Introduction of Novel Interactive Technologies into Demanding Healthcare Contexts

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Executive Summary

The research described herein, conducted in pursuit of the academic qualification of Master of Philosophy (MPhil), follows two themes. The first, and overriding theme related to how the ergonomic and environmental challenges associated with the design, construction, and introduction of a series of iterative prototype technology solutions, capable of delivering Virtual Restorative Environments within a demanding healthcare arena. The research has been both human (patient)-centred and stakeholder-led from the outset (involving clinical and nursing specialists and advisors from the Queen Elizabeth Hospital Birmingham (QEHB)), and was undertaken with the support of early hardware and software grant funding from the Royal Centre for Defence Medicine (RCDM). The second, which is a guiding theme relates to how *Virtual Restorative Environments* (interactive 3D computer reconstructions of scenes of nature, such as forests, coastal paths and so on) can be exploited in hospital and related healthcare settings as a "tool" to promote mental restoration and rehabilitation, particularly following a traumatic incident, such as serious injury or surgery.

What follows are a series of observational oriented studies (adhering closely to the ISO 9241-210 standard) that was conducted as an iterative pre-curser to a usability study that examined how patients, with varying degrees of injury coped with the use of a series of low cost control interfaces, combined with a prototype interaction module. Next it examined how the prototype technology can be iterated based on the evolving requirements of the stakeholder and a change in circumstances, to be re-deployed in a number of new environments to cater for different types of patient rehabilitation.

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1 Introduction

Figure 1.1. The Queen Elizabeth Hospital Birmingham (QEHB).

http://static.comicvine.com/uploads/original/

11/112306/2140750-2132284_birmingham_super_hospital_impressionw_newroofdesign.jpg

The following thesis investigates two overriding themes. Firstly the use of Virtual Restorative Environments (Kort de, Meijnders, Sponselee & IJsselsteijn, 2006; Krijn, M., Emmelkamp, P.M.G., Olafsson, R.P., & Biemond, R. 2004) as a tool to promote mental restoration and rehabilitation within a healthcare environment, and secondly, the ergonomic and environmental challenges associated with the design, construction, and introduction of prototype technology within the healthcare arena. The research which had been stakeholder led from the outset, and attracted limited early funding from the Royal Centre for Defence Medicine (RCDM) examined facilities and conditions at the Queen Elizabeth Hospital-Birmingham (QEHB) focusing on the building's design features that were according to stakeholder

feedback, failing to provide the patient with adequate views of the outside world, focusing in particular on views of natural scenes. It has been well documented that being exposed to nature or to simulations of nature have born positive results in terms of restoration (Ulrich, R. 1984; Kaplan, R. & Kaplan, S. 1989). Figure 1.1 provide a glimpse as to the layout of the so-called “super hospital”. The QEHB consists of three elongated circular subsections designed to maximise the ingress of natural light. One negative aspect of the design features views from the patients’ bed spaces as either a view to the opposite inner face of the circular subsection as illustrated in Figure 1.3, the bed space opposite (in the case of a multi occupancy room), or - at best - a limited view of the surrounding urban area.

Figure 1.2 A typical view from the window of a multi occupancy room at the Queen Elizabeth Hospital, Birmingham.

Image courtesy of Prof. Robert Stone

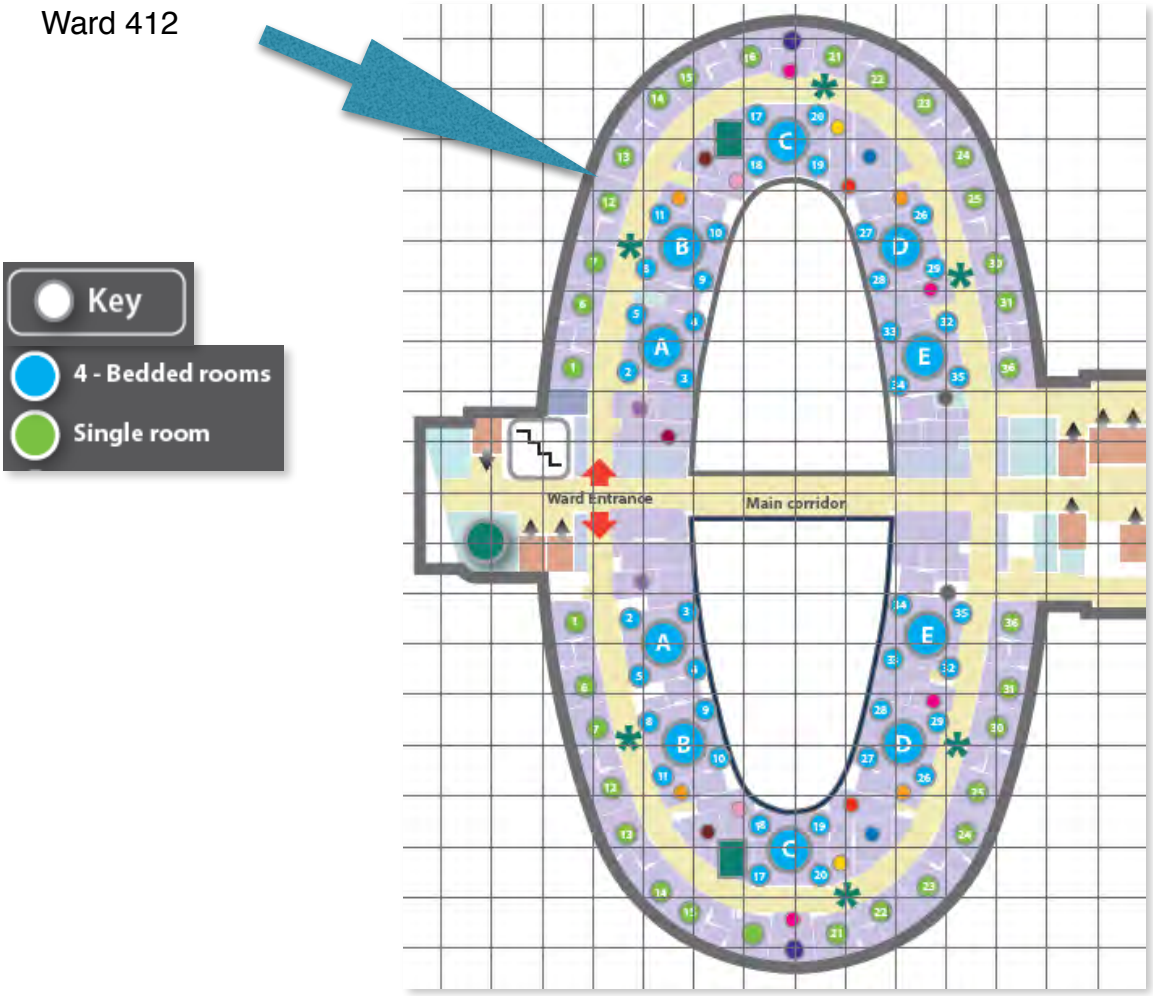


Figure 1.3 The structure of the wards, 412 occupies the upper semi circle.

http://www.uhb.nhs.uk/Downloads/pdf/QehbFloorplanGeneralWard.pdf

The stakeholder involvement and the location for the research had ties firmly with the nation's armed forces, specifically looking at post-deployment service personnel returning from active duty in Afghanistan upon sustaining trauma blast from Improvised Explosive Devices (IEDs) or gunshot injuries. At the time of writing the categorisation of incoming injures stood at fifty percent gunshot, fifty percent blast trauma from IEDs. The patients were situated within 412 ward which is designated a military ward.

At the time of the investigations, 412 ward consisted of two types of patient accommodation. These were sixteen single-occupancy side rooms as indicated on Figure 1.3 (and designated in green), positioned around the outer face of the building and allowing the patient to benefit from a limited view of the outside world, albeit from the fourth floor (Figure 1.4). Confined to the inner semi-circle were five multi-occupancy rooms (designated in blue) each capable of accommodating four patients. The view from the windows in these rooms was rather more restrictive (Figure 1.2) and promoted limited limited external views.

Figure 1.4 The view from a side room window, within 412 Ward.

Image courtesy of Dr. Charlotte Small

1.2 Patient Injuries

One of the main threats encountered during the Afghanistan conflict resulted in military personnel suffering traumatic injuries resulting from gunshots and IED detonations. The injuries ranged from nerve and tissue damage resulting in decreased dexterity / mobility, or, in the extreme, the loss of one or more limbs. All cases required a lengthy stay and more often than not high levels of pain requiring significant analgesic medication. Rehabilitation and intense physiotherapy follows in the majority of cases, and it was a certainty that, in the case of amputees a further period of rehabilitation would be undertaken at Headley Court, where amputees are fitted with prosthetics and trained to use such devices as they begin the final stages of recovery.

A common theme surfaced amongst patients (Franklin, B. 1974) that suggested many were harbouring extreme levels of anxiety due to a combination of factors, including anxiety about the injuries sustained, the volume of medication they were being administered, and the extreme boredom that arose from only days before being in a war zone to being confined to a bed with restricted access to the outside world.

A further issue was observed regarding the positioning of the bed within the side rooms with relation to the window. It was observed that patients were having to look to the side to gain any exposure to the outside world at all, and, due to the medical equipment in close proximity to their beds, further strain was put on the patients neck when any attempt was made to gain a reasonable view of the outside world.

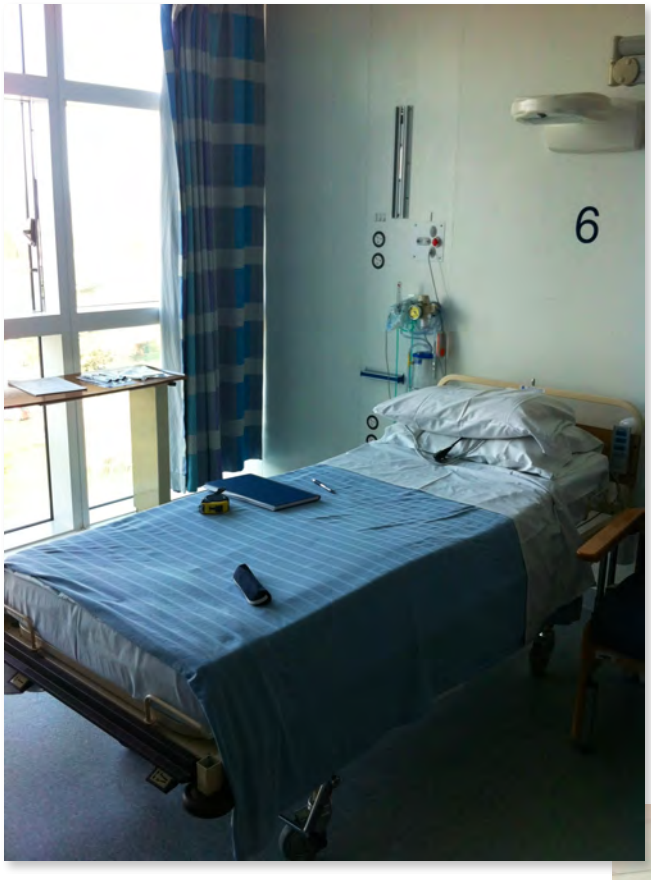


Figure 1.5 A side room located with in 412 ward QEHB.

Figure 1.6 A typical bed space, with a swing-out pay-to-use TV and a high-back arm chair.

1.3 Requirements

For the post-operative patient who could potentially be physically attached to an array of pain dispensing / diagnostic equipment, most of his or her time within the QEHB would undoubtedly be bed-bound. The range of activities provided for patients throughout the day was felt to be a limiting factor in promoting mental restoration. Patients experienced quite a solitary existence during their stay, and their daily routine was only occasionally interrupted by the need for intervention by medical staff or the visit of relatives. Located opposite every patent there was a basic wall mounted analogue clock (Figure 1.7). The multi-occupancy room featured either a view of a fellow patient opposite, or of the privacy curtain, which was pulled across during consultation or treatment. Both bed spaces featured a pay-to-use TV service (Figure 1.6.) available via a small swing out display, it provided basic functionality at a cost of £8 per day.

Figure 1.7 A view every patient who was confined to bed rest in ICU at the QEHB was presented with.

Image courtesy of Prof. Robert Stone

Early discussions with stakeholders and results from the initial review of the literature (see Section 2) suggested that virtual environment technologies were worth an in-depth investigation with a two-pronged approach: firstly, the design and implementation of a virtual environment that would enable the patient to be paired with an appropriate interface to best cater for the varying severity of his or her injury. Such an interface would allow for a comfortable and free rein for interacting with and exploring the virtual environment. An alternative would be to locate one or multiple simulated views within the vicinity of the patient with the ultimate aim of promoting restoration from mental fatigue and anxiety that would otherwise manifest itself as negative patient attitudes and, potentially, a delayed positive healthcare outcome.

Secondly, and running in parallel to the virtual environment effort, there would be a need for the research and evaluation of a series of human-centred “window-on-the-world” technology solutions to provide the basis for a series of iterative prototype interactive systems that would be self-contained, fully mobile, but above all adhere to the relevant ISO human factors and usability standards (for general and medical system design, including, ISO 9241:1997 Ergonomic requirements for office work with visual display terminals (VDTs) and ISO 9241:Part 210, Human-centred design processes for interactive systems). In addition, the systems developed or procured must follow the strict protocols for medical device implementation, technology acceptance and infection control.

1.4 Research Aims

Following on from the high-level contextual description of the project presented above, a series of research aims were formulated to fit within the project timeframe and budget restrictions, but avoiding having to compromise the function and quality of any prototypes developed.

The research aims were as follows:

(i) Investigate whether the design and use of an interactive 3D virtual restorative environment could act as a catalyst for mental and physical restoration for post-operative service personnel following trauma induced by IED blast / gunshot injures.

(ii) Evaluate the needs of the patients, care professionals and clinical staff, together with the impacts of the technology on the hospital environment, as part of a human-centred design process. Using the outcomes of this evaluation, in conjunction with established human-centred design standards, this will be undertaken throughout the creation of a series of Virtual Reality Interaction - Modules (VRI-M) to act as “windows-on-the-world”, capable of being moved from ward to ward and patient to patient.

(iii) Evaluate the needs of the patients focusing on interface evaluation and implementation to minimise discrimination based on the varying nature and severity of injuries.

(iv) Evaluate if a VRI-M can be re-adapted and re-deployed to promote mental and physical restoration in non-military patients.

2. Literature Review

The following literature review examines how an individual, after prolonged periods of concentration, can begin to develop mental fatigue. It then proceeds to detail how by exposure to something as simple and readily available as nature, can over time contribute to the restoration of depleted concentration. Next, it looks at the restorative benefits of exposure to nature by examining if using surrogates to nature, for example, substituting real world views for that of a large plasma display (Kahn et al. 2008) to act a conduit to nature can provide similar restorative effects to that of being within a real-world natural environment. The review moves on to look at simulated environments both mediated, views of nature through the playback of pre-recorded video, photos and slides of nature (Kjellgren & Buhrkall, (2010), and virtual, in the treatment of phobias (Hoffman et al. 2002). Finally the literature review turns to the idea of bringing new prototype technology to a medical arena, looking at the stages of creating an iterative design and looking at the stages of validation and verification.

2.1 Attention

It can be argued that one has an intuitive understanding of what it means to “pay attention” to an object or event. In the field of cognitive psychology, it has been suggested that “everyone knows what attention is”, others have countered that “no one knows what attention is” (Pashler, 1998). The idea that attention involves selecting some information for further processing whilst inhibiting other information from receiving

further processing. It was the great psychologist-philosopher William James who in 1892 whilst commenting on “attention", stated that it was an "involuntary" process and that it was evoked by the presence of some object, process or incident that was interesting or exciting in the environment. Attention, he argued, favoured simple responses and consumed lower mental processes.

In contrast a second type of attention, called "Directed Attention" (Struss & Benson, 1986), requires greater mental effort, since, the authors argue, by focusing selectively upon an environment and by voluntarily using ones higher mental processes, one is susceptible to fatigue. The limitation of directed attention is that one’s mental capacity to expend effort is finite and after prolonged exposure fatigue will become the overriding factor (Struss & Benson, *op cit*).

2.2 Directed Attention Fatigue

Extended periods of exposure to sources requiring extensive levels of directed attention can potentially lead to an adverse effect known as Directed Attention Fatigue (DAF). DAF occurs when specific parts of ones global mental inhibitory systems are depleted from over use. Global mental inhibition is a brain-wide modulating system which can numb activity in parts of the brain. This critical function protects the brain from producing scrambled thoughts and potential seizures (Beadle, S. 2006). DAF is not an illness, however it is a form of mental fatigue and is temporary (Cimprich, B. 1993).

Triggers that may bring on the onset of DAF include:

(i) multitasking

(ii) lack of sleep

(iii) stress resulting from emergencies such as medical trauma or a bereavement

(iv) illness or injury that interrupts brain circuits involved in maintaining attention

(v) prolonged concentration if certain tasks such as, trying to understand and process complex concepts.

Directed Attention is so ingrained in our thinking and functioning that it may go un-noticed until it has been depleted and fatigue sets in. When faced with Directed Attention Fatigue the most viable course of action is to begin and maintain a process known as restoration.

Restoration, in the context of the present research, has been defined as:

"the process of recovering physiological, psychological and social resources that have been diminished in efforts to meet the demands of everyday life"

(Hartig 2007)

2.3 Restoration

Hartig & Staats, (2003) defined restoration as a process whereby the renewing of diminished resources and capabilities takes place. It enhances the ability to focus attention (Hartig, Mang, & Evens, 1991), offers stress relief (Ulrich, 1983), and can lead to positive affective states (Hartig, Nyberg, Nilsson, & Garling, 1999). Two frameworks co-exist, one claiming recovery from psychophysiological stress as the central process (Ulrich, 1983), the other, recovery from directed attention fatigue (Kaplan & Kaplan, 1989).

Studies addressing restorative scenes have indicated that European groups show significant preferences towards natural scenes over urban (Purcell *et al.,* 1994; Stamps, 1996). Scenes consisting of vegetation and specifically water were able to sustain greater interest and restore attention levels. The idea that real-world natural environments could elicit positive feelings, the reduction of fear and limit stressful thoughts suggest that they have a unique potential to contribute positively to levels of personal restoration from stress and anxiety. In 1984, Ulrich sought to ascertain whether the location of rooms (Figure 2.1) within a hospital ward that overlooked out upon scenes of nature led to a greater increase in post operative recovery times when compared to rooms that overlooked a brick wall.

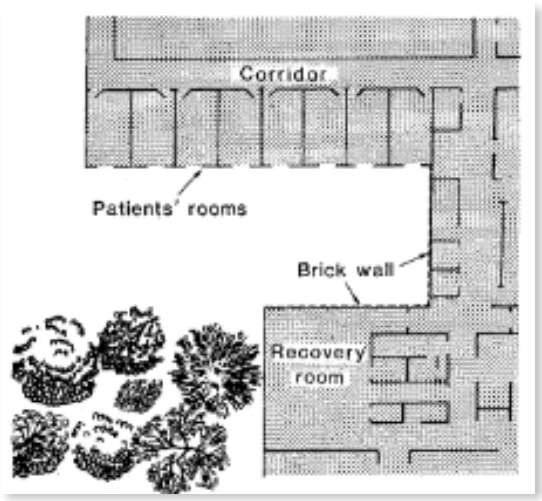


Figure 2.1 depicts the setting for the Tree vs Wall study conducted by Ulrich (1984).

