34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Evaluating the Usability of a Virtual Reality-Based Android Application in Managing the Pain Experience of Wheelchair Users

Fotios Spyridonis, *Member, IEEE**, Tor-Morten Grønli, *Member, IEEE*, Jarle Hansen and Gheorghita Ghinea, *Member, IEEE*

Abstract— **Pain constitutes an important medical concern that can have severe implications to a wheelchair user's quality of life. Results from studies indicate that pain is a common problem in this group of individuals, having a reported frequency of always (12%) and everyday (33%). This incidence signifies the need for more applicable and effective pain management clinical tools. As a result, in this paper we present an Android application (PainDroid) that has been enhanced with Virtual Reality (VR) technology for the purpose of improving the management of pain. Our evaluation with a group of wheelchair users revealed that PainDroid demonstrated high usability among this population, and is foreseen that it can make an important contribution in research on the assessment and management of pain.**

I. Introduction

Researchers have been studying the implications of VR technological solutions on a wide range of medical conditions, with findings suggesting a high level of viability and acceptance. Indeed, VR has introduced a new approach to practicing medicine within various healthcare settings, including rehabilitation, psychotherapy and medical education. For instance, VR technology has been used to help in the rehabilitation of people who have suffered a stroke. According to a study by [1], patients with stroke showed significant improvements in their upper extremity function after several sessions with a VR tele-rehabilitation system that they had designed.

VR technology has also been identified as a promising approach to treating psychological issues. For example, [2] designed a VR system that they used to effectively help people overcome their acrophobia by virtually exposing them to a height and monitoring their reactions. Similarly, persons with a fear of spiders could receive effective VR exposure therapy by giving them the illusion of physically touching a virtual spider [3].

*F. S. Author is sponsored by the EU-funded VERITAS Project – FP7 IP 247765

F. S. Author is with the Department of Information Systems and Computing, Brunel University, Uxbridge, UK (phone: +441895265503; e-mail: Fotios.Spyridonis@ brunel.ac.uk).

T-M. G. Author is with the Norwegian School of IT, Oslo, Norway (e-mail: grntor@nith.no).

J. H. Author is a research student in the Department of Information Systems and Computing, Brunel University, Uxbridge, UK.

G. G. Author is with the Department of Information Systems and Computing, Brunel University, Uxbridge, UK (e-mail: George.Ghinea@ brunel.ac.uk).

The development of VR systems could also change the nature of medical education. Learners could use VR systems, such as the one developed by [4], in order to study human anatomy, or to even seek anonymous expert health guidance through a virtual world (e.g. Second Life) [5].

A. Virtual Reality and Pain

To put the discussion into the context of this study, a search in the medical literature (Medline: keyword "Virtual Reality" AND "Pain") also revealed a considerable number of related research studies that have employed VR technology to address pain-related aspects. Indeed, the application of VR in pain research is quite popular, having been applied to a variety of settings over the years.

The employment of VR technology for burn pain care is perhaps one of the most widely researched application areas. In studies by [6] and [7], VR had been used as an adjunct to analgesics for burn pain after a wound. Specifically, VR in these cases was used as a distraction technique, where patients were asked to throw snowballs at virtual objects in order to grab their attention.

A considerable number of studies were also found dealing with the application of VR technology to the treatment of phantom limb pain. For instance, [8] studied the use of VR as a means of treating phantom limb pain in upper extremity amputees, with their results suggesting that VR can be effective for the intended purpose.

Finally, VR technology has also been well-reported by [9, 10, 11] in a series of studies to be an effective aid in reducing pain through hypnosis, as well as shown to decrease pain in persons with cancer [12, 13, 14].

Motivated by this situation and driven by our previous work [15], in this paper we propose PainDroid: a multimodal and VR-based application for pain management, which has been designed to run on handheld devices (i.e. a smartphone or tablet) that run Google's Android operating system. Employing the benefits of VR technology, the PainDroid application can provide the patient with a 3-D visualization of the human body through a Head Mounted Display (HMD), which enables the patient to describe the pain experience in a more realistic and interactive manner from the comfort of his/her home.

II. PainDroid Application Overview

The PainDroid application has been developed on the Android platform. The choice of this platform is grounded in the high availability of developer tools and third party

978-1-4577-1787-1/12/$26.00 ©2012 IEEE

libraries. Moreover, the system was built with a minimum requirement of version 2.2 of Android. The reason behind this decision was to add support for tablet-layouts.

