp for EEG tests or experiments as illustrated in Figure 3.

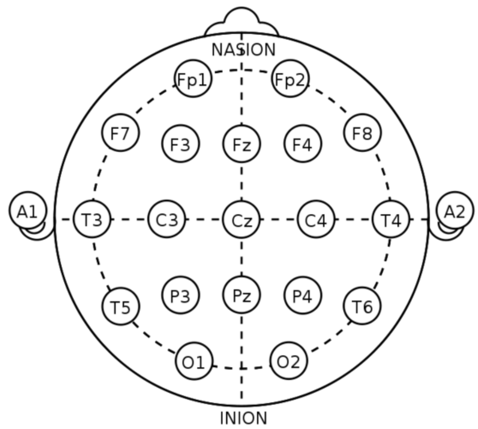

Figure 3 International 10-20 System Placement and Number Designation

The protype system is fully operational [28] and it's using a combination of Cognitive and Facial/Muscular functions. It is worth-mentioning, that the Emotiv Development Kit was used connecting the Emotiv Epoc headset to the Emotiv control panel to create and train a new user profile which takes approximately 30 to 60 minutes depending on the adaptability of the user.

IV. Roma Nova Serious Game

The interactive game is built upon Rome Reborn [29], [30] one of the most realistic 3D representations of Ancient Rome currently in existence. This 3D representation provides a high fidelity 3D digital model which can be explored in real-time. Rome Reborn includes hundreds of buildings, thirty two of which are highly detailed monuments reconstructed on the basis of reliable archaeological evidence. The rest of the 25 to 30 square kilometers model is filled with procedurally-generated buildings based on accurate historical knowledge. As a result, an obvious advantage of Rome Reborn is its accurate recreation of the ancient city of Rome c.340 A.D, and is therefore readily adaptable to a serious game teaching history (see Figure 4).

Figure 4 Rome Reborn Reconstruction [30]

The Roma Nova project builds on previous work at Coventry University [31], [32] and aims at teaching history to young children (11 to 14 years old). It allows for exploratory learning by immersing the learner/player inside a virtual heritage environment where they learn different aspects of history through their interactions with a crowd of virtual authentic Roman avatars. It addresses several serious game challenges where the main aim of the players is to be taught history by interacting with autonomous characters in a cultural heritage environment. It demonstrates the potential of game techniques for cultural heritage experiences, outlining the problems encountered when integrating a substantial number of different state-of-the-art techniques.

The Roma Nova game has been designed based on the 'Unity 3D' game engine using a 3D realistic reconstruction of ancient Rome. Unity 3D is an integrated development environment for computer game design and it runs on Microsoft Windows and Mac OS X [33]. For this simulation both C# and Javascript were used. The aim of the game is to navigate an avatar inside virtual Rome and interact with intelligent agents while learning at the same time. Both navigation and interaction is performed using brain-wave technology from the Emotiv headset. Figure 5 illustrates how the RomaNova game looks like.

Figure 5 Roma Nova Game Play

Intelligent interactions are based on the three Level of Interaction Framework (LoI) which was developed in collaboration between the Serious Games Institute (SGI) and Toulouse University [31], [32]. The LoI framework simplifies the interaction between the player and the NPCs. Graphically the LoI can be represented as auras of increasing complexity centered on the player's avatar as illustrated in Figure 6.

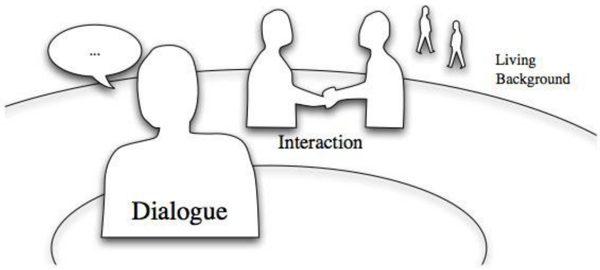

Figure 6 Level of Interaction Framework [32]

LoI is based on a simple social space metric [31], [32] and it consists of three components. The first level aims to populate the characters with authentic crowd in order to increase the immersion of the player. Characters located in closer surrounding of the player belong to the interaction level. Finally, a character inside the dialogue level interacts with the player in a natural way, ultimately using speech recognition and synthesis.

All the NPCs by default belong to the background level, but as the player moves on the environment and they happen to get closer or away from the player and thus enter or exit the interaction or dialogue levels [34]. Characters are not assigned a specific level of interactiona priori. By default, they all belong to the background. But as the player moves and/or they move freely in the environment going about their business, they happen to get closer or away from the player and thus enter or exit the interaction or dialogue levels [32].

The latest implementation of Noma Nova includes: (a) *a crowd of Roman characters in the Forum* and (b) *a highly detailed set of buildings that belong to the Rome Reborn model*. The NPCs are wandering in the 3D environment between predefined points of interest, while the player is able to move freely as shown in Figure 7.