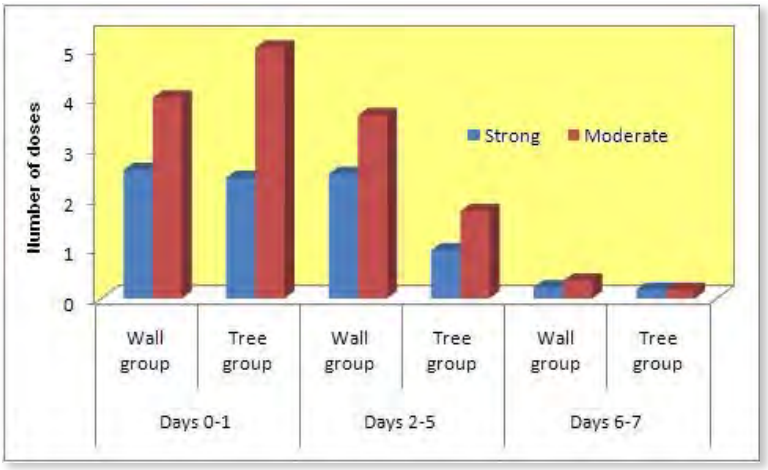
The participants involved had undergone a routine type of gall bladder surgery (open cholecystectromy). The surgery itself was unremarkable, with a negligible amount of post-operative complications. The results (summarised in Table 2.1) suggested that the need for post operative medication was reduced for the “Tree Group”, and also attracted fewer negative evaluative comments from nursing staff. The study concluded that the views of nature however limited had the potential to influence a patients recovery as well as reducing ill feeling towards care professionals.

In a report issued by the National Health Service (NHS) estates (Lawson et al. 2004) it was illustrated that architectural environments can contribute to the treatment of patients and have a significant impact on positive health outcomes. Conclusions made suggested that purpose designed contemporary buildings created an improved atmosphere, leading to patients with mental health problems being less combative and general patients requiring less analgesic medication.

Table 2.1 Comparison of analgesic doses per patient for wall-view and tree-view groups.

Analgesic strength	Number of doses					
	Days 0–1		Days 2–5		Days 6–7	
	Wall group	Tree group	Wall group	Tree group	Wall group	Tree group
Strong	2.56	2.40	2.48	0.96	0.22	0.17
Moderate	4.00	5.00	3.65	1.74	0.35	0.17
Weak	0.23	0.30	2.57	5.39	0.96	1.09

Figure 2.11 Graphical representation of Tree vs Wall study by Ulrich (1984).



2.4 Attention Restoration Theory (ART)

The premise of Attention Restoration Theory (A.R.T) (Kaplan, R., & Kaplan, S. 1989) suggested that an individual can possess increased levels of concentration following exposure to nature or by simply the act of viewing scenes of nature. Issues arose with directed attention, directed attention requires considerable effort, the task in hand may require effort and that exposure to nature and therefore the restorative effects may

cause confusion and distraction from the original task, which can have an adverse effect and require the extraction of further effort. It may be said that fatigued attention is related to irritability and irritability leads to aggression, then perhaps people deprived of natures restorative qualities would be overly aggressive (Kuo & Sullivan, 2001).Kaplan in (2001) posed the argument that a window that offered a real world view could provide the user with a series of micro-restorative experiences, momentary brakes in concentration that can provide respite from immediate tasks and demands. Tennessen & Cimprich, (1995) suggested that the restorative qualities of these momentary glances depended not solely on presence but the content during these glances and that the accumulation of said glances could over time deal with ones deficits in directed attention. Simon (1978) discussed that in a modern society ones attention is a finite resource, where sustained effort leads to mental fatigue. The argument that in order to gain any sense of restoration the process would best be suited to settings that required minimal amounts of directed attention.

2.5 Cognitive Behaviour Therapy (CBT)

When dealing with anxiety disorder the recognised and accepted form of psychotherapy is cognitive behaviour therapy (CBT). CBT trains the patient to alter preconceived patterns of thinking and actions in order to prepare them to face their fears (National Institute of Mental Health, 2006). The aim of the therapy was to reduce levels of fear or anxiety with the ultimate goal of eliminating avoidance behaviour, which is the thing we do to try and get away from experiencing something unpleasant. An example would be

the dependance on prescription medication in order to mask a series of upsetting memories from surfacing.

Once deemed to be at the required level the therapist will administer exposure using one of two methods:

Imaginal exposure

The use of imagination to recreate a feared situation

vivo exposure

The use of physical recreations of the fear situation

Imaginal exposure therapy's success hinges largely on the patients ability to reproduce similar levels of anxiety, thus making its results unpredictable. Vivo exposure therapy is more effective at eliciting anxiety as the feared stimuli is often faced directly. The prospect is daunting for the patient and the procedure can be costly, for example, fear of flying and enormous financial outlay involved with booking such an experience. The risk of public embarrassment also factored into the equation, as well as the therapists lack of control of the patients experience. Despite the negative elements vivo exposure is generally preferred as it resulted in a higher success rate (Krijin, Emmelkamp, Olafsson & Biemond, 2004).

To date only a limited number of studies of the effects of restoration have actually involved the participant being exposed to a real world area featuring nature (Hartig et al. 1991). The majority of exposure studies have been conducted in controlled laboratory conditions whereby the media administered consisted of photographs, slides, or videos. The assumption suggested that the levels of immersion would be sufficient enough to provide similar sensory levels to that of a real world environment. Levi and Kocher (1999) concluded that mass exposure to virtual nature and virtual reality would over time devalue the significance of real world nature.

Kjellgren & Buhrkall, (2010) sought to understand if the comparison of a natural environment bore similar or increased restorative effects in contrast with that of a simulated natural environment. The natural environment selected for the study was located in the Karlstad Nature Park, it comprised of four hundred year old pine and deciduous trees, lakes and rivers. A number of easily assessable footpaths and trails made for an ideal location for the participant to explore and absorb nature.

The simulated natural environment was installed in a light controlled window-less room measuring twelve metres square. Equipment present were a table, chairs and AV equipment consisting of an twenty eight inch display and a DVD player. Participants were placed at a maximum distance of two metres from the display to enhance levels of presence. The media in question was a series slides all taken from photos captured from within the park. The design followed a concept derived by (Kort et al. 2006) and in all, a total of ninety seven slides were implemented.

The study concluded that the natural environment resulted in a greater degree of altered states of consciousness (ASC). Altered states of consciousness are states of reality that are present outside of an individuals normal day to day reality. (Kjellgren, 2003; Tart, 1972) characterised ASC amongst other things, by alterations in emotional expression, feelings of rejuvenation, and enhancements in quality of life. The study also summarised that both the environments were equally efficient in reducing levels of stress, it raised the question, can a reproduction of a real world environment have similar restorative traits as its real work counterpart?

Research that sought to investigate the difference in restoration between simulated natural and simulated urban environments have drawn conclusions to suggest that the former promoted faster recovery from stress and sustained recovery from directed attention fatigue. Directed Attention Fatigue (DAF) is a neurological phenomenon that results from overuse of the brains inhibiting attention mechanism which handles incoming distraction whilst maintaining focus on a specific task.

The ethos of a restorative environment is one that provides an individual with exposure to a visually stimulating and pleasant vista. The idea that levels of exposure can reduce negative thoughts and elicit positive emotions, levels of anxiety and stress can be plateaued or reduced.

2.6 Window on the World

Kahn et al. (2008) broached an idea that built upon the work of Ulrich (1984), the comparison of nature vs brick wall saw nature provide greater levels of restorative respite than that of a sterile view. Kahn et al. (2008) took theory one step further by introducing the use of a plasma display to act as a window on the world.

Figure 2.2 The plasma display condition, simulating a virtual window on the world.

A 50inch plasma display (Figure 2.2) was installed into an existing window aperture to mimic the characteristics of a real window, a high-definition camera was mounted directly outside at an elevation of fifteen feet from ground level and was set to receive a live static feed. The other conditions were; curtain closed to simulate the wall condition and the curtain opened to simulate the natural view.

Conclusions drawn suggested that views over looking a nature scene afforded greater restoration than that of a view of a blank wall. The results validated Ulrich's (1984) study but interestingly found that the plasma display condition bore no significant improvement over a view of a blank wall.

An issue brought up by Radikovic et al., (2005) as to the failure of the plasma display research was the users physiological and psychological experience of nature would be dictated and indeed limited by the available technology, the poor visual fidelity and the absence of parallax. Parallax is the shifting of objects when viewed at differing angles.

2.7 Virtual Restorative Exposure Therapy (VRET)

Throughout that last twenty years computer generated simulation has began to evolve and with the advent of ever powerful computers and software, another form of exposure was born and subsequently evolved. By creating simulated marriage of both cognitive behaviour therapy methods, imaginal and vivo, participants who suffered from a fear of flying were now able to confront their fears using a new multi sensory approach using Virtual Reality Graded Exposure Therapy (VRGET). The therapy allows participants to view real situations in an immersive virtual environment, as with *vivo* exposure therapy where the stimuli would be presented in the real world, it could potentially lead to an increased levels of anxiety and a possible loss of controllability. VRGET can be administered in a controlled environment where control is in both the therapist and the participants hands at all time, Wiederhold et al., (2002).

What in a pre-curser to VRET would have seen a sufferer of Arachnophobia who was attempting to confront their fears, either have to summon up via imagination a particularly harrowing and distressing event in order to reach a treatable state of anxiety or would face exposure to real spiders in an attempt to begin the process of acceptance and desensitisation. A study by Hoffman et al., (2002) explored whether VR exposure theory was effective in the treatment of spider phobia, it was found that Virtual Reality exposure was effective in treating the phobia compared to a control questionnaire. 83% of patients who were subjected to VR treatment showed clinically significant improvements when compared to those in the waiting list group. This led to the conclusion that VR had the potential to positively influence in the treatment of Arachnophobia.

2.8 Issues in VR Treatment

The idea that Virtual Reality has the potential to provide favourable results despite the many inaccuracies in the replication of physical reality. Virtual Environments can create a superior sense of presence relative to imaginal exposure and pose a greater trigger to activating the underlying neural network accepted with fear processing (Rothbaum, et al., 2003. Foa & Kozak, 1986).

Presence is thought to be related to the suspension of disbeliefs (Wiederhold & Wiederhold, 2005). Presence may occur when a participant during interaction with a virtual environment experiences a greater level of interaction with a Virtual Environment

than with the current physical environment (Wiederhold & Wiederhold, 2000), a number of variables have been found to influence presence (Sadowski & Stanney, 2002), such as; user-initiated control, ease of interaction, length of immersion in a virtual environment, social interactions in a virtual environment, maximum pictorial realism, and hardware / software factors for example, graphics processor unit power (GPU), central processing unit (CPU) and the maturity of the game engine used to create the Virtual Environment. Wiederhold & Wiederhold (1999; 2005) stated that levels of presence induced in a virtual environment may correlate to the treatment outcome. The idea is encouraging as it can be said that some people do not seem to react emotionally to Virtual Environments (Walshe, et al., 2003).

2.9 Medical Device Design

Human factors are a series of systems, behaviours or actions that alter human performance, and how an individual interacts within an environment. Utilising human factors engineering principles can improve human performance with medical devices and can improve patient, work place safety and reduce errors (Weinger et al., 2010).

Good medical device design can suppress the likelihood and consequences of error (Clarkson et al., 2004). Buckle et al., (2006) argues that medial devices are usually developed by smaller companies who lack resources to exploit effective ergonomic principles and this would change if there was a chance of a monetary return either by improving sales or creating a better product.

The idea of producing a device that can satisfy the needs and requirements of the user calls for a number of factors to be considered. The device must be designed to account for the proposed working environment for it to be used efficiently and effectively, so that the end user should not have to modify the device in anyway to make it function (Martin et al., 2008). A European Council Directive, defines a medical device as an instrument or apparatus whether used alone or in combination with the software necessary for its proper application, to be used by individuals for the purpose of diagnosing, prevention, monitoring, treatment or alleviation of an injury or handicap (European Council Directive 93/42/EEC). Medical devices are grouped into specific classes of device, a rule of thumb suggests that the greater the risk associated with the device, the greater the device class and in-turn the levels of regulation.

2.10 Conclusions

The literature review has detailed the causes of mental fatigue, which has suggested, that lack of sleep, stress induced from trauma and injury, all of which a convalescing patient within the confines of a hospital environment may face. The idea that something as simple as views of nature (Ulrich, 1984) however brief (Kaplan, 2001) can over time promote levels of restoration. If however the patient is devoid of the opportunity to venture out and take in nature, or worse still located in a hospital bed with no or very limited views of nature from their window, what can be done to help restore fatigue?

Having looked at the research that suggested offering static views of nature or simply the outside world using a HD webcam and a plasma display (Kahn et al., 2008) provided limited improvement over views of a blank wall (Ulrich, 1984). And looking at the findings by Radikovic et al., (2005) that suggested that the failure of the work by (Kahn et al. 2008) was in-part down to the poor visual fidelity and absence of parallax. A conclusion was formed to investigate, design and create a 3D virtual restorative environment based on a real world location, it would be hoped that this would negate the failings of Kahn et al., 2008 by providing dynamic user interaction, negating the parallax issues and also allowing the views to be changed to suit the user, by the user.

The second conclusion was to take the idea of a window on the world, to create a series of iterative prototype systems that would be installed within the patients bed-space allowing he/she to readily access virtual nature at any time of the day, with the hope that it may provide levels of mental restoration, increasingly so with the added capability of being able to self the area that provides the greatest respite.

3 ISO 9241-210:2010. Ergonomics of human-system interaction

- Part 210: Human-centred design for interactive systems

Throughout the design process for each of the following prototype builds (Sections, 5,10 and 13) ISO 9241 Part 210 was consulted, it provided requirements and recommendations for human-centred design principles and activities throughout the life cycle of computer-based interactive systems.

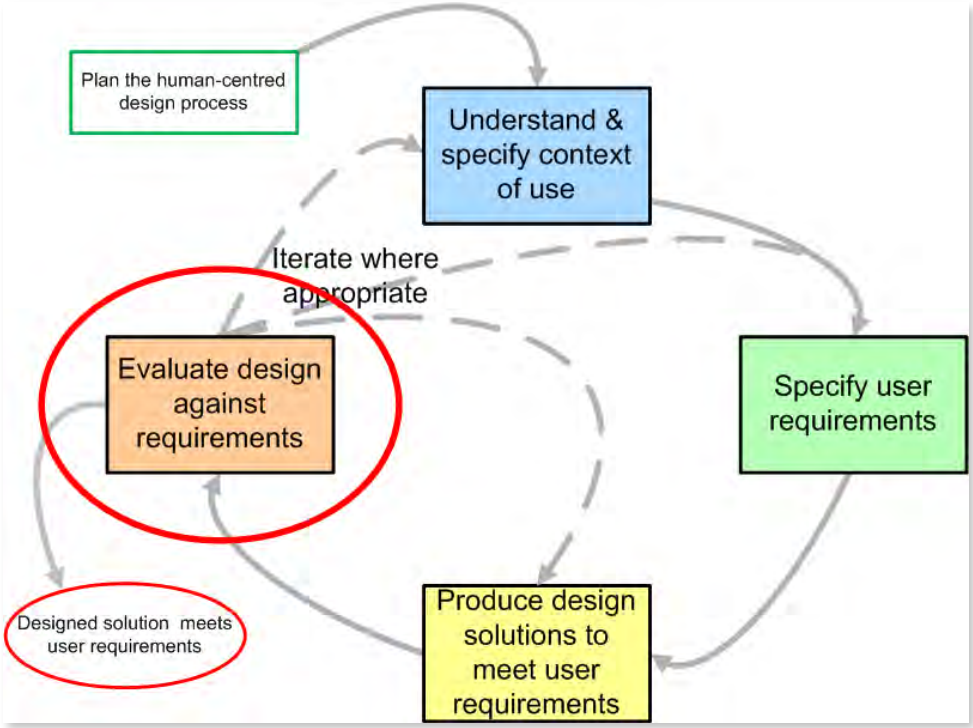


Figure 3.1 ISO 9241-210 Human-centred design for interactive systems.

https://thestandardinteractiondesignprocess.files.wordpress.com/2012/04/is0-9241-210-diagram-evaluate.png

The ISO 9241-210 standard (Figure 3.1) characterises the stages necessary to ensure a design is user-centred; it should involve [ISO 9241-120, p.17];

1. The design is based upon the definite understanding of the user, the task required and the working environment.

2. The user must be involved throughout the design and development process.
3. The design must be driven and refined by user-centred evaluation.
4. The process is iterative, the most appropriate design cannot typically be achieved without iteration.
5. The design should address the whole user experience.

Based on the following stages mentioned above the first task was to evaluate a number of Commercial off-the-shelf (COTS) devices. COTS are essentially consumer technology that can be purchased from non specialist suppliers at a reasonable cost. The benefits of using COTS technology allows for rapid modifications to be made quickly and often on the fly, therefore keeping the systems downtime and costs to a minimum.

3.1 Initial Hardware Candidate Consideration

Following on from the outcomes summarised in the requirements section of the present report (Section 1), it was evident that a form of PC-based Virtual Reality display system would be required. The patient who, it was assumed, would be bed-bound when presented with the virtual environment, would be invited, if capable, to take full navigational control of a virtual environment under study. The bed was of standard NHS issue and incorporated a motorised upper body incline of up to forty-five degrees to best aid with patient comfort.

A PC had to be factored into the design of the hardware solution as the main component of the system purely as the virtual environment and any subsequent software were solely PC-compatible. The PC system would need to have a suitable display and a set of interface devices (i.e. data input devices) that would best match the patients' requirements

depending on the type and severity of injuries sustained or their physical condition following surgery. (Refer to sections 6, 11 and 13.4).

Figure 3.2 - Initial equipment suitability testing.

The required PC system would need to be flexible in its placement, being rapidly deployable in close proximity to the patient with the aim of providing the best possible levels of immersion whilst simultaneously respecting the needs of care professionals (many of whom had previously requested that all equipment be rapidly extracted in the event of an emergency patient intervention). Levels of immersion in terms of virtual reality is the perception of being physically present in a non-present world. The perception is achieved by surrounding the participant of the Virtual Reality display system with images, graphical environments and sound, all with the aim of providing a fascinating environment.

Figure 3.3 Laptop and interface placement in relation to the participant.

The initial hardware design considerations demonstrated how the use of a laptop (Figure 3.2) placed on a hospital-style tray table potentially satisfied many of these requirements in terms of providing the participant with a fully usable and interactive experience, as well as satisfying ISO 9241 part 210 - Human-centred design for interactive system (Section 3). The laptop selected for use during the investigation was a Dell Precision M4600, selected for its then high powered NVIDIA Quadro FX 1800M graphics processing unit (GPU) and full hight-definition (HD); (1920x1080) display. Using such a high powered laptop for the Virtual Reality system allowed for a self contained all-in-one unit that was easily re-deployable between participants but was more than capable of handling the graphical and real-time complexities of detailed virtual environments, allowing experimentation later with different integrated interface hardware options (including head-mounted displays and head tracking systems, for example). A flexible silicone keyboard was selected as it could be positioned to closer to the participant to aid with comfort, it could also be wiped down to satisfy the hygiene requirements of a medical environment. A standard USB mouse was

selected as it was ambidextrous to allow for use in either hand dependent on patient injury and levels of dexterity.

Figure 3.4 A simple clean look above but a major health and safety risk below.

Although the use of a single laptop was a promising first attempt in developing a “patient-friendly” interface solution, a number of issues began to rapidly outweigh the benefits. For example, in order for the laptop to be utilised efficiently, the contents of the patient tray table would need to be rearranged or relocated, which took time and also both invaded

patient privacy and compromised hygiene. Making use of existing furniture meant that available space for accommodating new hardware such as the laptop was at a premium. Positioning of equipment also became problematic. To avoid any issues of discomfort, the display needed to be situated behind the keyboard and in line with the participant. The original arrangement had the display located off to one side of the patient's mid-sagittal plane, meaning that he or she would have to look down to bring the keyboard into view and then look up and turn to face the display (see, for example, Figure 3.3, where the display is to the left of the patient's mid-sagittal plane).