As such, the developed application has been implemented using a third party 3-D library. Our choice landed on “jPCT-AE” [16], an open source, 3-D engine for Android. This tool supports all our needs, and is available free of charge for commercial, as well as personal use. Since this 3-D toolkit is the central part of the application, we have developed a class hierarchy around it to support the different features.

A. *PainDroid Design Considerations*

The 3-D model was initially created using the Virtual Reality Modeling Language (VRML) and then converted into a “.3DS” (3D Studio by Autodesk, Inc.) file format compatible of being interpreted by our 3-D toolkit. The model consists of individually named body parts/sections allowing for separate interaction. On the screen, the user is also presented with five different pain types: *numbness, stabbing, pins & needles, burning and stiffness*. These types were chosen carefully after consultation with medical staff, and are well-documented in the pain literature [17, 18, 19].

In PainDroid user interaction is based both on *touch* and *hand movement* interaction – in the anticipation that increasing the number of interfacing modalities can make an important contribution to the accessibility of any relatively small-sized interface. Specifically, touch interaction is implemented as follows: first, the user selects the appropriate pain type, and then the desired body part of the model is touched. Each color represents a pain type and the model is colored at the selected location (Fig. 1). To be able to see more details, pinch-to-zoom in/out, drag, and flipping of the model is implemented, so as to be able to position the model at an angle and zoom level sufficient for interaction.

The hand movement interaction has been employed to implement the rotation functionality of the application (rotation of the model), which was achieved by rotating the device itself.

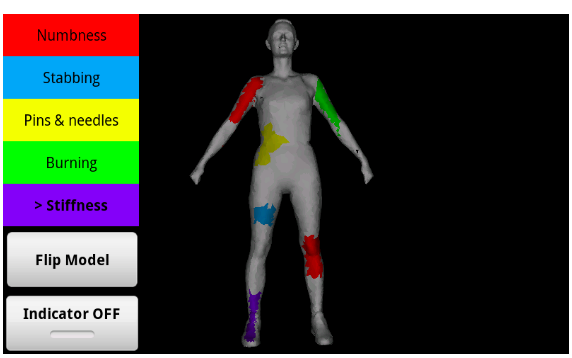

Figure 1. PainDroid in use

B. *Overall Architecture*

On application start, the 3DS-model is initialized with the jPCT library. The loading of the model and its textures were mainly contained in two classes, called “*ModelFactory”* and “*TextureType”*, both presented as white boxes in Fig. 2. By including these fairly heavy processes in “enum” classes that were loaded on start-up, we could cache the model in memory and only return a copy when the models were shown on screen.

There are two main components responsible for the overall system architecture, shown in Fig. 2: 1) the *Views*, shown in grey, and 2) the *Orientation listener*, shown in black.

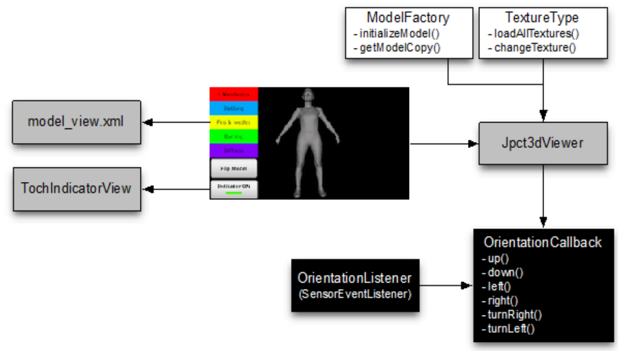

Figure 2. PainDroid architecture

Finally, the VR functionality has been integrated by utilizing the benefits of an external VR display - in our case, the Wrap 920 HMD glasses (two 640x480 LCD displays with 16 million colours, 60Hz scan update rate, weight less than 3 ounces) by Vuzix.

III. EVALUATION METHODOLOGY

A. *Participant Group*

The evaluation of PainDroid was performed with a group of 7 wheelchair users who volunteered to participate in the pilot study. The criteria for selection were that the participant has an age of 18 years or more and experiences some pain during the period of the study. The only exclusion criterion was that they should not have any severe type of impairment, visual or otherwise, which would have prevented them from experiencing the VR nature of PainDroid through the Vuzix HMD glasses. While the application is applicable to all pain sufferers, we have specifically targeted wheelchair users, due to their dynamic pain patterns and their severe mobility limitations that urge for a mobile solution. Moreover, two of the users also had manual dexterity problems and the extra options available through a multimodal interface could have been especially useful in their case.

