Realtime Adaptive Virtual Reality for Pain Reduction

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***Abstract*— Recent years have seen digital game mediums taking conventional amusement, entertainment and leisure industries by storm. They have revolutionized the system to the extent that the industry cannot now even dream to do without this overwhelming reality. The same game mediums that have capitalized on intrinsic leisure aspects have simultaneously focused with equal vigor on other equally, if not more, important collateral objectives. This paper builds on this concept and discusses a work in progress currently being carried out at the University of Malta. It proposes the use of games as a means of distraction therapy for individuals undergoing painful clinical treatment procedures. The creation of an adaptive Virtual Reality (VR) game within an Artificial Intelligence framework will without doubt be of a significantly greater benefit to the community than mere entertainment applications.**

Keywords—Artificial Intelligence, Affective Computing, Adaptive Games, Serious Games, Virtual Reality, Deep Learning

I. Introduction

There is an ever-growing realization that the power games have to engage and motivate individuals to accomplish specific tasks is by far more attractive and challenging than that of any other medium previously explored. This ability to engage individuals provides a platform to gain experiences that go far beyond the expectation of what one had come to expect from games for decades. In light of this, research has started looking at concepts such as 'Serious Games' and 'Gamification'. This realization is further corroborated by the increasing number of games with a purpose that are being released in a wide range of application areas. Perhaps one of the most popular examples of the use of games for a specific purpose is Microsoft's Flight Simulator which gave players a unique and realistic experience into how to fly aircraft, and inspired many of the pilots of tomorrow. Similarly, gamified experiences have been used in healthcare [6,19], helping patients in both physical and mental health, and in the field of classroom education.

The motivation behind using VR as a tool to help patients is a very strong one mainly because VR offers a safe way with which to help individuals without the side effects that other medication might have on the patient. Distraction therapy through the use of VR games has recently been given an increased degree of importance. Companies and researchers have started looking at this field more thoroughly [1, 2]. In our study, however, we want to take what has been done already to the next level by means of Artificial Intelligence (AI). Through the addition of AI concepts such as Affective Computing, we envisage the creation of a game that is able to adapt itself according to the affective state of the individual, and provide a personalized experience that goes beyond anything available to the public up until today.

The upcoming sections present research critical to the study and the methodology to reach the desired final objectives.

II. Literature Review

A. *Related Work*

It is widely acknowledged that by stimulating the visual, auditory, and proprioception senses, VR acts as a distraction to limit the user's processing of nociceptive stimuli [3]. The idea of using VR as a distraction tool during patient rehabilitation and treatment procedures is not entirely new. VR coupled with medication, was found to be effective in reducing the pain symptoms of patients during bandage changes for severe burns [4,5]. In other cases, VR has been used as a tool to distract young children during vaccination. Ogilvy Brasil designed a game whereby a child about to be vaccinated is transported into a virtual world. The patient assumes the role of a hero who is about to receive a powerful shield to beat the villain in the virtual environment. The experience that the child goes through is matched step by step by the nurse that vaccinates the child. In this case, the VR game was found to significantly reduce the elements of fear and anxiety that the child usually goes through during such procedures.

The work done by Kind VR [6] whose work is documented by Birnie et al. and Agrawal et al. is one of particular interest. In the work by Agrawal et. al. for example, the patient is immersed in an underwater scenario and can navigate around and interact with the environment during the therapy procedure which is similar to what is being proposed by this study. More importantly, however was that both documented studies showed positive results in terms of acceptability and effectiveness.

B. *Affective Computing*

When going through present literature one trend becomes glaringly apparent. While studies show positive results in terms of effectiveness in what they want to achieve, they all seem to adopt a one size fits all approach. The direct result of this could be that while some patients might be positively affected by the VR experience, other individuals may be completely unaffected, or worse, incur a negative experience that would cause more distress and make treatment more dreadful. For this reason, we are proposing the notion of an adaptive game driven by Affective Computing (AC).