Figures 3.2 and 3.3 illustrated how the bulk of the laptop occupied the majority of the available tray table space causing the keyboard to be positioned upon the participant's body. These findings suggested that the original idea of utilising existing hospital furniture, specifically the tray table - an item that more often than not situated at the side of every bed, was inappropriate. Additionally (and referring to Figure 3.3), another early assumption was that, by utilising a laptop, this would result in a "workstation" that had the advantage of providing a clean and uncluttered solution. However, note in Figure 3.4 the excessive amount of wiring located on the floor, which, as a bare minimum, was required to power the system. Adding other mains-powered hardware such as a docking station for wireless headphones, or power units for motion trackers, would only exacerbate the problem and would have major heath and safety implications for patients, medical staff and visiting relatives.

3.2 Conclusions

The outcome of the initial hardware consideration suggested that a more bespoke stand-alone system that was less intrusive to the participant was worthy of investigation, as long

as such a solution adhered to the strict environmental considerations of the hospital ward. The laptop itself was easy to move but lacked the immersive quality required due to the display size and the fact that, given the restrictions imposed by the patient's tray table, it had to be viewed off-centre (with respect to the patient's mid-sagittal plane). From a set up and break-down perspective, the system still failed to be rapidly re-deployable within an acceptable timeframe due in part to the mass of wiring and the lack of available storage for interfaces and peripherals.

4 Second Hardware Candidate Consideration

Building upon the conclusions reached during the consideration of the initial hardware candidate solution, a second solution was proposed and tested with the aim of attempting to eradicate as many of the earlier issues raised as possible. The major hurdle was the need to remove the mass of wiring that accompanied the laptop as well as to try and provide a more acceptable arrangement of the hardware (input device and display) as to avoid any possible patient discomfort during use. It was felt that the participant would gain the best possible user experience with minimal intrusiveness, but above all ensure that the system could be integrated safely within the confines of the immediate medical environment.

Figure 4.1 Placement of a PC / display arrangement on a wheeled trolley.

In the second candidate solution, the laptop was replaced by a more traditional PC configuration, consisting of a base unit and display, it was split into two elements, the base unit being installed on the lower section of a wheeled utility trolley and the display seated on top. The wheeled trolley was an important consideration that was born out of evaluating the laptop in a static position. By installing the key components on a manoeuvrable platform it now became more of a self-contained unit, yet was more easily transferable between participants and could, at a moments notice, be wheeled away to allow for access to the patient by medical staff or visiting relatives. A further benefit of the new arrangement was that both sides of the bed would remain clear and for patient care the trolley setup was able to remain in situ. Figure 4.1 illustrates how the display now sat at the end of the bed instead of off to one side. Note also how only the display is just visible over the foot-board of the bed. The advantage of this was that it allowed for an unobstructed view of the display without any distractions caused by the PC base unit, excessive wiring, or any interfaces device connections branching out from the sides of the previously evaluated arrangement.

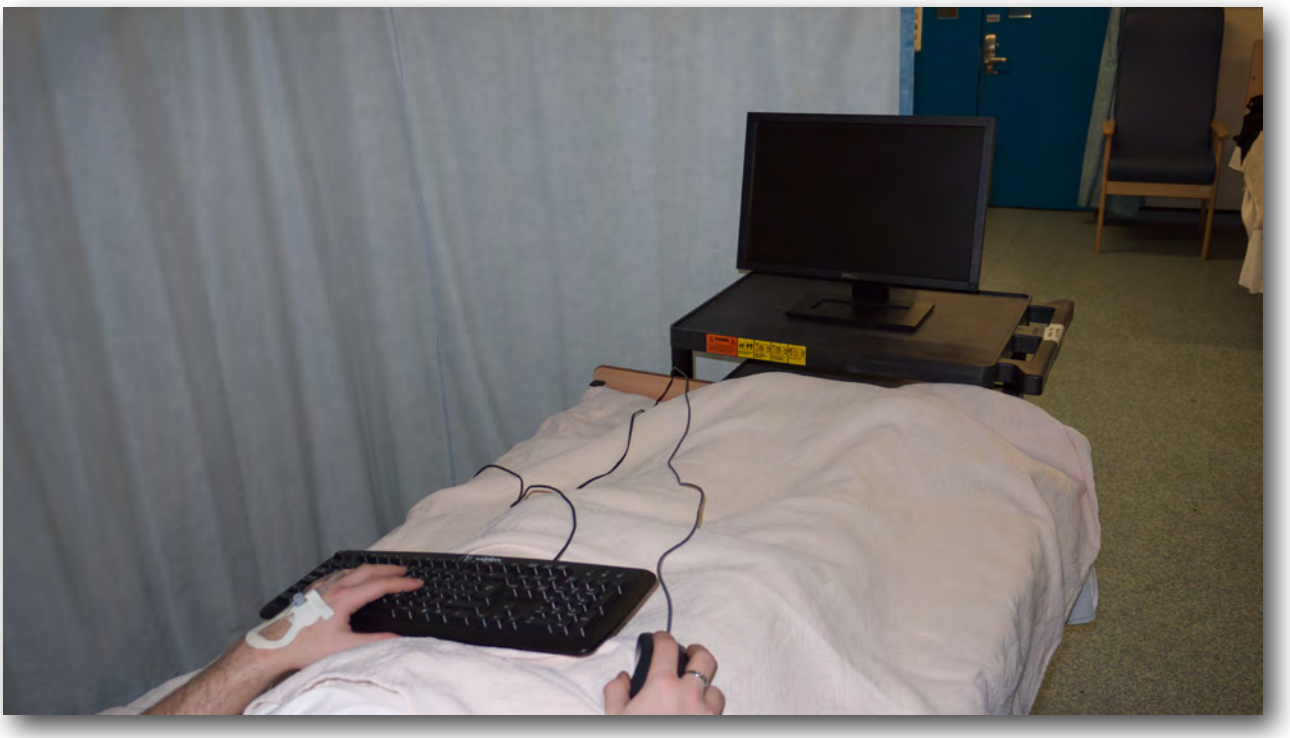


Figure 4.2 (previous page) Although the issue regarding the interface placement remained the display now sat inline with the participant's mid-sagittal plane.

Mains power was supplied via a single 13 amp mains cable mated to a four-way power distribution block (the same distribution block that fed the laptop). Figure 4.1 illustrates how just a single wire was fed along the underside of the bed. This avoided the cable clutter witnessed with the earlier laptop setup, although, the mains wire could just as easily have been fed centrally under the bed to provide a more heath and safety orientated design.

4.1 Conclusions

In this candidate solution, the keyboard interface still sat upon the participant's body (as is evident in Figure 4.2) which was unstable and thus unsafe but could easily be placed upon the bed tray sharing the area with the participants' personal possessions, causing less of an intrusion than commandeering the whole surface for a full sized laptop. Due to the small size of the screen it was observed that the keyboard placed on the tray table would partially obscure the view of the display. This came from the fact that the test display was 20inch and proved inadequate at providing the required levels of immersion due to the distance from the participant to the end of the bed. However, as a proof of concept embracing a system that was potentially manoeuvrable, largely self-contained, and had provisioning for the storage of interfaces, this solution was considered to be a step forward and would set the scene for the first in a series of prototype module builds.

5 The Virtual Reality - Interaction (VR-I) Module - Prototype 1

Building upon the knowledge gained from the results of the first two candidate hardware evaluations, it was concluded that there was a strong requirement to embed the lessons learned into the design and prototype build of a Virtual Reality / Interaction Module (referred to here as the “VR-I Module”). The following section details the design and build process, together with the modifications required to create a system that was, in the eyes of the medical stakeholders, fit for purpose.

5.1 Human Interface Systems - The Role of ISO Standards

In order to prototype a VR-I Module that provided the best possible interactive experiences for patients, whilst not compromising the day-to-day needs of the medical care professionals, and to integrate such a module seamlessly and safely within a medical environment, the prototype build process followed the recommendations contained within a selection of relevant ISO (International Organisation for Standardisation) standards. ISO standards are globally recognised as a route to compliance and are important contributors to UK Health and Safety legislation.

The ISO standards that were referred to during the build of the VRI-Module prototype were:

- ISO 9241:1997 Ergonomic requirements for office work with visual display terminals (VDTs)
- ISO 9241Part 210 Human-centred design processes for interactive systems.

The cornerstone of the VR-I Module build was the acquisition of a commercially available heavy duty trolley mount, (Figures 5.1, 5.2, and 5.3). The mount selected possessed the capability to accommodate a maximum screen size of 60 inches and handle a gross weight of up to 55kg.

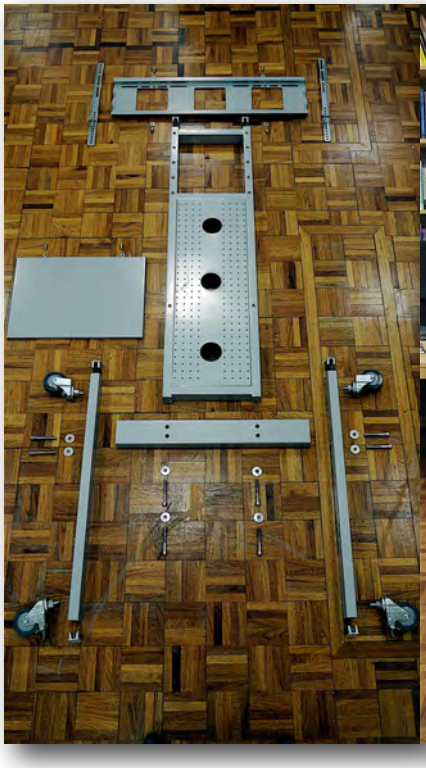


Figure 5.1 The trolley mount in its deconstructed form.

Figure 5.2 The trolley mount in its stock form - front view

Figure 5.3 The trolley mount in its stock form - side view

Due to the specific requirements of the VR-I Module's medical and patient orientated environment a number of modifications were carried out to the basic compassion of the trolley mount in order to make it fit for purpose, the following sections details the changes.

5.2 Re-Mounted Audio-Visual (AV) Shelf

Figure 5.4 Display positioned at the foot of a standard issue hospital bed.

The design called for the VR-I Module, when in use, to be located as close to the foot of a standard hospital bed as possible, (e.g. Figure 5.4) This would allow the patient to view the display without being distracted by the PC casing and fixtures, peripheral equipment and the mount itself. If the display positioning was other than in line with the patients's mid-sagittal plane, the potential for a distorted views of the virtual environment would lead to increased levels of anxiety due to variances caused by alterations to visual perspective.

In order to facilitate with the correct alignment of the mount vis-à-vis the position of the bed, the front-facing accessory shelf that was originally located two-thirds of the way down the front of the mount (see Figure 5.3) was relocated to the upper rear section of the vertical support. The choice of position meant that a wide range of installed computer equipment could be located directly behind the display and would, thus, offer no distraction to the patient. The relocation of the shelf (as shown in Figure 5.5) reduced the depth at the front of the module by 320mm, thereby allowing the non-patient user (experimenter, nursing staff, etc.) to simply and easily roll the VR-I Module until it rested against the foot of bed in a safe and optimal viewing position. Figure 5.4. illustrates the positioning of the VR-I Module when close to the foot of a standard issue hospital bed. Note how the base of the display aligns squarely with the top of the footboard providing the patient with an unobstructed view of the virtual environment but with only a limited view of the mount itself.

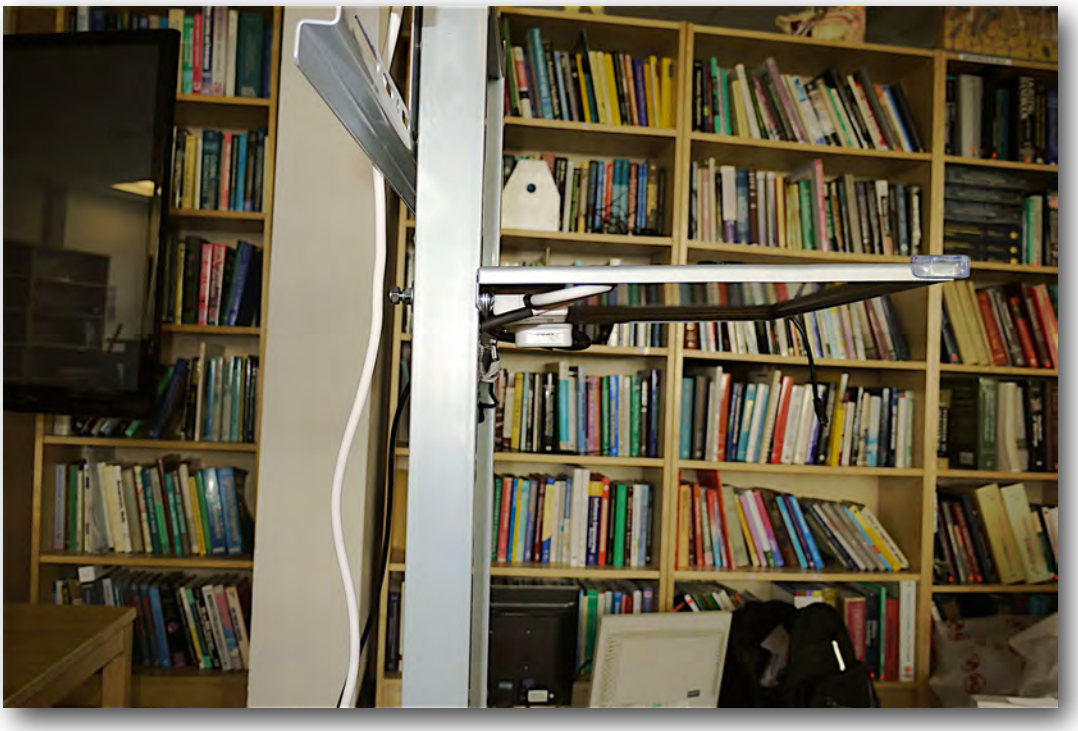


Figure 5.5 Re-Mounted AV shelf.

5.3 Universal Serial Bus (USB) Hub

The VR-I Module was designed to utilise a large array of interface devices from game controllers to audio sub-systems, and was required to be as flexible as possible in allowing technology changes to be made on site, with the minimum of down time. The addition of a

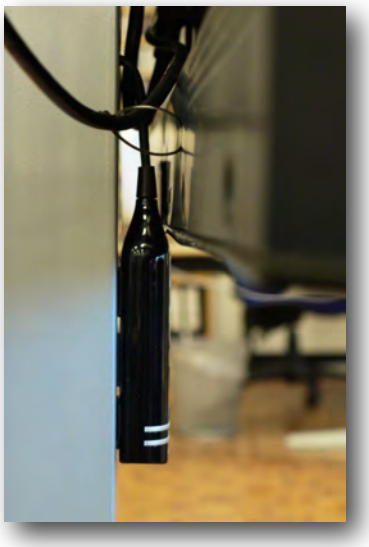


Figure 5.6

Side view of the USB hub as mounted on the trolly mount.

Figure 5.7

Front view of the USB hub as mounted on the trolly mount.

front-mounted four-way USB hub facilitated a quick and efficient method of hot-swapping non-wireless interface technologies, whilst the elevated mounting point allowed for the shortest and safest cable arrangement to the participant. Figures 5.6, and 5.7 illustrate how the USB hub was mounted to the stand.

5.4 Power

Caution was observed during the design of the wiring schematic (Appendix 1.9), although the electronics were consumer grade, a great deal of attention was paid to keeping the wiring as unobtrusive and as tightly packaged as possible. To that end the underside of the

Figure 5.8 Mains block mounted to the underside of the AV shelf.

Figure 5.9 Cable from the mains block exiting at the base of the stand via a flexible cable gland.

newly relocated accessory shelf was identified as the ideal location to mount a six-way anti surge mains power block. The advantage of such an installation was that all mains power-drawing devices could be located no further than 30cm from any given socket on the block. Figure 5.8, illustrates how the mains block was installed. Note how the power cable

has been fed through the drilled vertical box section and exits through a flexible gland at the base of the module in close proximity to the casters (Figure 5.9). Having a single point of exit for the mains cable was a health and safety consideration that allowed for the cable to be traced along the underside of the hospital bed out of the way of medical equipment specific to the patient. This also avoided causing a trip hazard. The single mains plug also provided minimal inconvenience when utilising one of the limited wall-mounted power points which at times provided the patient with a considerable range of critical care devices.

A grey electronics box (Figure 5.8) was mounted to hold excess signal cabling from the display and also to act as a route for the USB hub to reach the PC.

5.5 Auxiliary Mains Extension

Figure 5.10 A single gang mains block mounted on the rear of the display mounting panel.

Figure 5.11 A battery charger installed during testing ensured that the audio system remained functional at all time.

The six-way mains power distribution block was installed in such a location that it would offer little or no scope for the addition of any temporary devices such as laptops, or external hard disk drives, essential when updating the system or demonstrating changes

via the module itself. A single gang trailing socket was modified and installed to rear of the display mounting panel (Figure 5.10). The socket proved a valuable addition when a battery charger (Sanyo NC-MQN04B) was mated to it to charge AA / AAA cells in order to provide power for a wireless headphone system and a number of wireless devices (Figure 5.11).

5.6 Display

Figure 5.12. The display selected for the VR-I version prototype seated on a pedestal stand.

http://s7d3.scene7.com/is/image/TheBrick/50PA4500?$ProductDetails$

The display identified for use on the VR-I Module was the 50-inch LG 50PA4500, (Figure 5.12), selected for its slim foot print, slender bezel, and lightweight construction, weighing 25.8kg. As the display selected was of the plasma variety, it boasted a glass panel which ultimately being situated in a medical environment, would stand up to the rigours of a strict hygiene regime. The wiring for the display's power and signal input were installed for quick

release, allowing for rapid disassembly from the trolley mount for ease of transportation, storage, and relocation. It also allowed the mount to be reconfigured to act as a test bed for evaluating other screen types and sizes, for example IPS (in-plane switching) panels and LED (light-emitting diode) backlit displays.

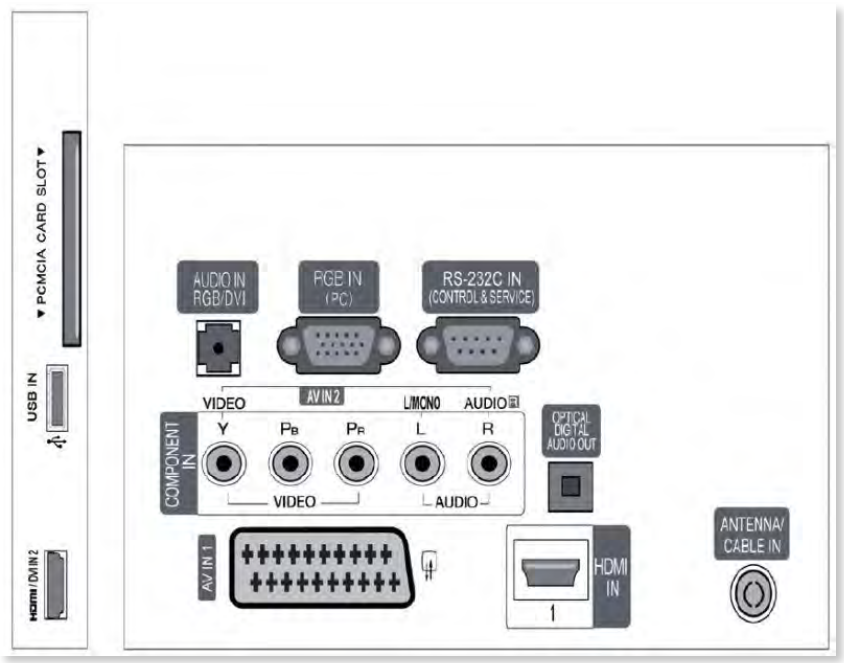


Figure 5.13. A image of the displays input board, for the purpose of the window system the HMDI 1 input on the main board was implemented.

http://www.neriba.lt/out/oxbaseshop/html/0/dyn_images/6/7e84fa0f90ddb106647391773_p6.jpg

5.7 PC

The heart of the VR-I Module system took the form of a custom-PC, equipped with an i5 - 2400Mhz CPU running at 3.4Ghz and a 2GB Nvidia GeForce GTX 560ti GPU. The processing power of the machine was required handle the real-time rendering of the complex virtual environment and also to also to handle the demands of a wide range of simultaneously running interface devices and audio equipment. Figure 5.14 illustrates how the PC was mated to the accessory shelf. Notice how the entire PC, together with the wiring, was shielded from the view of the patient, by the display, which is partly visible to the left of the image.