Figure 7 Procedurally Generated Roman Agents

When clicked on by the player, a NPC changes its current target to the position of the player, and hence starts walking towards the player. When the NPC is close enough to enter the dialogue level, a series of actions is triggered by the engine [32]: (a) *an animation is triggered to change the camera from a wide angle to a close-up perspective*; (b) *the smoothed highly detailed version of the Roman character mesh is loaded to replace the low polygon version, along with the corresponding animations* and (c) *the steering controller attributed to every background character is dropped and replaced by a simple ECA engine developed on purpose to play the scenario* (see Figure 8).

Figure 8 Dialogues in Roma Nova

Figure 8, illustrates how the dialogues are performed in the Roma Nova. At the end of the dialogue, the reverse procedure is performed allowing the 3D model as well as the steering behaviours to be re-applied to the NPC. This way, it carries on its navigation to its previous point of interest as the computer memory is freed from the ECA engine and the high definition 3D model [32].

V. BRAIN-COMPUTER INTERACTIONS

The basic idea is to use Cognitive functions (brainwaves) to move the player forwards/backwards, and the Expressive functions (facial expression) to turn the player left/right when the user blinks accordingly. To accomplish that, the Emotiv Epoc EEG headset had been used. The Emotiv Headset is a neuro-signal acquisition and processing wireless neuro-headset with 14 wet sensors (and 2 reference sensors) being able not only to detect brain signals but also user's facial expressions, offering optimal positioning for accurate spatial resolution [35].

Unlike other commercial BCI headsets, Emotiv needs a unique user profile to be trained in order to map users' brain-patters. In a training session no more than 1 hour, user's skills can be increased up to 65% for the forward & backward moves using the Emotiv control panel (see Figure 9). Training the profile is not an easy task and requires practice and familiarization, especially when the user needs to train more than two actions as it is easy to get distracted from outside stimuli and 'confuse' the training process of the users real 'intentions'.

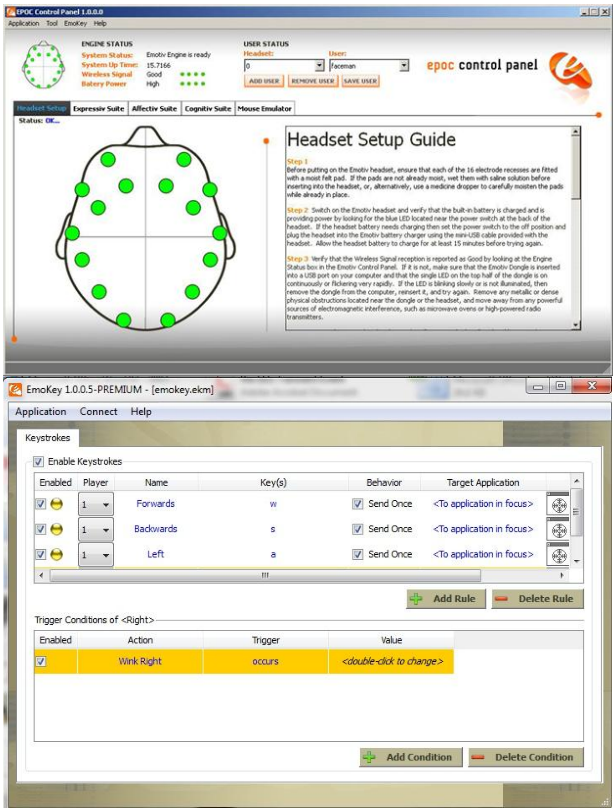

Figure 9 Emotiv Control Panel (top), Emotiv EmoKey (bottom)

To take control of the events the EmoKey (see Figure 9) the application was used in conjuction with the Emotiv Control Panel to generate keyboard events for each identified and trained thought. After that the EmoKey application is transferring these events to the game as key strokes.

The sensitivity adjustment display on the control panel supports two types of 'signatures' that are used to classify input from the neuroheadset as indicating a particular facial expression. Right Wink / Left Wink: these two detections share a common graph line as illustrated in Figure 10. A center level indicates no wink, low level indicates a left wink and high level indicates a right wink.

Figure 10 Panel Display

Emotiv's Cognitiv detection suite (see Figure 11) evaluates a user's real time brainwave activity to distinguish user's intentions in performing physical actions on real or virtual objects. The detection is designed to work with different actions and movements. Cognitiv allows the user to choose up to four actions that can be recognized at any given time. The detection reports a single action or neutral (i.e. no action) at a time, along with an action power which represents the detection's certainty that the user has entered the cognitive state associated with that action. Increasing the number of concurrent actions increases the difficulty in maintaining conscious control over the Cognitiv detection results. Almost all new players readily gain control over a single action quite quickly. Learning to control multiple actions typically requires practice and becomes progressively harder as additional actions are added.