B. *Instrumentation and Protocol*

The pilot study was approved by the Brunel University Research Ethics Committee. Informed consent was therefore obtained by each participant prior to the evaluation. The protocol centered on the evaluation of the usability of PainDroid. This was examined via a questionnaire, which the wheelchair users had to fill.

The protocol followed in the user evaluation was that, after an initial demonstration of how to use PainDroid, participants were then given the following tasks to perform:

1. Start the app
2. Rotate left/right, rotate up/down
3. Re-center
4. Zoom in/out and drag
5. Reset
6. Use above to select pain type and pain location on model
7. Save and exit

On completion of these tasks, evaluators were then asked to complete a 15-item questionnaire, which was adapted from the System Usability Scale (SUS) originally developed by [20]. The first 13 questions (see Table I) asked users to indicate on a Likert scale of 1 to 5 their (dis)agreement to a series of statements regarding the PainDroid. There was a roughly equal split between positively and negatively framed questions and these were evenly distributed throughout the evaluation questionnaire. Two further questions were open-ended and asked participants to indicate what they considered to be the best aspect of PainDroid on the one hand, and to point out what they though needed the most improvement, on the other. The seven user evaluations lasted approximately between 15-18 minutes each.

TABLE I. EVALUATION QUESTIONNAIRE AND RESULTS (MEAN LIKERT SCALE SCORE PER QUESTION AND RESPECTIVE STANDARD DEVIATION)

Question	Mean	St. Dev.
Q1. I think that I would like to use this application frequently	3.85	1.46
Q2. I found the application unnecessarily complex	2	1.15
Q3. I thought the application was easy to use	4	1
Q4. I think that I would need the support of a technical person to be able to use this application	1.14	0.38
Q5. I found the various functions in this application were well integrated	4.29	0.49
Q6. I thought there was too much inconsistency in this application	1.28	0.76
Q7. I would imagine that most people would learn to use this application very quickly	4.14	1.07
Q8. I found the application very cumbersome to use	2.57	1.72
Q9. I felt very confident using the application	4.57	0.53
Q10. I needed to learn a lot of things before I could get going with this application	1.14	0.38
Q11. I liked using the interface of this application	3.85	1.07
Q12. The information (e.g. menu) provided by the application was clear and helpful	4	1
Q13. I felt it difficult to recover after making a mistake	1.85	1.21

IV. EVALUATION RESULTS

Reliability analysis of the responses received indicated a *Cronbach alpha coefficient of 0.890*, which underlies very good internal consistency. Accordingly, the wheelchair users' evaluation highlighted positive bias in respect of the application's usability and functionality. On the one side, there was relatively strong disagreement with statements targeting the amount of learning (Q10) that they had to have before using the PainDroid (Fig. 5) and with any perceived inconsistencies in the system (Q6). It is of no surprise, then, that users found that the different functionalities of PainDroid were well integrated (Q5) (Fig. 4).