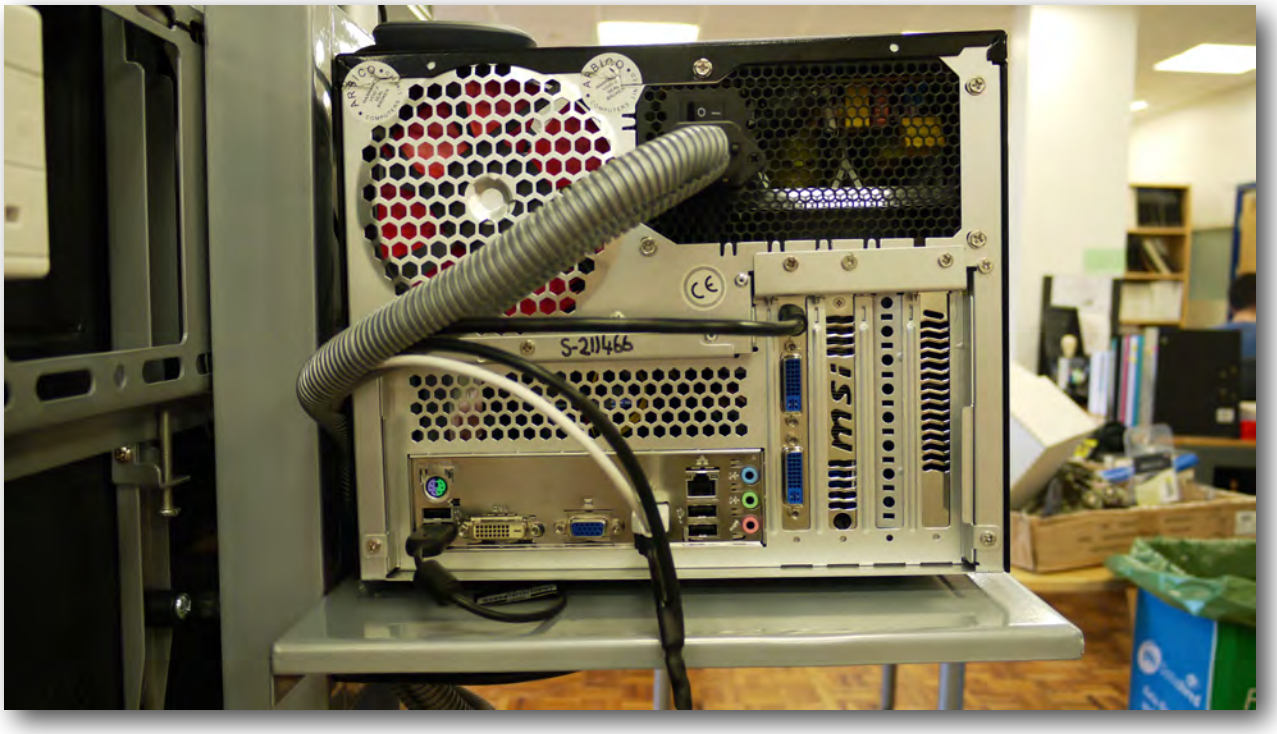


Figure 5.14 PC installed and wired up on the VR-I Module.

5.8 Scentscape

Figure 5.15 The Scentscape module photographed alongside a AA battery to illustrate its small platform.

At the time of writing, Scentscape (Figure 5.15), from the US company Scent Sciences, was a revolutionary prototype scent or smell delivery system (an “olfactory display”. Based on an electrically-heated matrix of small wells containing scents in solution, the system was designed to emit up to twenty different scents into the environment, each at pre-programmed point in time (or to coincide with an vent within a virtual environment). Scents ranging from delicate flowers to the smell of smoke were developed to elicit an enhanced feeling of presence from the user of a virtual environment already featuring visual and auditory stimuli. The unit itself was an early commercial prototype and suffered from a very limited availability of replacement scent cartridges.

Figure 5.16 The Scentscape system fitted to the VR-I module during evaluation.

A preliminary study into scene, sound and smell (Knight et al., 2012) found that out of 14 participants who took part in a study using a VE equipped with Scentscape found that 100% reported detecting an odour when triggered. This was backed up by changes in skin conductance response (SCRs) that showed that once the odour was triggered a short delay would occur until it dispersed into the air before reaching the participant, this would create an change in SCR levels before returning to normal.

An issue as to the type of odours used and in what context would need to be considered. If an unpleasant odour was triggered it may effect a flight-or-fight response. For example, if the recipient was a burns patient and a single or combination of scents evoked a traumatic past experience the system could potentially ruin the whole VE experience. Although in contrast could continual exposure to a fear inducing odour help as form of desensitising treatment (Emmelkamp, 2005; Herz, 2007). Scentscape was evaluated but not included in the usability study primarily as the QE is a sterile medical facility and the potential of cross

contamination of scents may have had led adverse effects on patients who were on various medications, and during testing there would be not guarantee if the participant would be in a single occupancy side room or on the ward.

5.9 Audio

The VR-I Module was designed primarily to be a single-user system in which the patient would be free to self-select his or her preferred destination in the virtual environment and, with the aid of a suitable interface device, navigate through the scenario taking in both the sights and the sounds. The sounds were brought to life with the aid of a pair of wireless headphones. Wireless technology was identified as the most viable option as it would prove impossible to establish in advance of deploying a VR-I Module what levels of medical equipment any particular patient may be connected to especially in the upper body region. Therefore, eliminating the risk of trailing audio cabling potentially interfering with critical medical equipment was deemed to be of paramount importance.

Figure 5.17 TDK WR700 headphones.

Many differing types of wireless technology were identified for consideration, bluetooth, radio frequency (RF), and infra-red. All of these were accompanied by various technical issues, ranging from sporadic signal drop out, to background interference, and in the case of RF, extreme sound degradation as the on-board power started to wane. The TDK WR700 (Figure 5.17) was finally selected as the technology with which to provide the participant with audio, as the headphones boasted a new technology named “Kleer”. At the time, Kleer offered the capability to stream uncompressed lossless audio at 44.1kHZ and at 16-bit. The connection between headset and transmitter was achieved using a frequency of 2.4GHz, which had zero sound degradation, zero drop out, but above all exhibited zero interference with existing sensitive wireless medical systems.

5.10 Display Audio

For occasions demanding a demonstration of the VR-I Module to groups of medical stakeholders and healthcare professionals, the audio stream could be switched via the onboard mixer on the PC. The audio would then be relayed through the display’s speaker system. The system was a 2.0 arrangement featuring 10w + 10w full range through each channel (left and right). A full range speaker reproduces as much of the audible frequency range as possible despite the size limitation often due to the lack of available space in this case, the 50” display.

5.11 Batteries + Charger

To provide a readily available supply of power to the wireless interfaces, namely an Xbox controller, wireless keyboard and mouse and wireless headphones, a battery charger was installed in the auxiliary mains extension socket (shown in Figure 5.10). This solution

proved not only to be cost effective, but also convenient, as there was always a source of on-demand power. To that end a Sanyo Eneloop charger (Figure 5.11) and a combination of high capacity AA/AAA cells were selected. Due to the Nickel-Metal-Hydride technology of the cells, they could hold maximum charge during extended storage suffering only a 10% loss per annum.

5.12 Wheels + Casters

The wheels supplied with the original heavy duty trolley mount were of a solid plastic (Figure 5.18) and were designed for use on carpeted flooring. They offered next-to-no traction on a typically polished hospital surface, even with the brakes deployed.

Figure 5.18 - The original plastic wheels. (left)

Figure 5.19 - Updated rubberised casters.

(right)

To overcome these issues, improved rubberised casters that adhered to [ISO 22882:2004] were procured (Figure 5.19) - these were more like the wheels supplied with mobile hospital equipment and provided the much needed stabilisation for the VR-I Module with the trolley brakes enabled.

5.13 Hygiene / Infection Control

From the initial conception of the VR-I Module to its final delivery at the Military Ward at the Queen Elizabeth Hospital Birmingham hygiene, and infection control issues ranked as a top priority equal only to participant and environment safety. The patients who would be recovering from traumatic and often life changing events and protecting them during acting as participants in the early trails of the equipment would be recovering from traumatic and often life-changing events, and protecting them during testing from contracting any forms of infections of paramount importance.

The transmission of pathogens via the hands of healthcare workers ranked amongst the most common cause of cross infection (Damani, 1997) occurring either directly from patient contact or indirectly via contact with the environment (Pratt et al., 2004).

5.14 Hand Washing Procedure

The NHS issued poster entitled “Your Five Moments for Hand Hygiene” (see Appendix 1.1), presents the most critical stages in the levels of hand hygiene that should be observed during care delivery and during the performance of routine tasks (National Patient Safety Agency, 2009). As stipulated by the medical stakeholders for the project, the two types of hand wash required during the deployment of the VR-I Modules at the QEHB,

both in terms of equipment handling and hospital etiquette are “social hand wash”, and the application of alcohol gel.

The term “social hand washing’ refers to washing that is performed to render the hands physically clean and to remove transient micro-organisms. Some examples of when to perform a social hand wash are:

Before:

- any patient contact.
- entering / leaving clinical areas.
- entering / leaving isolation cubicles.
- using a computer keyboard in a clinical area.

After:

- any patient contact.
- contact with patient surroundings.
- visiting the toilet.
- the removal of gloves.
- hands becoming visibly soiled.
- handling laundry / waste.
- using a computer keyboard in a clinical area.

The wash should be conducted using liquid soap (antimicrobial). Social hand washing should take a minimum of thirty seconds and hand should be dried using only paper towels. Appendix 1.2 details the prescribed method for the safe and effective cleaning of hands.

The use of alcohol gel maybe used if the hands are visible clean and can be a substituted for a social hand wash. Alcohol gel;

- Will not remove dirt and organic matter and should only be used hands are visible clean.
- Is not effective against Clostridium Difficile and Norovirus. Hands must be washed with soap and water in the event of patient contact.
- Post application of alcohol gel its must be left to dry naturally on the skin.
- Hands should be washed following several applications of alcohol gel.

5.15 Hygiene, Cleaning, and the VR-I Module

Hospital approved and supplied medical wipes were utilised, the wipes were specifically designed to disinfect medical equipment and were alcohol-free. This worked well on the all areas of the VR-I Module and peripherals except the displays' glass panel itself, the residual detergent wipes being alcohol free was unable to evaporate off the glass surface and was prone to streaking (refer to section 13).

Following any period of storage, the VR-I Module was given a complete and thorough wipe-down, including the full VR-I Module housing, and both front and rear of the display. Every interface device and component, together with associated cabling, was visually inspected and disinfected. Spares of all interfaces and headphones were held in reserve in the event of damage or irreversible contamination. A further disinfection of each interface device was performed in full view of the participant or patient before its handover. Upon completion of the system usability testing, the interface device was once again disinfected before being stowed. The process was repeated for every interface device.

The following bullet points detail the steps undertaken to ensure that the VR-I Module remained safe and hygienic at every stage of its deployment and storage during participant testing.

- After any period of storage - Complete disinfection (using hospital approved multi surface wipes) of the VR-I Module, display, interface devices, headphones, and cabling.
- Prior to the handover of any interface device to the participant, disinfection of that interface will take place in full view of the participant.
- Following every test condition - disinfection and storage of interface devices.
- Prior to the storage of the VR-I Module following testing - Full wipe down of the VR-I Module, interfaces and cabling.

5.16 Headphones

For each new participant or patient a set of disposable headphone covers (Figure 5.20) with latex-free banding was attached to each of the headphones ear-pads, The remaining housing components were wiped down to the same standards as the other interfaces.

Figure 5.20 The headphones used together with disposable pad protectors.

5.17 VR-I Module Safety Considerations

As stressed earlier, safety concerns ranked alongside those of hygiene during the design of the VR-I Module. To that end, the identification of areas of the VR-I Module design that had the potential to impact negatively on the well-being of the participants, patients, care professionals, or relatives or investigators, was crucial to producing a viable system.

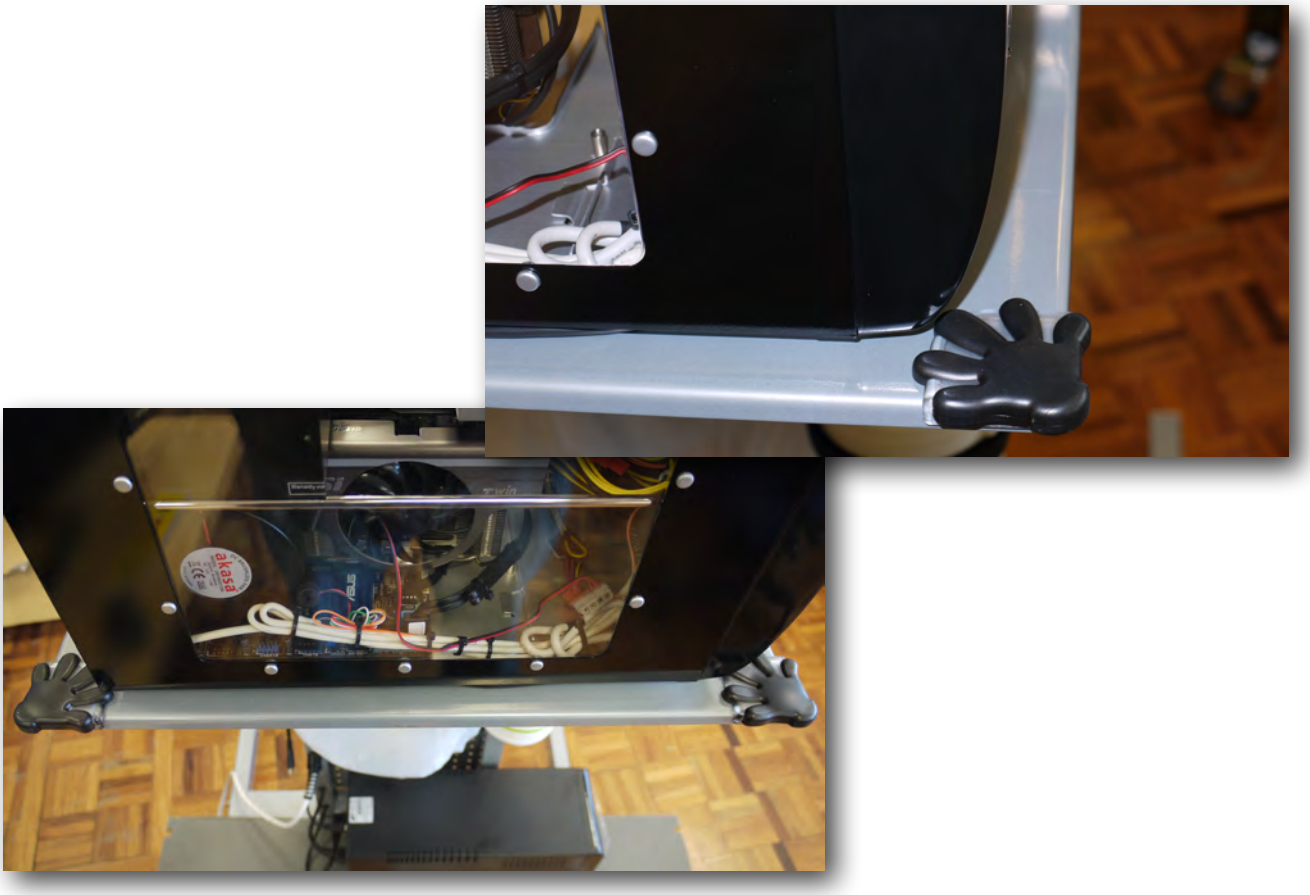


Figure 5.21 The two images above depict the corner protectors added to prevent collision injury.

The main design features that were identified as a probable injury risk were the corners of the rear-mounted AV shelf. Although powder coated to reduce the sharp edges, these corners still posed a significant risk if walked into. To help prevent injury a pair of rubberised and highly visible corner protectors were added to each corner (Figure 5.21).

5.18 The Completed VR-I Module Prototype 1

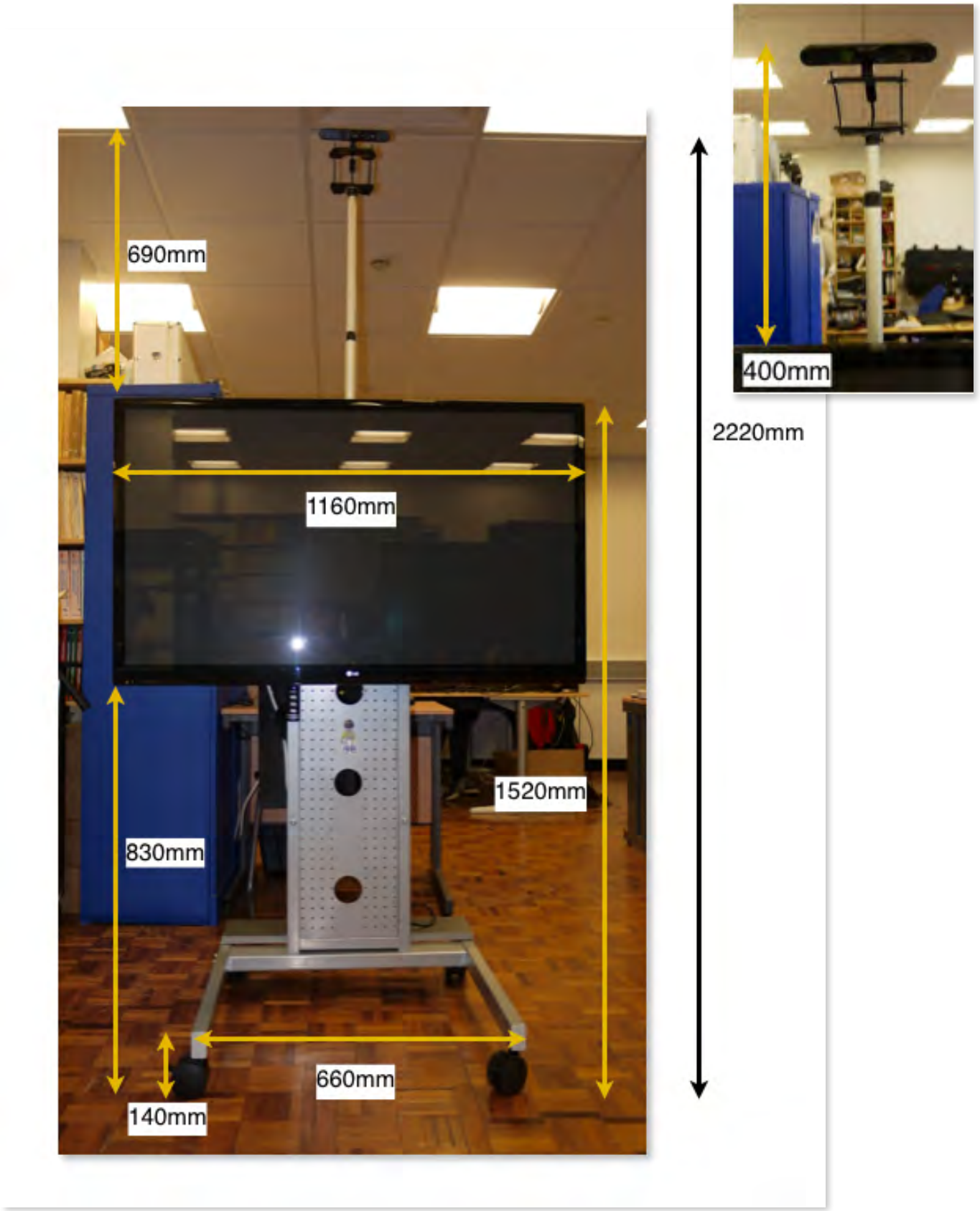


Figure 5.22 The Completed VR-I Module Prototype 2.