AC is the study of trying to assign computers the human-like capabilities of observation, interpretation and generation of affect features [7], and is currently one of the most active research topics. It is an important topic for the harmonious

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human-computer interaction that aims to increase the quality of human-computer communication and improve the overall intelligence of the computer. Software is nowadays able to detect human emotions with remarkable accuracy through sensing manifestations of physiology, speech and body motion amongst others. Through analysis of this data, software is now capable of inferring the emotional state one finds himself in. Yannakakis [8] goes as far as describing AC as a multidisciplinary field that studies various ways by which computational processes are able to elicit, sense and detect manifestations of human emotion.

When discussing AC, the main concern is the implementation of what is known as the affective loop [9]. The affective loop is a four-stage loop that defines the key phases with which to achieve affect enabled software and is made up of the below phases;

1. Affect Elicitation phase
2. Affect Sensing phase
3. Affect Modeling phase
4. Affect Driven Adaptation phase

The Affect Elicitation phase, as the name suggests, is the phase that involves evoking and eliciting emotions in a human through various mediums such as images, sound and video. The Affect Sensing phase follows whereby the software, having successfully elicited an emotion in an individual, must be equally capable of knowing how to capture that emotion for further processing through measurement of physiological responses. The Affect Modeling phase is the phase which makes sense of the physiological data. Calvo & Mello [10] further dissect this phase into a signal processing phase, a feature extraction phase and a machine learning phase. Finally, completing the loop is the Affect Driven Adaptation phase which is the phase where the software starts altering its behavior according to the affective state of the individual. Adaptation can take place through a multitude of approaches mostly depending on what the software in question is, for example if the affective computing has been put in place inside a game, adaptation might occur through alteration in the digital content presented to the individual.

C. Virtual Reality & Gamification

Two key areas of study in the context of this research are VR and Gamification. The reason why these two areas are discussed together in this section is that VR has provided a platform for Gamification to thrive on. VR offers capabilities that are ideal for the design and implementation of effective Gamification. Virtual reality is one of the areas attracting the interest of AI researchers for its enormous potential and the countless scenarios where it can be deployed. The ability to transport an individual to a completely different world which can be controlled and with which the user can interact has provided researchers a very useful tool that can be utilized at fairly limited costs. On the other hand, Gamification is the concept of using game elements to motivate an individual into performing a particular task to achieve a predetermined goal. Gamification uses game-based elements and strategies to increase engagement, motivation, learning, and even solve problems.

When discussing the implementation of VR systems Sherman & Craig [11] mention five elements that are crucial to the creation of a VR experience. The first three of these five elements are the participants, the audience that will be making use of the VR experience; the creators themselves, that need to cater for the audience they are targeting; and the virtual environment where participants will find themselves in once they are making use of the VR. The most important in the context of this research are perhaps immersion and interactivity. Immersion is considered the degree to which an individual feels engrossed or enveloped within the virtual environment. In addition to immersion, researchers also take into consideration the element of presence which is defined "as the experience of one's physical environment; It refers not to one's surroundings as they exist in the physical world, but to the perception of those surroundings as mediated by both automatic and controlled mental processes" [12]. While presence is the subjective value of the illusion one experiences when using the system, an increase in immersion often leads to an increase in the presence felt by the user [13, 14]. Interactivity is the element that sets virtual reality apart from other communication mediums. For VR to seem authentic, it should be able to respond to an individual's actions like a real-world environment would typically react, and herein lies perhaps the biggest challenge in the creation of an effective and truly immersive virtual experience.