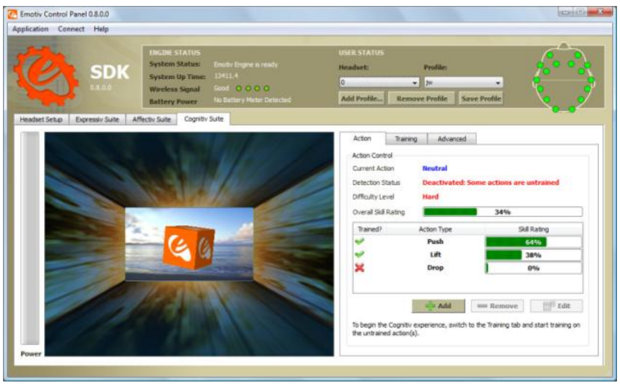

Figure 11 Cognitiv Suite Panel

The Cognitiv Suite panel uses a virtual 3D cube to display an animated representation of the Cognitiv detection output. This 3D cube is also used to assist the player in visualizing the intended action during the training process. The Cognitiv training process enables the EmoEngine to analyze users' brainwaves and develop a personalized signature which corresponds to each particular action. As the EmoEngine 'learns' and refines the signatures for each of the actions (as well as neutral) detections become more precise and easier to perform.

Initially, the cube on the suite panel screen (see Figure 11) will not move, as the system has not yet acquired the training data necessary to construct a personalized signature for the current set of actions. After Neutral and each enabled action have been trained (at least once) the Cognitiv detection is activated and the cube will respond to the users' mental action detection, in real time. Some users' find it easier to maintain the necessary mental focus if the cube is automatically animated to perform the intended action as a visualization aid during training.

Mental dexterity with the training Suite is a skill that will improve over time. As players learn to train reproducible mental states for each action, the detection becomes increasingly precise. Most players typically achieve their best results after training each action several times. Overtraining can sometimes produce a decrease in accuracy – although this may also indicate a lack of consistency and mental fatigue. Practice and experience will help determine the ideal amount of training required for each individual user to successfully interact with the serious game.

VI. INITIAL EVALUATION

To identify how fast the players adapt on brain-generated events, an evaluation has been conducted with five participants in a laboratory environment. Feedback was received in direct reply to the questions, as well as by raising additional issues. All participants had no previous experience with BCIs so some time was given to familiarise with the technology. Since all users interacted with a virtual object using their brainwaves for the first time, it was necessary to perform repeatable profile training using the control panel. That way the players managed to familiarise with the prototype system by receiving neurofeeback for the brain. At this stage, the system extracts and classifies more accurately the player's intentions.

The aim of this initial evaluation was primarily to gather information on the playability and enjoyability of the Roma Nova serious game, but also to discover potential technical problems in terms of the interaction. All participants had to complete a small task (ranging between 5 to 10 minutes). The task was to move an avatar inside the virtual city (the Roma Nova 3D environment) and interact with the agents using just brainwaves and facial expressions. An example screenshot from the user testing is illustrated in Figure 12.

Figure 12 User Testing

In terms of the positive feedback, all participants mentioned that it was a unique experience to interact with the game through brainwaves. Even if it was 'slower' to interact with the game (compared to standard input devices such as the mouse and the keyboard), they reported that this way of interaction is far more enjoyable. Moreover, all of them enjoyed the graphics quality of the game as well as the 'clever' dialogues with the intelligent agents. The majority of the players mentioned that the brain computer technologies can be very useful for interaction of games and it can be combined with other techniques (such as other natural interaction techniques).

On the negative side, some participants found it hard to adapt in taking control of the agent straight away. The main reason was that they got distracted by external stimuli. Initially, some mentioned that it was not easy to concentrate to navigate in the game and they would prefer a more immersive environment. Even if, through time and concentration they started to get control and adapt to the prototype system, it became apparent that more time for training would be good. Finally, some participants found the BCI technology not as accurate as standard input devices. Even if in this particular game there were no significant requirements on accuracy in navigation, in other computer games that could be problematic.

VII. Conclusions and Future Work

This paper proposed a novel BCI system for controlling serious games for cultural heritage. As a case study, a serious game for ancient Rome, called Roma Nova, was employed. The aim of the game is to navigate an avatar (agent) inside virtual Rome and interact with intelligent agents while learning at the same time. Both navigation and interaction is performed using non-invasive BCI technology from the Emotiv headset. Initial user testing was very encouraging and results indicate that brain computer technologies can be very useful for the creation of serious games for entertainment, education and neuro-rehabilitation although more effective algorithms can be designed to improve interaction accuracy.

In the future, more advanced BCI devices (with more sensors) will be employed to control the game much more effectively and accurately. A more immersive environment using virtual reality equipment such as a head-mounted display and 3D mouse will be integrated for doing a comparative study. In addition, the attention and engagement levels of the user will be captured and analyzed during the learning experience. This can be used in training users with learning difficulties and those who suffer from Attention Deficit Hyperactivity Disorder (ADHD) [15]. Finally, more gaming scenarios will be developed and a large evaluation study will be performed to test the learning capabilities of the serious game as well as the enjoyability of the brain-wave interaction and classification algorithms for BCI research in serious games and virtual worlds.

Acknowledgements

The authors would like to thank the Interactive Worlds Applied Research Group (iWARG) and the Serious Games Institute (SGI) members for their their support and inspiration.

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