The prototype VR-I Module was now complete, Figure 5.22 provides an insight as to the size and dimension of the system. The images in this figure are of the second prototype module, the primary functional difference being the height-adjustable motion tracking camera mount. (seen raised above the main display in Figure 5.22). Figure 5.4 offered a glimpse as to how the system slotted in at the foot of a typical hospital issue bed and how the height from the ground to the base of the display (830mm) provided the participant with an satisfactory view, with only a minimal amount of the module itself being visible.

The prototype was now at the stage where it was ready to be integrated with the Virtual Restorative Environment (pictured in the remaining few images), together with the interface devices.

5.19 VR-I Prototype Integration Images

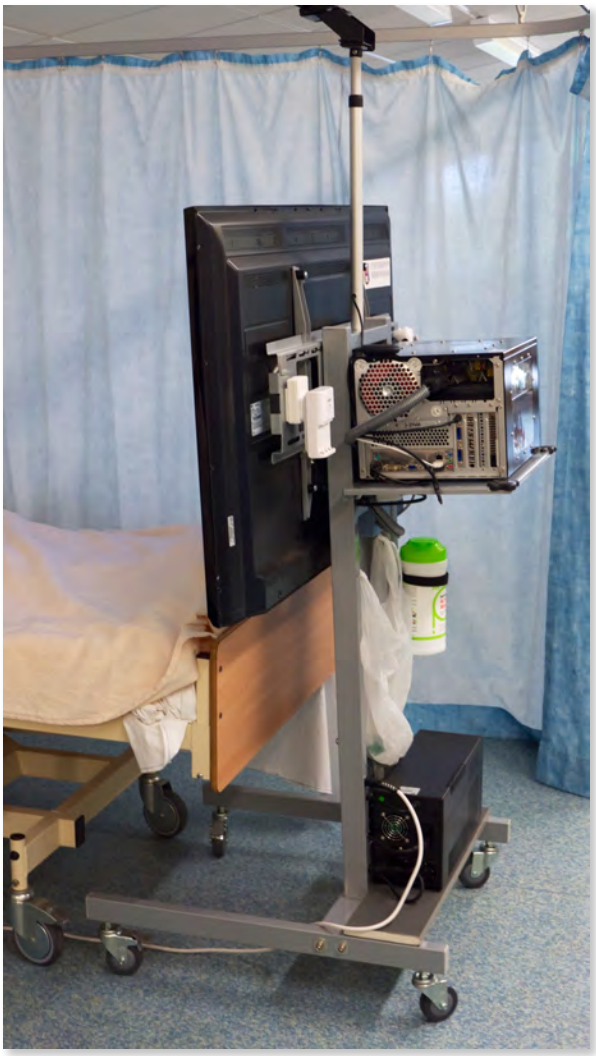


Figure 5.23 (left) A Side View of the VR-I Module Installed at the Foot of a Typical Hospital Issue Bed.

The image to the right (Figure 5.24) is of the rear of the VR-I Module.

However due to photography restrictions at the QEHB, the remaining images in this part of the report (Figures 5.24 and 5.25) are of prototype 2, early evaluations of which were conducted within a mock-up ward environment situated at the School of Physiotherapy at the University of Birmingham.

Figure 5.25 The VR-I Module from the side.

6 Interface Technology - VR-I Module Prototype 1

During the usability testing of the VR-I Module Prototype 1 at the Queen Elizabeth Hospital Birmingham, a number of interface technologies were explored and utilised that best catered for the broad spectrum of participants who presented with varying severity of injuries sustained. Injuries ranged from gunshot wounds to IED blast damage, with some instances of blast damage that had resulted in the loss of single or multiple limbs. A constant theme throughout all of the injuries was the need for high doses of medication to suppress pain, neuropathic pain - pain caused by nerves not working properly, and increased levels of anxiety.

A selection of interfaces were deployed with the VR-I Module prototype, they were chosen based on the observations of participants who had sustained various injuries but still possessed some degree of hand / arm dexterity. A selection of interfaces were considered but discounted due to their poor build quality and / or lack of use by either hand, as an example, Figure 6.0 shows a combined mouse / trackball device. The device failed to cater adequately for the needs of the participant due to being tailored for right handed users. The other issue that arose was essentially this device was two mice in one, a laser mouse and a trackball which both functioned simultaneously and behaved erratically during use.

A list of the interfaces that were examined but discounted are detailed in Appendix 1.5

Figure 6.0 A combination trackball / mouse.

6.1 Xpadder Key Mapper

Figure 6.1 Xpadder configuration screen during the mapping process.

In order to provide a unified range of movements across all the interfaces a software package entitled Xpadder (version 2012.01.19) was implemented. Xpadder is a key mapper that allows for the full replication of all keyboard inputs together with a mouse “look” function to be emulated across a multiple array of interfaces all whilst retaining key press / tracking values. If the participant selects any interface no advantage nor disadvantage would be gained other than the physical composition of said interface. If the participant selected the joystick (Figure 6.3) and preceded to navigate forward using the ball type hand grip, then selected the Motion XS controller (Figure 6.8) and did the same using the thumb stick, there would no difference in performance other than the physical shape of the interface.

Figure 6.1 depicts the Xpadder configuration screen. Each of the interfaces’ (in this case an Xbox 360 controller) buttons and analogue control sticks can be selected and mapped to any keyboard value, the same applies to the mouse. For example, the analogue control

stick on the far left of the gamepad shown in Figure 6.1 was configured to replicate the w,a,s,d, keyboard combination (a default used to control movement for most games and screen-based VR walkthroughs). This was also extended to the directional (Dpad) pad located below, leaving the right-hand analogue stick to accommodate mouse look. This provided the optimum flexibility when constructing the layout that, it was felt best suited the characteristics of the participant based on injury or injuries sustained.

6.2 Micro-Switch Joystick

The Competition Pro Retro Joystick (Figure 6.2) was a modern version of the classic Commodore 64 controller of the 1980s. The joystick was selected for the “return to centre” nature of the stick, this was achieved with the use of heavy duty micro switches. The ball type hand grip was beneficial to participants with limited finger / hand movement, with them being able to simply push the ball in the desired direction of travel would.

Figure 6.2 The Competition Pro Joystick.

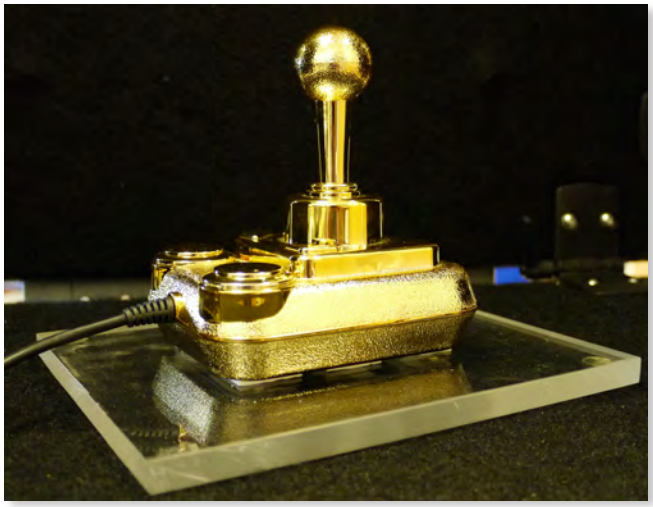


Figure 6.3 The Competition Pro Retro Joystick modified after stability issues were identified following single handed usage.

It was felt that the stiffness of the microswitches in the joystick led to stability issues when being used which were exacerbated when the participant used one hand. A perspex plate (Figure 6.3) was adapted to fit under the base of the controller and this was found to provide the much-needed stability, which in turn, was seen to improve usability.

6.3 Keyboard and Mouse

For a more traditional interface that would provide the participant with something familiar in contrast to the more games-biased style of controller, a keyboard and mouse set-up was implemented. This was used either with one hand, where the participant would switch between the keyboard and mouse to navigate, stop, look and repeat, or by using both hands to navigate and carry out mouse-looks simultaneously. A flexible USB silicone keyboard (Figure 6.4) was introduced as it had to serve a dual purpose during testing. Firstly it was required to provide the tester with the means to configure, reset, and log data for post-condition analyses. Secondly, it was to act as an interface for the participant during the actual testing phases. The rubberised composition of the keys meant that it could easily be sanitised, without damage to the keys, before and after each use.

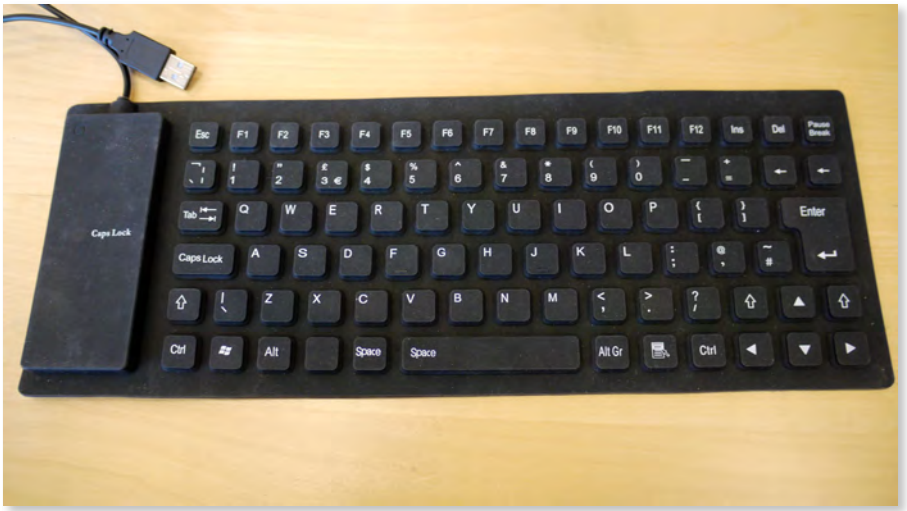


Figure 6.4. Flexible Silicone Keyboard.

A simple USB mouse (Figure 6.5) was mated to the keyboard to provide the mouse-look for the participant. The simple ambidextrous design of the mouse offered no advantages to both left - or right - handed users.

Figure 6.5 Mouse employed during usability study.

6.4 Microsoft Xbox 360 Wireless Controller for Windows

As it was assumed that a a good many of the participants in these early trials would have some degree of gaming experience, an Xbox 360 (Figure 6.6) controller was provided, the interface of which was primarily aimed at participants who had full range of motions on both hands. The controls were reconfigured to map the existing properties of the keyboard and mouse, all other buttons were disabled. Figure 6.7 (overleaf) is a screen shot of Xpadder during the interface mapping process.

http://neogaf.com/forum/showthread.php?t=476697

Figure 6.6 Wireless Xbox 360 controller used during testing.

Figure 6.7 Screen shot from Xpadder during Xbox 360 controller mapping process.

By referring to the far left of the Xpadder screenshot, it can be seen that the w,a,s,d keyboard motion pattern was reassigned to the Xbox controller's left-hand analogue stick. the same range of movements were also reprogrammed to the Dpad. The right-hand analogue stick was programmed to provide the mouse look function. The Esc key and right-mouse click functions were applied to the start button and A button respectively.

6.5 Motion XS Thumb Controller

The Motion XS controller (Figure 6.8) is a USB version of the Nintendo *Wii* nun-chuck controller, supporting six-axis motion sensing which allows for a simple left or right twist motion to be translated into game movement. The lightweight and single-handed ergonomic design with rubber grip accents allows for ease of use amongst those participants who find using specialist input controllers to be a difficult or an unfamiliar experience.

Figure 6.8 Motion XS USB Controller.

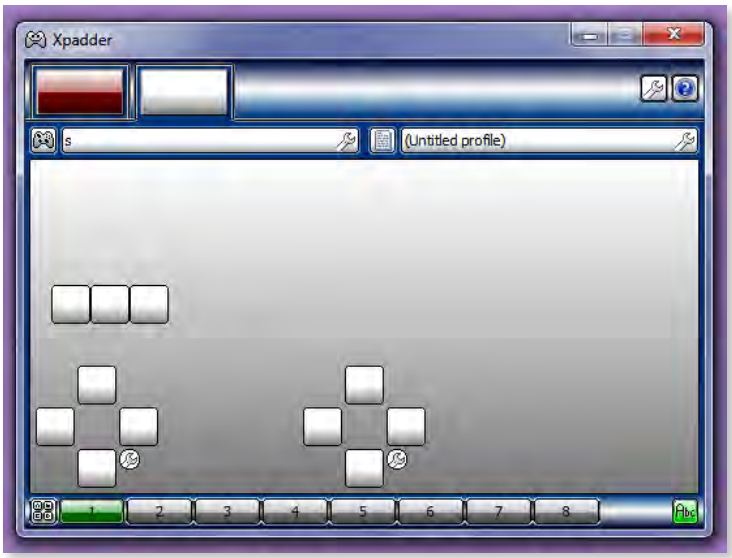


Figure 6.9 Screen shot from Xpadder during Motion XS controller mapping process.

6.6 Mapping Constraints

Once the three selected interfaces had been programmed to replicate the values from the keyboard and mouse, each of the profiles were saved and left unaltered throughout the duration of the usability testing phases. It was crucial that no alterations were made once testing had commenced, since any changes to the mapping values could lead to the invalidation of any data gathered. The complete interface profiles can be found in Appendices 1.6.1, 1.6.2 and 1.6.3.

7 3D Virtual Restorative Environment - Burrator Reservoir

The research conducted was part of a larger multi-discipline study, one of the original aims was to design and run Virtual Burrator (detailed in this section) during participant testing. Focus switched to prototype hardware design and Virtual Wembury designed by Cheng Qian was implemented. What follows illustrates how a virtual restorative environment was created, bear in mind that Virtual Burrator could be substituted for Virtual Wembury in future studies.

From the literature review presented in Section 2, it can be concluded that the bulk of the research considered during the review focused on comparing static views of nature against views of nothing, or at best pre-recorded video. The systems described afforded the user with at best, a glimpse of a world albeit through the eyes of a third party, a photographer or camera operator, for example. The mediated exposure did, however gain some favourable results, and the following section attempts to build upon the idea of simply being a passive observer by detailing the design and creation a fully interactive three dimensional (3D) virtual environment of a natural scene.

Figure 7.1 An overhead imagine of Burrator Reservoir.

The Virtual Burrator (Figure 7.1) environment was developed using a variety of 3D modelling, image processing and run-time tools. The virtual topography of the environment was based on commercially available Digital Terrain Model (DTM) data. DTM databases typically comprise of dense fields of digital elevation points. In the case of the Burrator data, these were supplied at a resolution of 5m and a vertical accuracy of 1m. Sometimes referred to as “Bald Earth” Models, the DTM database is devoid of any trees, vegetation, buildings and other man-made features, providing developers with measurements relating only to the underlying terrain. In the case of Virtual Burrator, a DTM area of 6km sq. The area modelled is outlined in red as indicated on Figure 7.1.

Once the DTM model was converted into a polygon-based mesh, the virtual terrain was of a form suitable for importing into an appropriate Virtual Environment (VE) or gaming toolkit. (Figure 7.2, lower segment) For the present project the Unity3D game development tool was chosen to create Virtual Burrator. Unity3D is a cross-platform game engine that features an Integrated Development Environment (IDE). The graphics engine utilises OpenGL that favours the NVIDIA family of Graphics Processing Unit (GPU). Unity3D is flexible enough to embrace a number of file format imports ranging from low-cost packages such as Google Sketchup and Blender, to mainstream software such as 3D Studio (3ds) Max and Adobe Photoshop.

The newly imported mesh was then flat-shaded and endowed with a high resolution texture map, (Figure 7.2, middle segment) itself generated from an aerial photograph of 12.5cm resolution (Figure 7.2, upper segment). This texture map provided a visual template which was invaluable in helping to locate key natural and man-made features - trees, large plants, meadows, rocks, streams, buildings, pathways and enclosures. The

virtual counterparts for these were either sourced from the web or in the case of bespoke objects such as Burrator Dam (Figure 7.3) was created using 3ds Max.

Figure 7.2 Converted Burrator Reservoir DTM Data (Lower Segment) and Corresponding Aerial Image (Upper and Middle Segments).

A series of photographic, video and sound surveys were also conducted at the Burrator Reservoir site. Digital photographic images were not only used for reference purposes during the development of *Virtual Burrator*. Suitable enchanted and manipulated using Adobe Photoshop, they provided a rich source of detailed textures for natural and man-made objects.

The recorded sounds were assessed to consider their appropriateness for the virtual scenario. Where background sounds, such as excessive noise caused by the prevailing winds, rendered an audio file unusable, alternatives where sourced from the Web. Sounds of birdsong and running water (in the case of the waterfall) were then programmed into the VE, to create a dynamic soundscape which varies depending on the users spatial location. Procedural time of day (24-hour day-night cycle) and weather effects were also implemented, using the UniSky software system.