In the same manner designing for Gamification requires particular considerations if it is to be 'meaningful'. 'Meaningful gamification' signifies that it can provide genuine motivation and is effective on the individual. Among the elements that require consideration when designing for gamification are engagement and choice. These two elements can be considered to be the most in line with what was discussed previously in relation to interaction within the context of virtual reality. The element of engagement defines both the game's ability to provide an engaging gameplay experience and the game's ability to create opportunities for players to engage with others in meaningful ways. People have a more positive mental well-being when they feel connected to the world around them [18] and therefore engagement on this level is crucial to the effectiveness of a gamified system. When discussing engagement, Nicholson reintroduces the concept of flow. Many gamification systems, Nicholson argues, do not get more challenging which results in an element of boredom. Engagement, in this context, is reached when challenges match the skill level of the player. Finally, Choice is another crucial element. Choice puts the player in control of how one engages with the gamified system and stems from the reasoning that a person will have a more positive sense of self-being if one has autonomy. This autonomy often translates in a player being able to make meaningful choices within the system.

III. Methodology

Having highlighted the main areas of research for this study, this paper will in this section discuss the methodology behind the implementation of the system being proposed.

A. Design Specification

In the scheme of things being proposed, there exist 3 key components that make up the system. First is the patient, who will be making use of the VR experience during the procedure, second is a wearable device that will read bio-feedback from the individual, and finally the VR game itself that will act as the distraction therapy tool for the patient. The general idea is quite straightforward; the patient will wear the wearable device during the therapy procedure, and the wearable device will in turn read bio-signal data off the patient, to promptly feed the game that adapts its behavior to keep the patient engaged. This loop remains active until the patient effectively decides to stop using the VR experience.

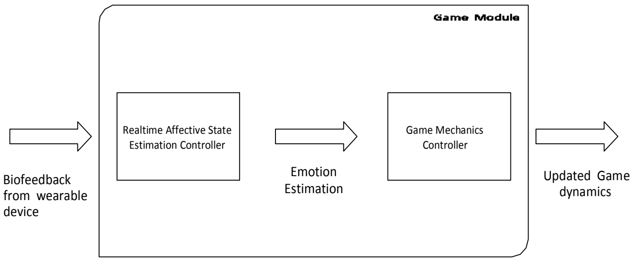

Figure 1: Description of the components that make up the game module (Source: Dingli & Bondin, Realtime Adaptive Virtual Reality for Pain Reduction)

Naturally, most of the processing that will take place during execution of the system will be handled by the game component. In order to make the implementation of the component more understandable and manageable, the tasks that the game component must perform are assigned to two separate sub-components residing in the game.

First, an Affect Detection sub-component is tasked with receiving the information from the wearable device, and performing actions akin to the phases that make up the affective loop discussed earlier. In short, these tasks will include cleaning the bio-signal data coming in, training a model that is able to detect the affective state of the individual and drive the adaptation in the VR experience. In addition to these tasks in line with what was proposed by Sundstrom [9] an extra phase is to be added that will act as a prediction phase. This prediction phase will predict the individual's affective state as he or she goes through the VR experience. The idea is that in time, the game will be driven by this prediction rather than by the bio-feedback data coming in from the wearable device. When the patient is making use of the system, the predictor will unobtrusively be trained to predict the patient's affective state journey. For this task, we propose the use of Generative Adversarial Networks (GANs). During the first runs, the predictor will in all probability fare relatively badly, but performance is expected to improve drastically after a number of runs which refine the predictor's results. Once the predictor's accuracy reaches sufficiently accurate levels, the main driving behind the adaptation of the game will shift from the data being read from the wearable to the data generated by the predictor. This does not mean that the wearable will be eliminated completely from the equation, but that it will now act as a validator of the predictor rather than being the main actor. Through this, any changes in the affective state of the individual can be anticipated before actually occurring, and cater for prior to risking the patient getting alienated from the game and starting to focus on the pain symptoms instead.

The second sub-component is the game controller itself. Its function is to react to the adaptation cues that are the result of the Affect Detection sub-component. The component alters dynamics of the game that are identified as influential and relevant to the changes in the patient's affective state.