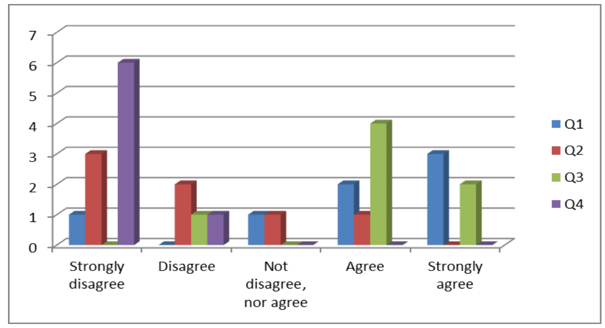

Figure 3. Breakdown of responses: questions 1-4

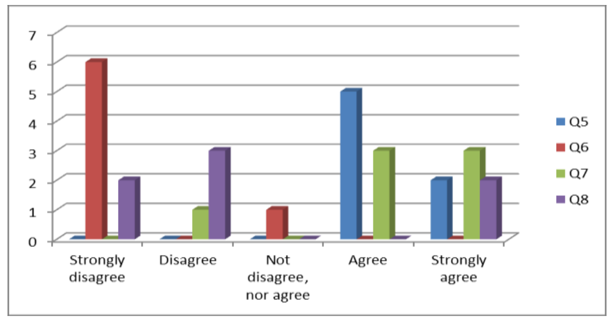

Figure 4. Breakdown of responses: questions 5-8

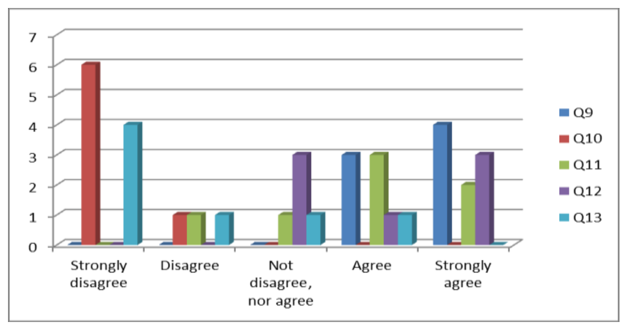

Figure 5. Breakdown of responses: questions 9-13

These attitudes were also reinforced in open-ended comments targeting the best user perceived aspects of PainDroid, for instance:

"Easy concept to understand, useful for describing pain remotely…" (P06)

"Easy to visually show where the pain is located and what type of pain it is…it's relatively accurate…" (P07)

Moreover, users were strongly against the notion that they would need the support of technical people in order to use PainDroid (Q4). These attitudes were reconfirmed by user responses to Q9 (users generally felt very confident using PainDroid). Additionally, the stakeholders displayed strong agreement to the potential of other people finding it easy to learn how to use PainDroid (Q7) (Figs. 3-5).

The same positive trend is displayed in questions which target the ease with which one recovered after making an error in PainDroid (Q13), the complexity of the application (Q2) and its ease of use (Q3). Participants were generally happy with the PainDroid interface (Q11), and thought that the menu information provided was clear and helpful (Q12). It is therefore reassuring that participants indicated that they would see themselves using PainDroid frequently (Q1) (Figs. 3 and 5).

The only exception to the general positive trend observed is given by responses to Q8, in which users were found to be ambivalent towards how cumbersome the application was to use.

P02, however, felt that the use of VR glasses to counteract the limited screen real-estate of lighter phones was a really good idea.

V. Conclusion

Pain is a prevalent, but sometimes, underemphasized medical concern. Whilst there is an abundance of sophisticated, but expensive clinical tools and apparatuses to investigate the underlying physiological causes, there is a scarcity of tools which address self-expressed dimensions of pain. In this paper, we have addressed the latter concern and have described PainDroid, a prototypical Android-based multimodal and VR application for pain management.

Pilot evaluations with a group of wheelchair participants have highlighted a generally positive attitude towards the usability of the application. Whilst we acknowledge that the application is in a prototypical stage and has been evaluated with a relatively small stakeholder sample, our findings, nonetheless, reveal encouraging signs of stakeholder acceptance and satisfaction with the developed proof-of-concept. Larger scale evaluations and assessment of clinical efficacy both form part of our future efforts.

Finally, PainDroid is foreseen to have the following potential benefits/applications:

- Remote management and monitoring of effectiveness of pain medication/treatments
- Pain diaries, allowing for a better understanding of how pain varies in time
- Reduces the need for surgery visits, and thus, the cost of care for pain patients
- Non-verbal indications of pain location and type, e.g. children, people with language and learning difficulties
- The patient becomes a stakeholder in the management of their own pain

Acknowledgment

The authors would like to acknowledge Cyberware, Inc. for providing a 3-D model, which we adapted and then manipulated and extended to meet this study's needs. We also acknowledge EDB ErgoGroup for providing employee time to evaluate our application.

References

[1] M.K. Holden, T.A Dyar and L. Dayan-Cimadoro, "Telerehabilitation Using a Virtual Environment Improves Upper Extremity Function in Patients with Stroke", *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* vol. 15, pp. 36-42, Mar. 2007.

[2] P.M.G. Emmelkamp, M. Bruynzeel, L. Drost and C.A.P.G. van der Mast, "Virtual Reality Treatment in Acrophobia: A Comparison with Exposure in Vivo", *Cyberpsychology and Behavior,* vol. 4, pp. 335-339, June 2001.

[3] H.G. Hoffman, A. Garcia-Palacios, A.C.T.A. Furness III and C. Botella-Arbona, "Interfaces that Heal: Coupling Real and Virtual Objects to Treat Spider Phobia", *International Journal of Human-Computer Interaction*, vol. 16, pp. 283-300, 2003.