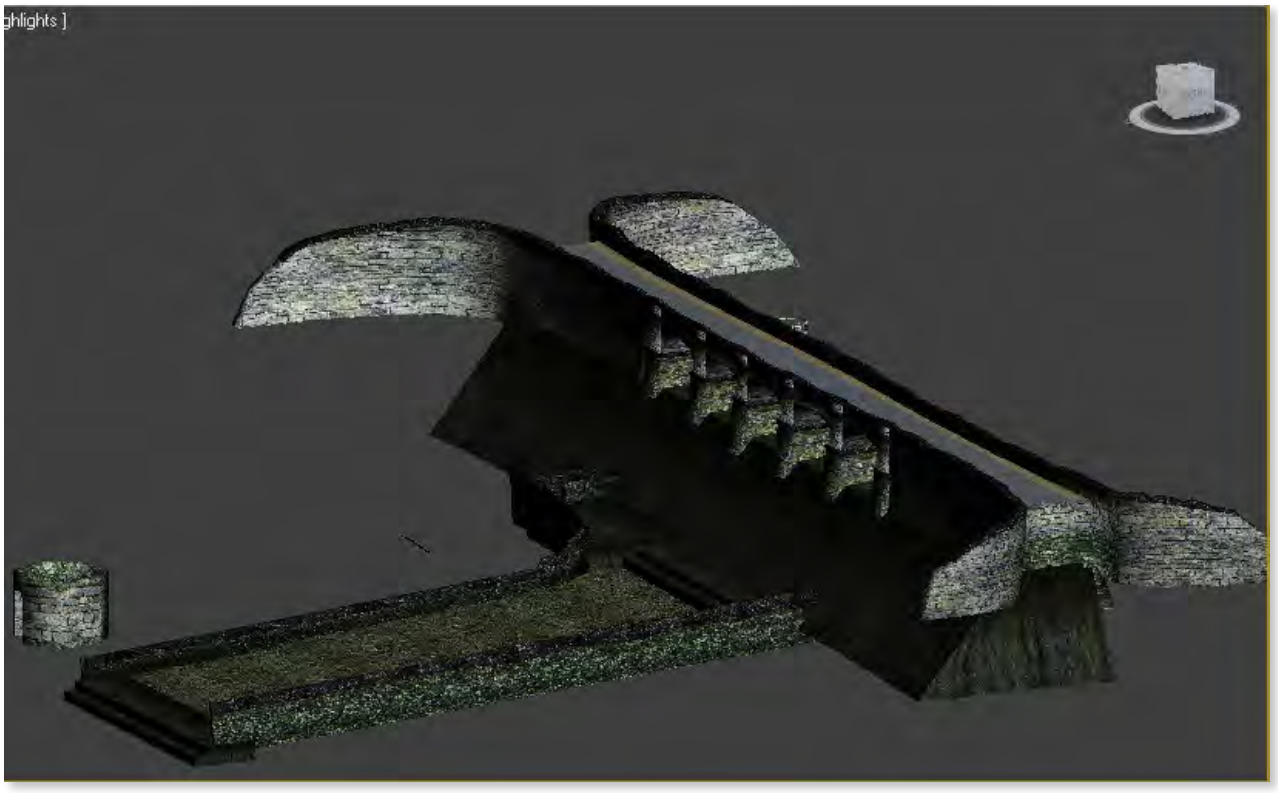


Figure 7.3 Burrator Dam created using 3D Studio Max.

7.1 3D Virtual Environments, to Imagine or to Reproduce?

A question that is often asked of developers of VE recreations of real-word scenes and that is, why model something that already exists in reality? There are three answers to this question, the first of which can be explained from a research standpoint. To simply create a VE purely for the sake of creating a VE, that shares no common features with reality would undoubtedly still provide the user with a form of distraction from their current environment. However the idea of selecting an area of outstanding natural beauty, such as Burrator Reservoir, offers the opportunity to make future comparisons (in terms of acceptance of and impact of the VE on users/observers between real *vs* verses simulated scenarios. Indeed there appears to have been a distinct lack of documented evidence that has seen the participant exposed to both real and virtual counterparts of the same natural environment.

Secondly, and examining Burrator from a heritage standpoint, the idea of being able to digitally recreate, even restore historical artefacts such as old railway lines, pathways, and buildings, may help to (a) engage patients in a healthcare setting even more than just a simple “nature-only” recreation, (b) encourage locals of the area to learn about life before and during the construction of the reservoir and to be able to experience what archaeological features may still exist underwater and would otherwise stay forgotten, and (c) help the older generation to reminisce about historical scenes and incidents as they were growing up and, thus, to contribute to the development of a rich archive of digital heritage.

Finally, the development of a VE such as Virtual Burrator will provide a range of development opportunities for future stakeholder research and support the re-use or expansion of the VE's functionalities for other applications. For example, In the case of Figure 7.4, the idea of Virtual Heritage can be demonstrated, by the user holding up an iPad so that the camera can identify the small Augmented Reality Marker on the ground, a 3D model of the temporary suspension bridge can be re-imagined using the original and still present anchor points a guide.

Figure 7.4 An augmented reality representation of the old suspension bridge constructed during the rebuilding of the main dam.

7.2 Build Issues

As the VE development progressed a number of real time rendering issues began to hamper progress, this was caused in part by the use of high polygon assets such as trees, flowers, rocks, essentially any highly textured objects placed on the terrain. As the camera tracked across any given viewpoint every object in view would be individually loaded up (rendered) in real time, due to the excessive number of objects the frame rate would instantly deteriorate, a low frame rate would cause the gameplay to stutter as the GPU would fight to process all of the assets. As rule of thumb, the higher the number of polygons the greater the levels of fidelity would exist but lead to a greater demand on resources. Three possible solutions were investigated with the aim of optimising GPU loading and thus achieving better rendering on the fly.

Figure 7.5 The lowest polygon representation of a tree, known as a billboard.

The replacement of trees from high-polygon to billboards; by replacing the current trees with low resolution counterparts, Figure 7.5. illustrates the difference in textural fidelity, the tree in the centre, a billboard representation and to the right, a medium-polygon version, notice the massive differences in the detailing and physical appearance. The major issue here is when using lower polygon models in a main stream game, for example Grand Theft Auto, (Figure 7.6) the emphasis is not on the trees but on the story and the missions the character undergoes so they almost become an after thought. When creating a Virtual Burrator the emphasis was on the

Figure 7.6 A game play screenshot taken from GTA III Rage Classic.

http://gtaforums.com/topic/521034-wip-gta-iii-rage-classic/page-24

restorative properties of the environment, the richness of the textures the depths of colours, there were no objectives to fulfil. To that end the best course of action was to discount the use of billboard for trees and foliage.

2) The trade off between levels of fidelity was next on the list, to many high-polygon trees placed in a tight grouping would cause a massive reduction in frame rate and in turn cause sluggish game play.

Figure 7.7 on the left is a medium polygon tree, the colouring of the leaves are basic but passable, the tree trunk however has a scab like appearance.

Figure 7.8 on the right demonstrates a high-polygon tree, notice the multi textual colouring on the leaves and the grain effects on the trunk, it is the best representation of a 3D tree.

Of course the high-polygon model would be the ideal choice but how can the overriding issue of real time GPU rendering and the poor frame rate be addressed?

3) The final solution was to divide the vast area into equal sections (Figure 7.9), in total sixteen were segmented. The idea was treat each section as its own separate entity that would render the closest sections to the vicinity of the players location, the entire terrain was exported to Adobe Photoshop and manually divided and then reimported back into Unity. Rendering was improved by thirty percent and allowed for better asset management and preloading.

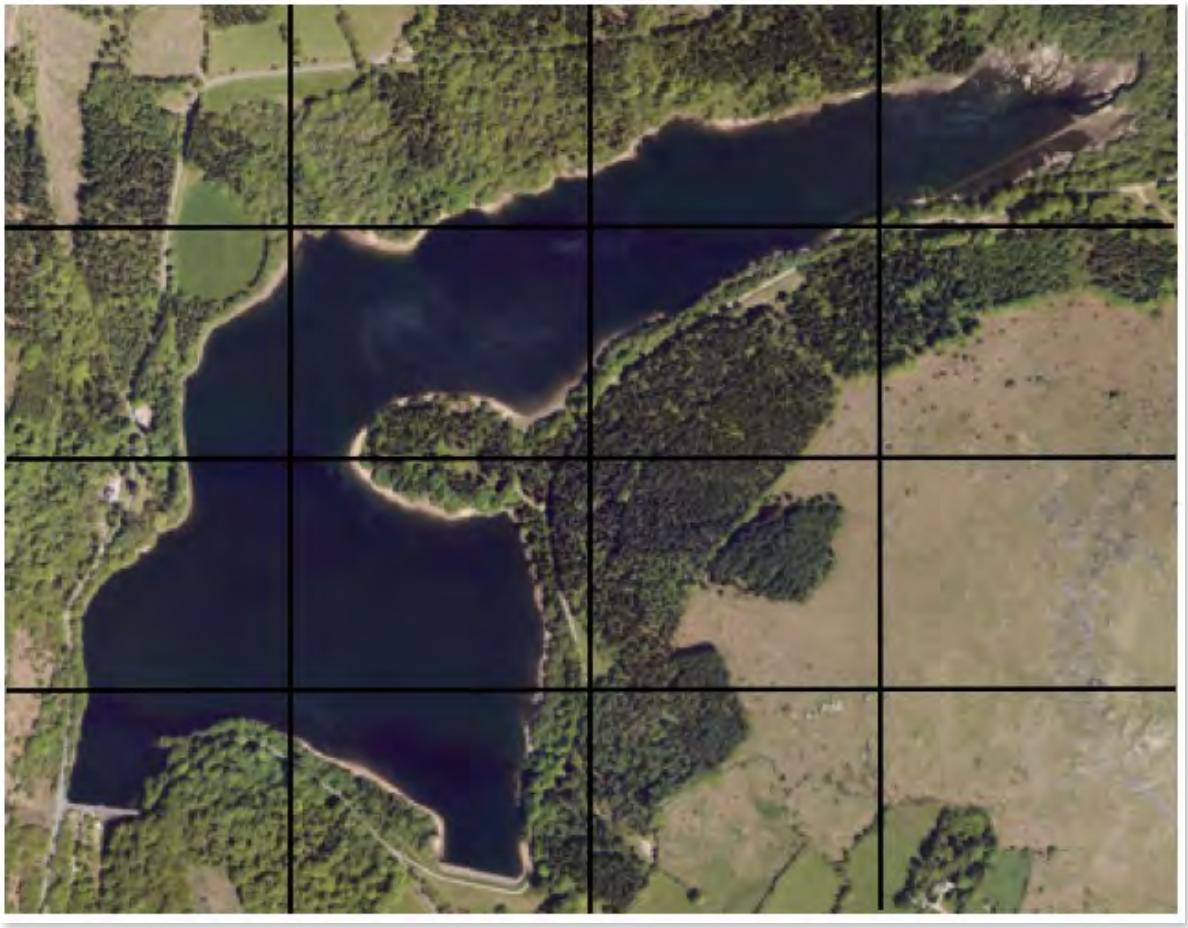


Figure 7.9 The Burrator DTM in segmented form.

7.3 Stitching issues and visible tearing

The achievement of a performance increase came at a cost, the reattachment of the sixteen segments proved to be highly problematic. Figure 7.10 illustrated the point in question, notice the spit running diagonally up the screen capture, this was as a result of the terrain levels not realigning properly, the issue was that such a gap can allow the player to fall through the terrain and crash the runtime, any risk however remote would prove wholly unacceptable during participant testing.

Figure 7.10 The misaligning terrain issues.

After stitching the terrain (Figure 7.11) the final stage would be to blend the the textures create a seamless joint. The path had already been completed and shows no evidence of the segmentation.

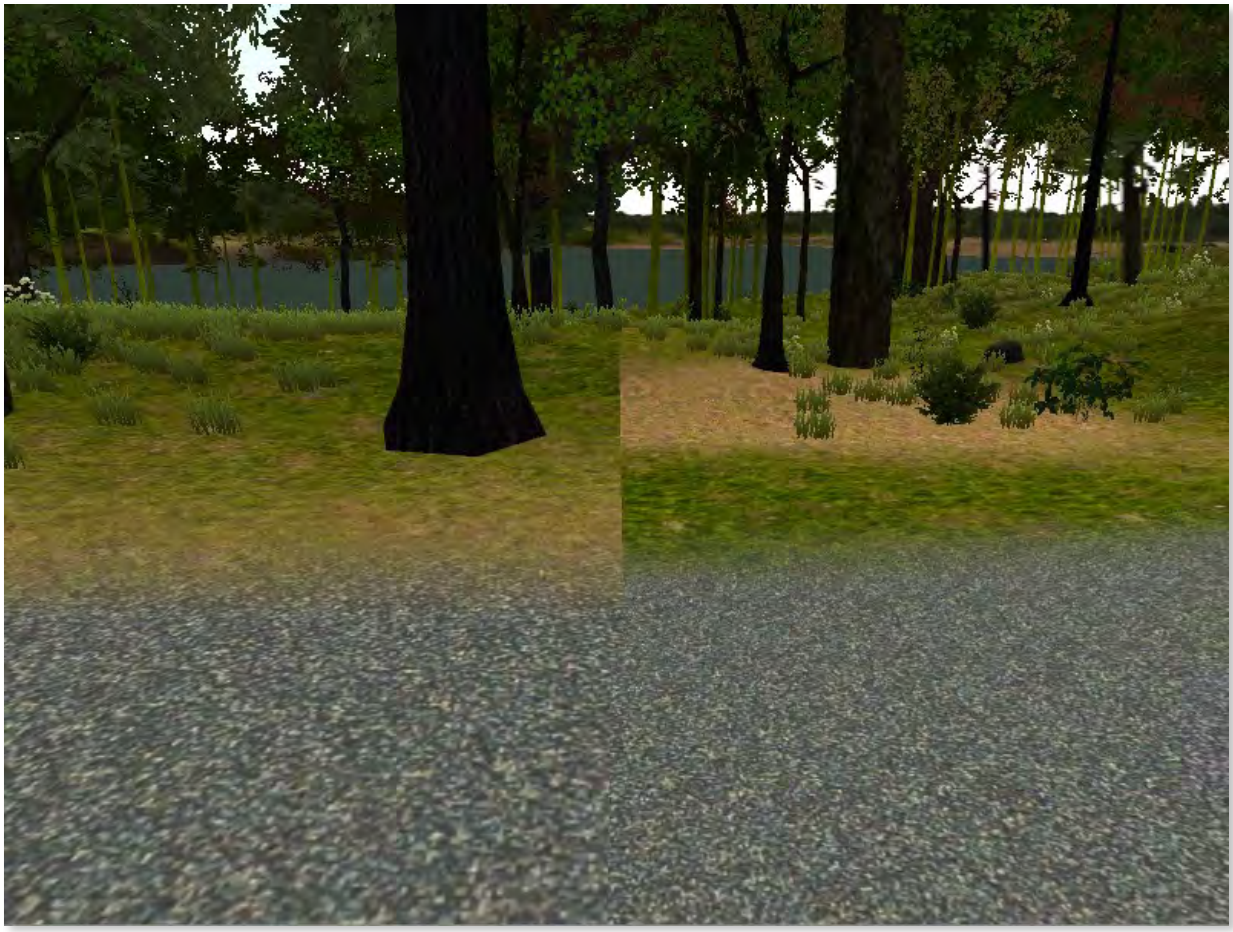


Figure 7.11 The environment after correct stitching, the terrain is now aligned correctly.

7.4 Final Build Images

The following images visually demonstrate the completed Burrator Reservoir Virtual Environment. Further images can be found in Appendix 1.10.

Figure 7.12 An example of an area populated with flowers and grass.

Figure 7.13 An example UniSky, note the lens flare.

Figure 7.14 The area dense with tree and wild flowers.

Figure 7.15 The area dense with tree and wild flowers.

8 Usability Study

The first prototype VR-I Module saw testing within the confines of a ward at the Queen Elizabeth Hospital, Birmingham. The ward catered for the post operative and critical care needs of returning service personnel from seeing active service, primarily in Afghanistan. The nature of patient injuries as of Q4 2012 consisted of an equal balance of fifty percent gunshot wounds and fifty percent IED blast damage. Typically gun shot wounds would result in nerve and tissue damage, damage that would often lead to loss of cognitive function and restricted body mobility. IED blast damage was more wide spread where injures ranged from, single or multiple loss of upper / lower limbs together with the aforementioned nerve and tissue impairment. All injuries had to some degree caused physical impairment and in all cases required closely monitored levels of medication. The types of participants who were convalescing trauma patients were ideal candidates for taking part in the usability study as prior to there stay in hospital they were fit and healthy and serving with the nations armed forces.

The rational behind the usability study was to identify from which, out a range of interfaces administered a particular interface best suited a participant based on the varying levels of injury sustained. Testing combined the use of the VR-I Module with the Virtual Wembury Environment, the purpose of the usability study was to determine how the hardware faired both in a medical environment and with constant use by participants.

8.1 Virtual Wembury

Virtual Wembury in the same way as Virtual Burrator, was a 3D virtual environment based on a real world location. Wembury in contrast to Burrator was more of a coastal seaside

type environment. The VR-I Module prototypes were able to handle either environment but for this study Virtual Wembury was selected as the investigations in question were related to interface usability and the integrity of the VR-I Module. Virtual Wembury was designed and modelled by Cheng Qian. The two virtual environments were designed to be interchangeable, at the time of the usability study Wembury was at more advanced stage in its design than Burrator due to the change in direction from software to the advancement of the prototype hardware design and evaluation.

(Figure 8.1 is of two screenshots taken from Virtual Wembury).

Figure 8.1 Two screenshots of Virtual Wembury.

8.2 Aim

The aim of the current study was to identify usability issues of the VR-I Module in situ within a hospital environment through user testing on military patients. Given the range of injuries and disabilities encountered on the ward, the study also aimed to investigate user interface issues specifically by comparing different control input devices. These devices represent COTs (Consumer Off the Shelf) equipment that can easily be interfaced with the VR-I Module and would realistically be expected to be used in a fully incorporated system within a hospital environment by a range of patients.

8.3 Participants

For consideration in participating in the study. the participants were initially screened for selection according to a medical consultation with clinical personnel. Judgements were taken with regards their ability to cope physically, mentally, and emotionally during the experimental program. And ensure that the experiment would not interrupt the treatment or care of the patient in anyway.

On being deemed suitable for inclusion by medical staff patients were invited to participate. No participants were coerced into participating and were made aware that they were able to withdraw from the study at any time and for any reason.

Following the medical screening 15 participants agreed to participate in the study. They were all male, aged between 20-30yrs.

8.4 Task

The task the participants were requested to undertake involved the navigation along a path within Virtual Wembury. The participants were asked to stay as centrally as possible on the path, following a route designated via flags. For each condition, the participant was asked to complete the condition three times. Completing one route took approximately three minutes.

8.5 Conditions (Independent Variables)

The task undertaken by the participants was completed under four input device conditions:

1. Keyboard and Mouse.
2. Single handed thumb controller (Motion XS controller).
3. Two-handed gaming controller (Xbox 360 controller).
4. Micro-switch joystick.

Figure 8.2 Images of the control interfaces used during the study.

There was a single display device used for all conditions. A 50-inch plasma display.

Figure 8.3 The 50-inch display used throughout testing.

http://s7d3.scene7.com/is/image/TheBrick/50PA4500?$ProductDetails$

8.6 Protocol

The testing took place at the bed of the patient. The VR-I Module was positioned at the foot of the bed and adjusted for height and inclination of the display to the participants preference. The participant could adopt any posture they wished during the testing, while others were restricted by their injuries, such that some undertook the tasks sat on the bed while others were recumbent and inclined on their back.

The input devices were positioned in front of the participant on a hospital issue adjustable tray table. The participants were invited to use the input devices as best they could and were permitted to pick up the devices and have the table removed if they wished or could support the device on the table. Prior to attempting each condition, the participants were given time to familiarise themselves with the input device and make suitable adjustments (i.e. position, posture) to maximise comfort.

For each condition, the participant was asked to complete the task three times. Completing one route took approximately three minutes. The experiment employed a repeated measures design, where all participants were asked to undertake all four conditions.

The order in which the participants undertook the different conditions were varied between participants using a cascaded latin-square method (Bailey, R. 1996) for control order and learning effect. (a copy of the latin-square method used is located in Appendix 2.1)

8.7 Measures (Dependent Variables)

The study collected subjective data of usability, workload, discomfort and reference which was collected using rating scales following the completion of the third attempt for each condition, it comprised of questionnaires to measure:

1. Usability of controller and display

   Located in Appendix 2.4.1 and 2.4.2
2. Ratings of workload (NASA TLX)

   Located in Appendix 2.6
3. Comfort/fatigue (Borg CR-10)

   Located in Appendix 2.3

The questionnaires consisted predominantly of Likert scales. The participants were guided through questionnaires by the experimenter, where the experimenter allowed the participant to explain or add qualitative statements to the ratings.

After completing the fourth and final condition the participant was asked to rank in order the preference of the four control input devices.