B. Biofeedback sensing

Biofeedback sensing is one of the main topics of discussion within this study. It forms the basis of all that is to be achieved by the proposed system and drives its affective computing capabilities. While this study opts for a wearable device approach to gather the data, other researchers have investigated other approaches to bio feedback data gathering. Dingli & Giordimaina [15], for example opt for a non-contact approach, making use of webcams to monitor the heart rate of the individual by extracting the RGB channels from the face region. In the context of this study however, this was not suitable, since the individual's face will be covered by the VR headset most of the time. As a result, a contact-based approach was adopted, where the data is retrieved by smart-watch like devices.

For the first iteration of the research, only heart-rate data is considered. Several researchers have highlighted other bio-feedback data relevant to the goals to be achieved. In line with this consideration was taken of what Picard & Healey [16] describe as "affective wearables", that is, wearable devices capable of reading various physiological data from the individual. In addition to heart-rate data, other researchers have investigated the use of galvanic skin response, an indicator of skin conductance that increases linearly with a person's level of overall arousal, and Electromyography, which measures muscle activity and has been shown to correlate with negatively valanced emotions [17]. However, the acquisition of such data usually requires specialized equipment which is not always easily accessible by the public and therefore limits the audience that the system might otherwise reach. Hence, a decision was made to make use of heart-rate data since heart rate sensors are commonly available in many of the commercially available smart watches on the market.

C. Affect Modeling

There exist many theories as to how affect can be modeled. While some researchers attempt to classify emotions into a number of categories, such as "joy" and "anger", recent work tends to focus more on sensing the state one is in, for instance, when all is going well or when going badly. It is on this line of thought that the research is built. It is important for the system to notice the affective states the individual finds himself in when faced with specific events and then model the experience accordingly.

In order to achieve this, a classifier is first trained to recognize valence and arousal on data belonging to a dataset obtained online. The idea is that at the end of this training phase, the system will be able to make sense of the stream of heart-rate data being fed. With this classifier in place the game can start recording the user's affective journey and associate affective states with particular events occurring in the VR experience, i.e modeling. The game will know that, for example, putting the participant in an environment high up in the mountains has a much more calming effect on the individual as opposed to putting the individual in the middle of a bustling metropolis. This data will then be used to achieve affect driven adaptation. Affect modeling, in the context of this study is seen as an autonomous process that is continuously ongoing without requiring explicit human intervention.

D. Game Adaptation

For all the good work done by the other components of the system, the game adaptation component is tasked with perhaps the most important work of all. Having successfully modeled affective states of an individual and "learned" what causes arousal or valence in the individual himself, it is the game itself that has to make use of this information to eventually reach the desired goals of the study. The idea in this case is to have an infinite runner game where scenarios and characters change dynamically according to the affective state of the patient. The user will be asked to perform tasks and carry out challenges along the way until the game eventually comes to an end concurrently with that of the therapy session.

The design and implementation of the game component brings together numerous established concepts in the field of game design most notably the theory of "flow". Adaptation capabilities must ensure that when a game is becoming too difficult, or too easy, game dynamics adjust accordingly so that the user remains engaged in that tiny segment we call "flow". During the affect modeling phases, the system will also learn what colors, sounds, or activities have an effect on the patient and therefore all this will be taken into consideration when adapting the game in real time to cater for the individual's affective state at that current point in time.

IV. Conclusion

Virtual reality as a tool for pain distraction therapy has for long been a topic of discussion and a field of research that has been explored by numerous researchers. Studies have shown VR to be effective in this area with studies reporting significant drops in pain scores. However, we firmly believe that more can be done in this respect. The one size fits all approach that has for long characterized the implementation of such systems has provided the ground work for this area of study but has also highlighted shortcomings that need to be addressed to encourage wider acceptance of such treatment methods. For this reason, this study is proposing a novel way into the creation and utilization of VR systems for pain reduction in the belief that the approach chosen will provide the desired results and lay the foundations for a new standard in the creation of such systems.

V. Funding

This research is funded by the Vodafone Malta Foundation and has received backing from the Sir Anthony Mamo Oncology Centre in Malta.

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