[4] H.M. Huang, Y.L. Chen and K.Y. Chen, "Investigation of Three-Dimensional Human Anatomy Applied in Mobile Learning", in *Proc. Int. Computer Symposium (ICS),* Tainan, 2010, pp. 358-363.

[5] A. Gorini, A. Caggioli, C. Vigna and G. Riva, "A Second Life for eHealth: Prospects of the Use of 3D Virtual Worlds in Clinical Psychology", *Journal of Medical Internet Research,* vol. 10, e21, Aug. 2008.

[6] C.V. Maani, H.G. Hoffman, M. Fowler, A.J. Maiers, K.M. Gaylord and P.A. Desocio, "Combining ketamine and virtual reality pain control during severe burn wound care: one military and one civilian patient", *Pain Medicine,* vol. 12, pp. 673-678, Apr. 2011.

[7] C.V. Maani, H.G. Hoffman, M. Morrow, A. Maiers, K. Gaylord, L.L. McGhee and P.A. DeSocio, "Virtual reality pain control during burn wound debridement of combat-related burn injuries using robot-like arm mounted VR goggles", *The Journal of Trauma,* vol. 71, pp. S125-130, Jul. 2011.

[8] A. Gaggioli, A. Amoresano, E. Gruppioni, G. Verni and G. Riva, "A myoelectric-controlled virtual hand for the assessment and treatment of phantom limb pain in trans-radial upper extremity amputees: a research protocol", *Studies in Health Technology and Informatics,* vol. 154, pp. 220-222, 2010.

[9] D.R. Patterson, J.R. Tininenko, A.R. Schmidt and S.R. Sharar, "Virtual reality hypnosis: a case report", *The Inter. J. of Clinical and Experimental Hypnosis,* vol. 52, pp. 27-38, Jan. 2004.

[10] D.R. Patterson, M.P. Jensen, S.A. Wiechman and S.R. Sharar, "Virtual reality hypnosis for pain associated with recovery from physical trauma", *The Inter. J. of Clinical and Experimental Hypnosis,* vol. 58, pp. 288-300, Jul. 2010.

[11] D.R. Patterson, S.A. Wiechman, M.P. Jensen and S.R. Sharar, "Hypnosis delivered through immersive virtual reality for burn pain: A clinical case series", *The Inter. J. of Clinical and Experimental Hypnosis,* vol. 54, pp. 130-142, Apr. 2006.

[12] S. Sander Wint, D. Eshelman, J. Steele and C.E. Guzzetta, "Effects of distraction using virtual reality glasses during lumbar punctures in adolescents with cancer", *Oncology Nursing Forum,* vol. 29, pp. E8-E15, Jan-Feb. 2002.

[13] A. Windich-Biermeier, I. Sjoberg, J.C. Dale, D. Eshelman and C.E. Guzzetta, "Effects of distraction on pain, fear and distress during venous port access and venipuncture in children and adolescents with cancer", *Journal of Pediatric Oncology Nursing,* vol. 24, pp. 8-19, Jan-Feb. 2007.

[14] K.L. Kwekkeboom, C.H. Cherwin, J.W. Lee and B. Wanta, "Mind-body treatments for the pain-fatigue-sleep disturbance symptom cluster in persons with cancer", *Journal of Pain and Symptom Management,* vol. 39, pp.126-138, Jan. 2010.

[15] G. Ghinea, F. Spyridonis, T. Serif and A.O. Frank, "3-D pain drawings: mobile data collection using a PDA", *IEEE Transactions on Information Technology in Biomedicine*, vol. 12, pp. 27-33, Jan. 2008.

[16] jPCT-AE. Welcome to jPCT-AE – a free 3D engine for android [online] Available: http://www.jpct.net/jpct-ae/

[17] D.D. Ohnmeiss, "Repeatability of Pain Drawings in a Low Back Pain Population", *Spine,* vol. 25, pp. 980-988, Apr. 2000.

[18] C.W. Chan et al., "The pain drawing and Waddell's nonorganic physical signs in chronic low-back pain", *Spine*, vol. 18, pp. 1717–1722, Oct. 1993.

[19] A. Uden, M. Astrom and H. Bergenudd,"Pain Drawings in Chronic Back pain", *Spine,* vol. 13, pp. 389-392, Apr. 1988.

[20] J. Brooke, "SUS: a 'quick and dirty' usability scale", in P. W. Jordan, B. Thomas, B. A. Weerdmeester, & A. L. McClelland *Usability Evaluation in Industry*. London: Taylor and Francis, 1996.