8.8 Usability

Usability of the controller and display was rated using scales adapted from VRUSE (Kalawsky, 1999) which is a tool for usability evaluation of synthetic / virtual environments. The full VRUSE questionnaire is composed of 100 items. This was considered too exhaustive and taxing for this study, which might result in participant fatigue and loss of interest. Therefore the most appropriate elements were selected for inclusion in the study. The usability questionnaire developed consisted of 17, 7- point Likert scales to rate input device usability as well as two scales to rate controller sensitivity and 7 point scales for over 'ease of use' and 'satisfaction'. The questionnaire also included 8, 7-point Likert scales to rate the usability of the display as well as 7-point scales to rate 'size', 'field of view' , position and 'overall satisfaction' of the display (See Appendix 2.4.1 and 2.4.2).

8.9 Workload

Ratings of workload were carried out using the NASA TLX (Hart and Staveland, 1988) which employs 6, 20 point scales to rate mental, physical, temporal, performance, effort and frustration elements of workload (see Figure 8.4).

Title	End points	Description
Mental demand	*Low / High*	How much mental or perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical demand	*Low / High*	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal demand	*Low / High*	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	*Low / High*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	*Low / High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration level	*Low / High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

Figure 8.4 NASA-TLX Workload rating (scored on 20-point scales)

8.10 Discomfort

Ratings of physical execration, pain and discomfort in the fingers, hand, wrist, forearm, upper arm, shoulder, neck and other were scored using the Borg CR-10 scale (Borg, 1975) (see Figure 8.5).

Figure 8.5 Borg CR-10 Scale for intensity of physical exertion, pain and discomfort.

8.11 Preference

After completing the fourth and final condition the participant was asked to indicate which was their most and least preferred of the four control input devices.

8.12 Ethical Issues

The study was completed under the supervision of QEHB staff at all times.

Participants were approached and informed of the usability study and what was to be asked of them, no participant was at anytime coerced into participating. They were informed that they had the right to withdraw from the study at any time and for any reason and that all information and data collected will be made anonymous. Participants interested were asked to provide informed consent prior to taking part in the study.

A copy of the participant consent form is located in Appendix 2.0.

A copy of the Ministry of Defence, Research Ethics Committee Application Form is located in Appendix 2.0.1

A copy of the Research Project Authorisation from the UHB Research governance office is located in Appendix 2.0.2.

A copy of Page 1 of the Protocol for the study is located in Appendix 2.0.3.

9 Results

Analysis was conducted on data from the participants who completed the study (N=12). During the testing, three participants were unable to complete all four conditions and their data was removed from the study. A copy of the SPSS output used throughout the following section can be found in Appendix 2.13 and the Questionnaire Reliability Analysis in Appendix 2.12.

9.1 Experience of controller use

Table 9.1 shows ratings for frequency of use for the four controllers, it shows that the participants have the most experience with Xbox controller, Keyboard and Mouse somewhat, but very little or no experience of both the Joystick and the Motion XS controller.

Table 9.1 Usage experience of the four controllers.

Frequency	Joystick	Keyboard & Mouse	Motion XS thumb	Xbox
Never	6	4	4	-
Little experience / Rarely	5	3	6	3
Occasionally / Sometimes	1	2	2	1
Often	-	2	-	3
Frequently / Always	-	1	-	5

9.2 Controller Usability

Scores from the 17, 7-point controller usability Likert scales were combined to produce a single usability score for each participant. To generate a combined mean,

scores from scales that were negatively phrased (i.e. Q2, Q5, Q7, Q15) were reversed. With reference to Figure 9.1 it shows average usability ratings for the four controllers. The Xbox controller scored highest suggesting that it provided that greatest usability amongst participants, the other three all scored about the same.

Statistical analysis on the usability data was carried out using SPSS Version 21 where a one-way analysis of variance showed a significant main effect on the rating of usability due to the controller [$F(3,33) = 4.180$, $p=0.013$]. Subsequent pairwise comparisons showed that the Xbox controller's usability was rated significantly higher than all the other three controllers [Xbox vs. Joystick: $p=0.018$; Xbox vs. Keyboard & mouse: $p=0.033$; Xbox vs. Motion XS: $p=0.002$]. Between the Joystick, Keyboard and mouse and Motion XS the differences in usability rating were not significant ($p>0.05$).

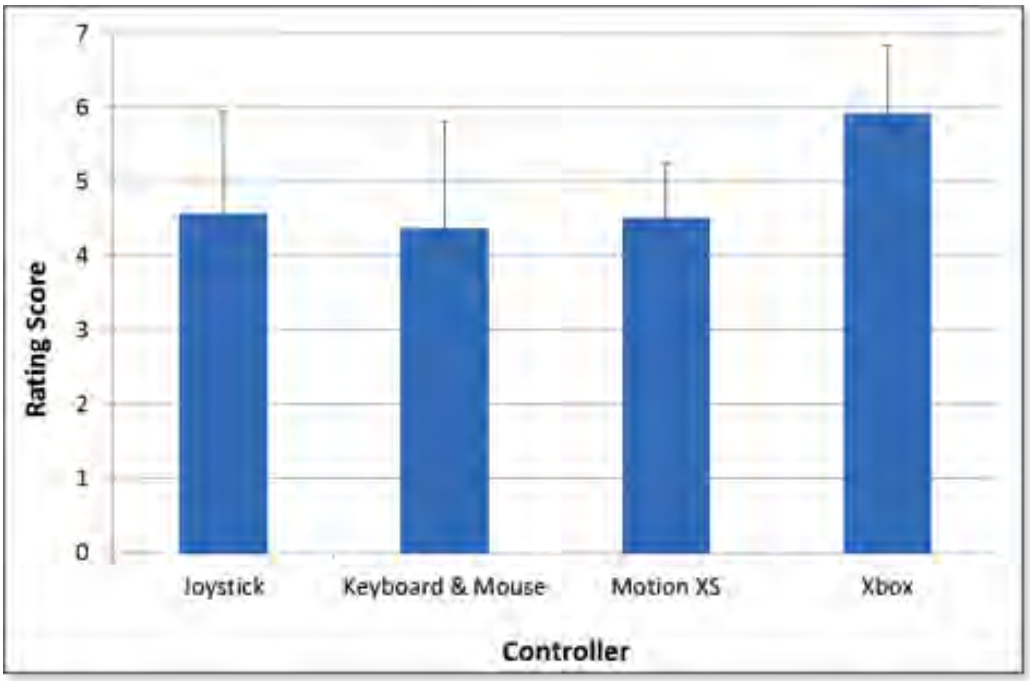


Figure 9.1 Mean usability rating for the four controllers

(y-bars indicate 1 standard deviation)

Tables 9.2 & 9.3 show the frequency of participants ratings for the force required to manipulate the controller and its sensitivity.

The majority of participants rated force and sensitivity OK for all four of the controllers, 25% rated the Joystick force Too high whilst 100% of participants found the force required whilst using the Xbox controller to be OK. Most of the deviations from the OK rating was for the Motion XS controller, it rated 25% Too low and 25% Too high - and ultimately 50% thought there was a sensitivity issue. The other three controllers, at least 3 participants (25%) rated some issue with sensitivity.

Table 9.2 Frequency count for ratings of ***Force required*** pressing buttons or manipulating the controls

	Too low			***OK***			***Too high***
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Joystick	-	-	-	9	2	1	-
Keyboard & Mouse	-	-	-	11	1	-	-
Motion XS thumb	-	1	1	9	-	1	-
Xbox	-	-	-	12	-	-	-

Table 9.3 Frequency count for ratings of the ***Sensitivity*** of the controls

	Too low			***OK***			***Too high***
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Joystick	-	-	1	9	1	-	1
Keyboard & Mouse	1	-	-	9	-	1	1
Motion XS thumb	-	2	1	6	-	2	1
Xbox	-	-	-	9	1	2	-

Frequency counts for single point ratings of ease of use and overall satisfaction for the four controllers are shown in Tables 9.4 and 9.5.

The Xbox controller had more ratings for ease of use and provided overall satisfaction at the higher end of the scale (Rating 6-7 = 67%) than the other controllers (Joystick 25%. Keyboard and Mouse = 25%, Motion XS = 8%). The keyboard and Mouse had more ratings at the lower end of the scale (rating of 1-2) for both ease of use (33%) and overall satisfaction (42%) than the other controllers. These results support the previous analysis of usability (Figure 9.1) rating that the Xbox controller is the most usable for these participants.

Table 9.4 Frequency count for ratings of ***Ease of use*** of the controllers

	Low						***High***
	1	**2**	**3**	**4**	**5**	**6**	**7**
Joystick	-	3	2	4	-	1	2
Keyboard & Mouse	3	2	-	2	2	3	-
Motion XS thumb	-	1	4	5	1	1	-
Xbox	-	1	-	1	2	5	3

Table 9.5 Frequency count for ratings of ***Overall satisfaction*** of the controllers

	Low						***High***
	1	**2**	**3**	**4**	**5**	**6**	**7**
Joystick	-	3	2	4	-	1	2
Keyboard & Mouse	3	2	-	2	2	3	-
Motion XS thumb	-	1	4	5	1	1	-
Xbox	-	1	-	1	2	5	3

9.3 Display Usability

Scores from the 8, 7-point display usability Likert scales were combined to produce a single usability score for each participant. To generate a combined mean, scores from scales that were negatively phrased (i.e. Q2, Q4, Q5, Q8) were reversed. Figure 9.2 shows average display usability ratings across the four controllers.

The usability ratings are high >5, it suggests that the overall display usability was high. There is little or no apparent difference between the four controller conditions, which leads on to the statistical analysis. It shows that on the usability data that was carried out using SPSS Version 21, where a one-way analysis of variance showed that there was no significant effect on the rating of display usability due to the controller [F(3,33) = 1.748, p=0.176].

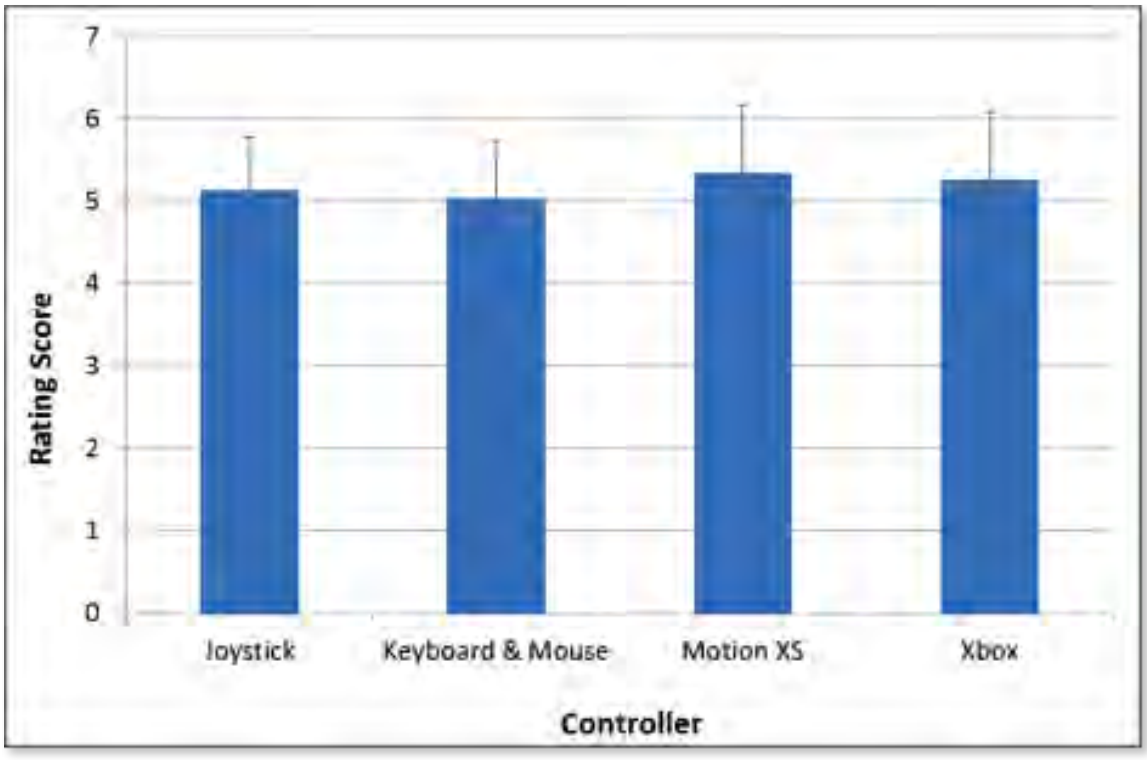


Figure 9.2 Mean display usability across the four controllers

(y-bars indicate 1 standard deviation)

Ratings on design, positioning and layout characteristics of the display (i.e. display size, FOV, display position) are shown in Table 9.6 and ratings of overall satisfaction for the display are shown in Table 9.7

There were absolutely no differences between the controller conditions for the design characteristics data so a single set has been presented to represent all conditions. Pretty much all of the participants thought that the dimensions and layout of the display around the bed environment was suitable. While there is some minor difference in distribution, for all four controllers all participants rated overall satisfaction of the display in the upper half of the scale.

The design characteristic ratings and satisfaction ratings support display usability ratings and that the display is suitably designed for the hospital environment, at least as far as the patient is concerned and for this kind of task (i.e. Virtual navigation).

Table 9.6 Frequency count for ratings of various design characteristics of the display

Dimension	Scale end points	-3	-2	-1	0	1	2	3
Display size	Too small / Too big	-	-	-	11	1	-	-
Field of view	Too small / Too big	-	-	-	12	-	-	-
Position of display	Too close / Too far	-	-	1	11	-	-	-
Position of display	Too low / Too high	-	-	-	12	-	-	-

Table 9.7 Frequency count for ratings of overall satisfaction of the display across the four controllers.

	Low 1	2	3	4	5	6	*High* 7
Joystick	-	-	-	4	2	4	2
Keyboard & Mouse	-	-	-	3	3	4	2
Motion XS thumb	-	-	-	5	2	4	1
Xbox	-	-	-	4	4	2	2

9.4 Workload

An overall rating for workload (out of 20) is calculated as an average of the ratings of the 6 NASA-TLX sub-scales where the rating for Performance is reversed. Figure 9.3 shows mean ratings of overall workload for the four controllers.

Across all conditions the overall workload is generally low, i.e. at the lower end of the scale, the Xbox controller was rated with the lowest workload but the Keyboard and Mouse was rated with the highest workload. However, one-way ANOVA showed that there was no significant main effect on rating of overall workload due to the controller used [$F(3,33) = 2.246$, $p=0.101$]. In other words, the differences in overall workload rating for the four controllers was not significant ($p<0.05$).

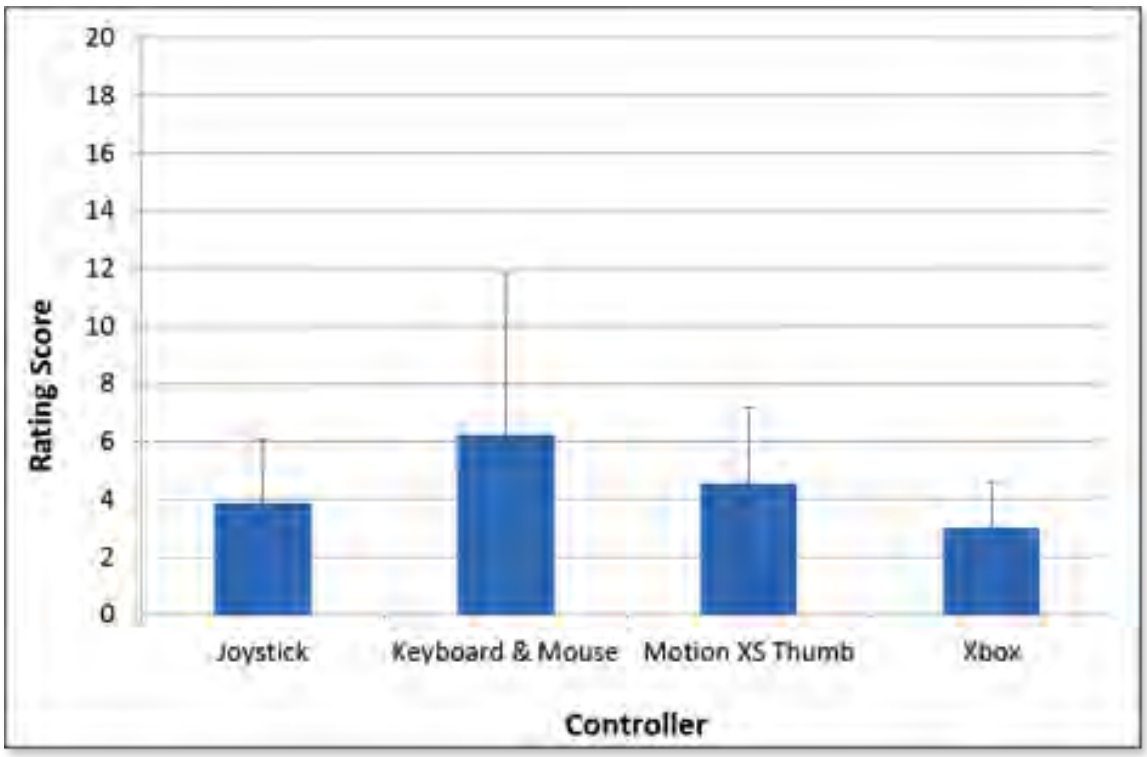


Figure 9.3 Mean ratings of overall workload for the four controllers

(y-bars represent 1SD).

Figure 9.4 shows a break down of workload rating across the 6 NASA TLX sub scales for the four controllers. As with the overall workload graph below, the Xbox controller scores best (lowest Mental, Physical, Temporal, Effort and Frustration; and highest for Performance). The keyboard and Mouse scored highest for all workload dimensions except Temporal Demand where the Motion XS controller was highest, and the Keyboard and Mouse scored lowest for performance. The highest ratings were for Physical demand, Frustration and Effort for the Keyboard and mouse, (note, Performance is reversed so a high score is good).

However, one-way ANOVAs showed that the differences for the 6 workload dimensions for the four controllers were not significant ($p>0.05$).

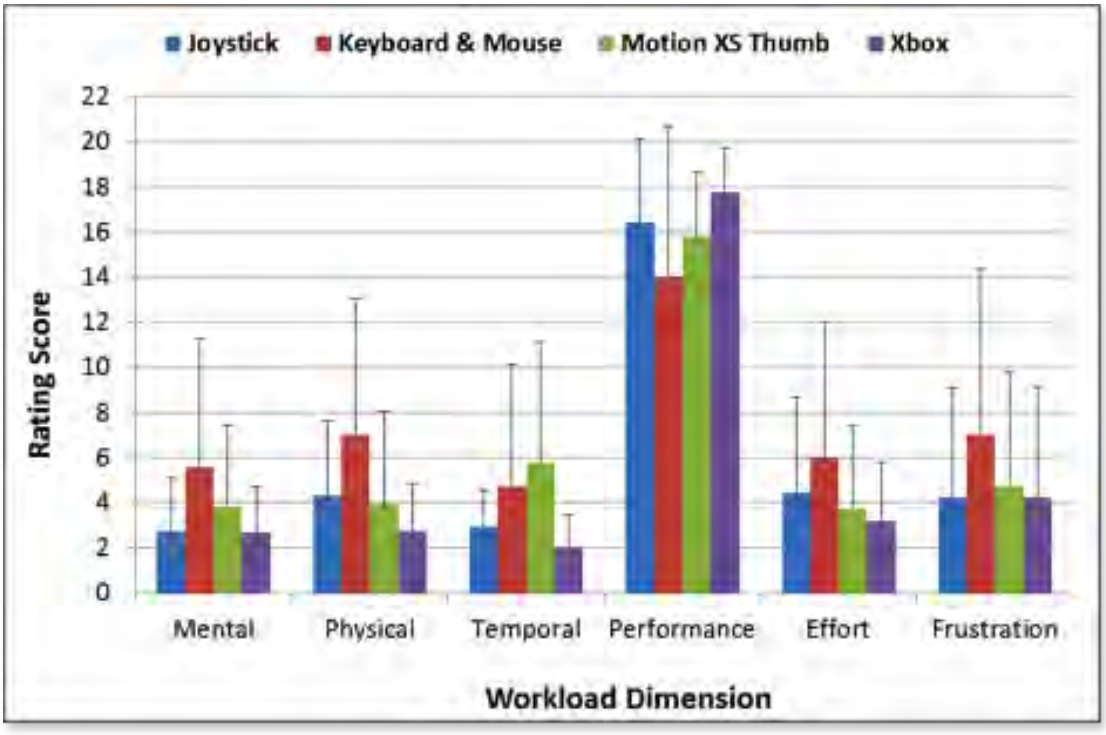


Figure 9.4 Mean ratings for each workload dimension for the four controllers (y-bars represent 1SD).

9.5 Discomfort

Table 9.8 (overleaf) shows frequency counts of experiences of pain and/or discomfort when using each controller.

There were more participants reporting pain/discomfort at the low to moderate rating (0.5-1 and 2-3) for the Joystick and Keyboard & mouse, which are focused mainly around the fingers, hand, wrist and forearm. There were also very strong ratings of pain and discomfort (>6) were reported for the Xbox controller, Motion XS and Joystick, although, these rating of came from the same participant who clearly had problems using these controllers and preferred the Keyboard and Mouse.

While the Keyboard and Mouse had no reporting of very high (>6) levels of pain it had most instances of strong (4-5) sensations of discomfort, with multiple reports (i.e. more than one participant) around the fingers and hand.

Overall, the Xbox controller and Motion XS had fewer reports of pain and discomfort, though there were some, including one participant at high levels, which suggests that one controller for all is not appropriate.

Table 9.8 Borg CR-10 rating of pain or discomfort.

Borg Score	Body Region	Joystick	Keyboard & Mouse	Motion XS thumb	Xbox
0	Fingers	3	3	5	4
	Hand	5	4	9	8
	Wrist	3	5	9	10
	Forearm	4	7	10	10
	Upper arm	8	10	11	10
	Shoulder	9	10	11	10
	Neck	11	10	11	11
	Total	**43**	**49**	**66**	**63**
0.5 - 1	Fingers	5	2	3	4
	Hand	3	2	2	1
	Wrist	6	4	2	1
	Forearm	4	3	1	1
	Upper arm	3	1	1	1
	Shoulder	2	1	1	1
	Neck	1	1	1	1
	Total	**24**	**14**	**11**	**10**
2 - 3	Fingers	4	3	3	3
	Hand	3	4	-	1
	Wrist	2	2	-	-
	Forearm	3	1	-	-
	Upper arm	-	-	-	-
	Shoulder	1	-	-	-
	Neck	-	-	-	-
	Total	**13**	**10**	**3**	**4**
4 - 5	Fingers	-	4	-	-
	Hand	1	2	-	1
	Wrist	1	1	-	-
	Forearm	-	1	-	-
	Upper arm	-	1	-	1
	Shoulder	-	1	-	-
	Neck	-	1	-	-
	Total	**2**	**11**	**0**	**2**
>6	Fingers	-	-	1	1
	Hand	-	-	1	1
	Wrist	-	-	1	1
	Forearm	1	-	1	1
	Upper arm	1	-	-	-
	Shoulder	-	-	-	1
	Neck	-	-	-	-
	Total	**2**	**0**	**4**	**5**

NB. Value represents number of participants (out of 12) who reported pain or discomfort. 'Total' value is the sum of all reported instances of pain or discomfort across the whole body and so includes occasions where participants reported pain or discomfort in more than one region of the body for the respective Borg score.

9.6 Preference

Following completion of all conditions participants were asked to state which of the controllers they would most prefer and which they least (Table 9.9). Chi-squared analysis showed that the distribution of rating of the Best controller was significant [χ^2= 11.333, df = 3, p = 0.01] with a preference for the Xbox. The Worst rated controller was fairly equally distributed between the Joystick, Keyboard and Mouse and Motion XS thumb controllers, and this frequency distribution was not statistically significant with respect to any controller (p>0.05).

Table 9.9 Post-test rating of controller preference.

Condition	Best	Worst
Joystick	2	5
Keyboard & Mouse	1	4
Motion XS thumb	1	3
Xbox	8	0

9.7 Discussion

9.7.1 Controllers

As the results suggest, generally the whole system is usable. All participants could use it and overall rated usability high. The Xbox controller was considered the best for usability, workload, pain/discomfort and preference, however on the occasions when it was not, it was due to the type of injures the participant had sustained,

injuries that prevented them from using both hands, which was required by the Xbox 360 controller.

There were 3 participants with hand injuries. Table 9.10 below shows preferences for hand injured and non-hand injured participants.

Table 9.10 Preference with hand injured and non-hand injured participants.

Condition	All *(N=12)*		Non-hand injured *(N=9)*		Hand injured *(N=3)*	
	Best	Worst	Best	Worst	Best	Worst
Joystick	2	5	0	5	2	0
Keyboard & Mouse	1	4	1	1	0	3
Motion XS thumb	1	3	0	3	1	0
Xbox	8	0	8	0	0	0

For the hand injured the Xbox controller was not the best, Joystick or Motion XS controller was the best. For the participant who had the use of one hand, the worst controller was the Keyboard and Mouse, having to switch hand between Keyboard and Mouse increased workload, making the task frustrating and time consuming.

The Joystick was rated worst amongst non-hand injured participants, this maybe related to the specific Joystick as the microswitches proved to harsh, meaning the force required to make any navigational movement would be greater than a non micro-switched Joystick. The reason for using this type of Joystick was that as soon as the ball grip was released it would move back to centre, therefore halting movement, other types of joystick would not return to centre. So the Joystick controller concept was ok, but better type/design of Joystick is needed.

Some issues with the sensitivity of the controls were noted (specifically the Motion XS controller). This may have been an issue of practice (i.e. getting used to it), but the sensitivity could also be modified in the settings via Xpadder (See section 6) - adjusted to the specific user's requirements. Ultimately, to incorporate this into the system a method of settings adjustment would have to be devised that is quick and easy for the user to carryout, which doesn't need technical assistance.

With regards the Joystick and Keyboard, the tasks required the use of controllers on a table, this meant that the participant had to reach for it, therefore increasing shoulder and arm fatigue. In contrast the Xbox controller and Motion XS could be held closer to the body thus reducing shoulder and arm fatigue/pain/discomfort.

To conclude, there was no one controller solution for all participants, the range of controllers needed was dependant on user ability, though one can argue discarding the keyboard and mouse option for this type of task (virtual navigation) as these are better suited for other computer based tasks (e.g. typing, internet, communication).

9.7.2 Display

There were no major problems or issues with the display, its size or position and participants could view it when either sat or reclined.

9.7.3 Issues with the study

There where a few issues that were noted following the study, the data is only generalised to similar patients, e.g. youngish 20-30 year old males who all had experience with console gaming and so familiar with an Xbox controller, most used it often or frequently. The question that could be posed would be, how would less experienced older participants perform/rate the system? more research is needed for these these types of participants.

To conclude, the first use of the system by participants in a real world hospital setting was promising, there were no apparent critical user issues.

10 Virtual Reality - Interaction (VR-I) Module - Prototype 2

During the usability study conducted within the Military Ward of the QEHB (Section 8), a number of observations were made, all of which pointed to a number of possible improvements that could be made to improve upon the design of the first prototype VR-I Module. The first recommendation from these observations was the addition of a UPS (Uninterruptible Power Supply), essentially a rechargeable battery pack (Figure 10.1) that allowed for connected equipment, such as the PC and any attached interfaces, to remain functional in the event of a sudden loss of mains power. Such a loss would come primarily from having to relocate the system, either following a change of participant or due to the need for an unplanned patient intervention. Although the PC was built to a high specification and had a rapid boot up time, issues arose with either the virtual environment or the range of interfaces needing to be rechecked / re-calibrated before being released to participants (which, in certain circumstances cost valuable time).

Figure 10.1 Location of Uninterruptible Power Supply.

The fitting of the UPS demanded the rewiring of the power cabling that directly supplied the PC. This was fed directly to the UPS and a return cable was sent back to the PC to complete the loop. Once activated, the UPS provided up to 124 minutes of backup power. The decision was taken to omit the plasma display from the UPS feed, as, when connected at the same time as the PC, the combination only afforded a total of 31 minutes of reserve power. The idea powering the system purely on battery power was considered, but was discounted as a greater emphasis was put on tailoring the usability of the system to fit the tight time constraints instead of making sure the participants would have as much time as need to successfully working through the testing schedule. With reference to Figure 10.2, The modified cabling for the UPS was:

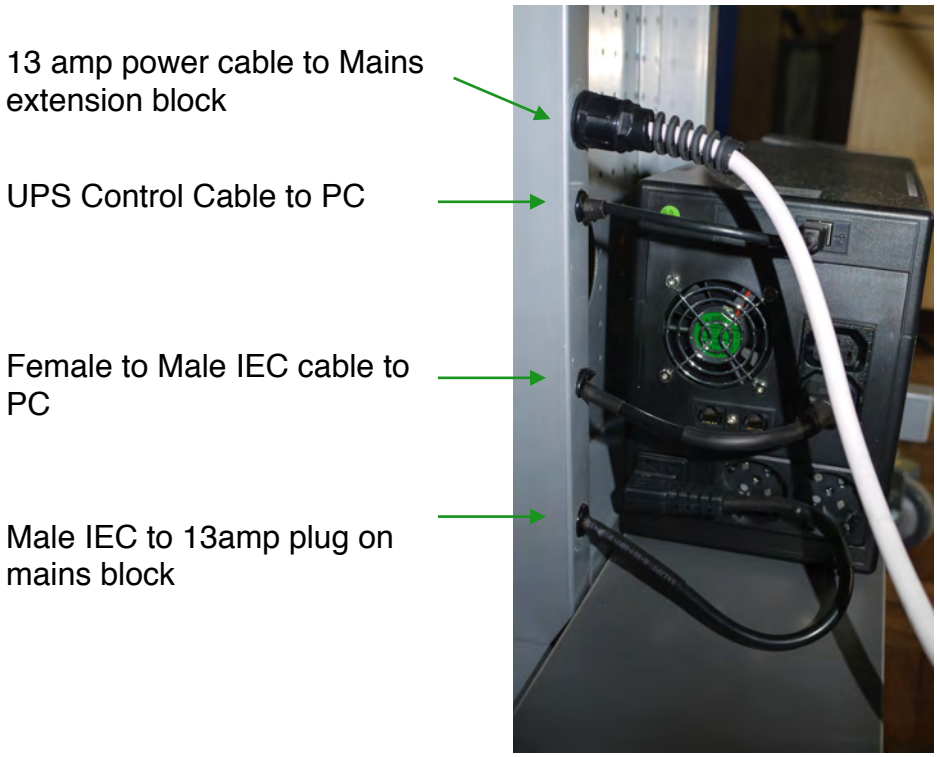


Figure 10.2 The table above illustrates how the VR-I module was reconfigured to accept the UPS.

A wiring schematic for the installation of the UPS to VR-I Module is located in Appendix 1, 1.9.1

10.1 Storage Issues

Another issue that became apparent during the usability study was the lack of available storage space for module-specific equipment such as interface devices, headphones, disposable earphone protectors and medical wipes (Figure 10.3). The VR-I module design had a limited capacity for adding additional storage space and the top of the PC was already being used as a shelf. This often led to a cluttered environment and items of equipment falling as the module was relocation. This was wholly unacceptable due to the potential infection risk.

Figure 10.3 The image illustrates the cluttered nature of the VR-I Module during the usability study.

The solution was to make use of the shelf that supported the UPS and also the UPS itself (Figure 10.1). The additional space meant that each interface had its own designated location and was easily obtainable as and when the testing strategy called for it.

10.2 Hygiene and Waste Management

Issues also arose with the disposal of soiled headphone protectors and medical wipes. No consideration was made during the original design as to waste management. It was assumed that the wards and side rooms would have adequate waste receptacles, but, in the event it proved difficult continually having to make multiple journeys to dispose of waste.

Figure 10.4 Velcro Strap to hold a canister of medical wipes.

Figure 10.5 Improved rear of the VR-I module based on observations made under test conditions.

A series of minor modifications to the module provided a workable solution to hygiene support and waste management. To accommodate the medical wipes, a re-sizeable Velcro strap was fitted using a self-tapping screw and washer combination. It was attached to the cable-less side of the VR-I Module (Figure 10.4), this also helped to clear the cluttered surface of the PC. To address the issue of waste management a number of hooks (Figure 10.5) were colour-matched to the finish of the VR-I Module and were attached using high-strength adhesive. A 40-litre refuse bag was also attached to capture and store waste.

10.3 Keyboard and Mouse Limitations

Figure 10.6 Logitech wireless keyboard and mouse.

One of the conditions during participant testing called for the use of a keyboard and mouse, the interfaces in question is referred to in Section 6.3 and illustrated by Figures 6.4 and 6.5. The keyboard-mouse combination was required by the research team and experimenter in order to configure the system, manage and launch the virtual environment, log captured data and to toggle between conditions within the virtual scenario. The system was found to work well until the participant was required to use the keyboard and mouse during condition testing. A comprehensive wipe-down had to be conducted on very regular occasions as the interfaces were exchanged between experimenter and participant. TO overcome this problem a Logitech K260 wireless keyboard and mouse were introduced as an additional new interface, it (Figure 10.6) and was offered for use exclusively by participants, running in tandem with the original setup.

10.4 Secondary Display

As well as having to use the participant allocated keyboard and mouse on several occasions whilst undertaking testing, it was often necessary for the experimenter to move into the area between the participant and the display, usually following the conclusion of a

test condition, in order to capture data and attach a new interface device. These regular intrusions prompted the acquisition and testing of an additional display. The display chosen for the test was a 10-inch Lilliput UM1012-NP/T USB powered display (Figure 10.7). A suitable location for the display was found at the rear of the VR-I Module. By using the now clutter-free upper panel of the PC as a makeshift platform for a keyboard and mouse, this solution provided an ideal location from where to exercise control over the complete system.

Figure 10.7 Lilliput USB display test fitted to the rear of the VR-I module.

Unfortunately, the biggest limitation with the dual display setup, and one which led to its eventual abandonment, was the 10-inch display's limited resolution which offered only a maximum of 1024 x 576. Whilst this might have been acceptable for a such a small display in isolation, it caused serious compatibility issues with the larger 50-inch panel. Suitability tests carried out to mirror the image from the main display onto the smaller one, even extend it over both, led to the PC's Nvidia GPU downgrading the larger display's resolution

of 1920x1080 to the match the inferior resolution of the small, which seriously impaired the viewing experience. The idea of introducing a second display was abandoned but was to be revisited during the VR-I Module Prototype 3 build (Section 13) where the use of a high performance gaming laptop would provide both UPS element and also the much needed secondary display.

10.5 Limb Tracking

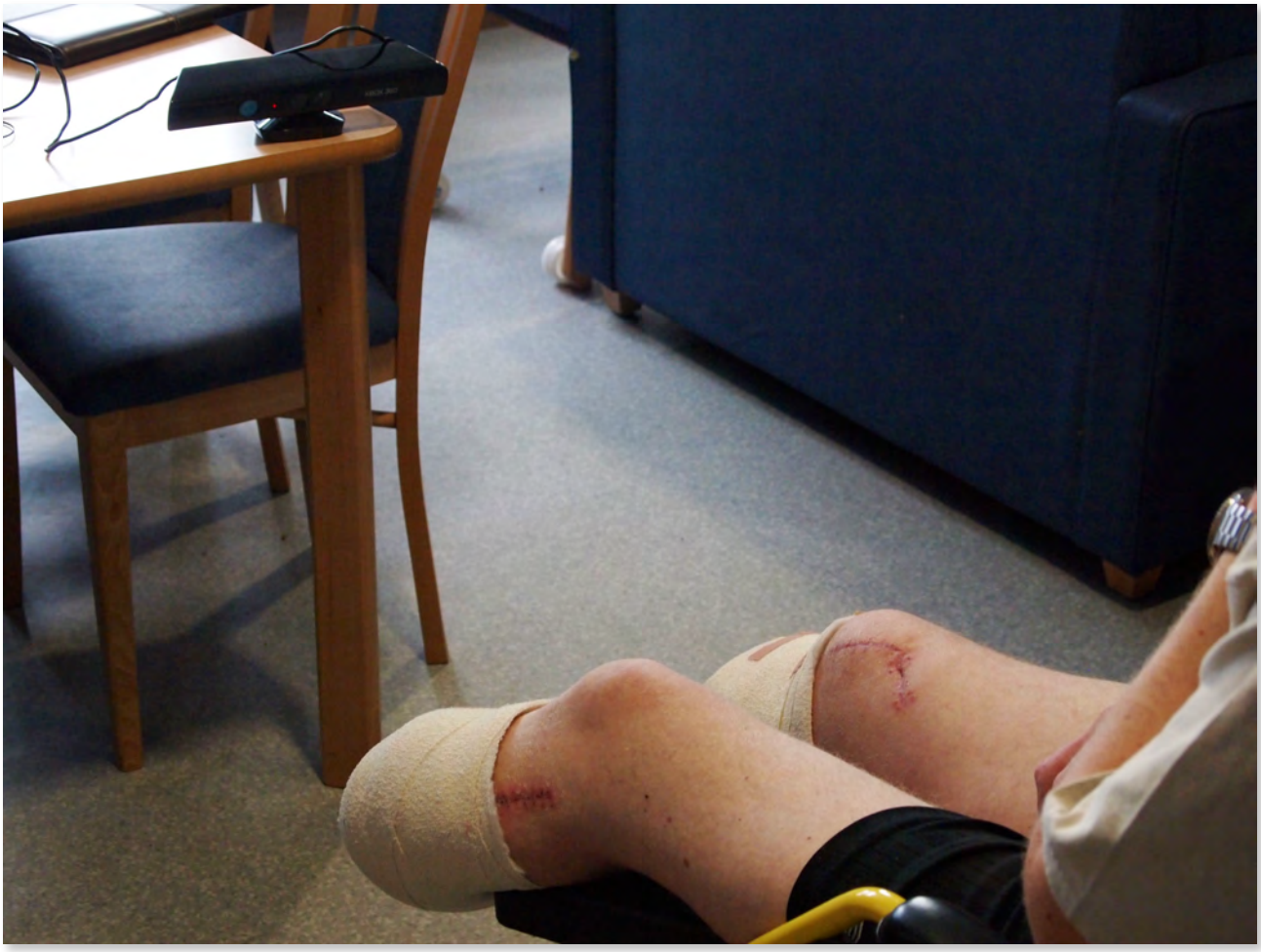


Figure 10.8 Amputee being tracked by an Xbox Kinect, QEHB.

Image courtesy of Prof. Robert Stone.

The most significant modification to the second iteration of the prototype VR-I Module came from the types of injures observed during the usability study (Section 8), where a

number of hand based input devices were evaluated. There was need brought forward by clinical and rehabilitation staff to investigate if the VR-I Module could be adapted to provide rehabilitative support for participants who had suffered lower limb loss and indeed, upper limb injures (Figure 10.8) so severe that the use of the recently evaluated interfaces would prove limited. The support came from the addition of an Asus Xtion Pro Live motion tracking camera, (Figure 10.9). This particular system represented an incremental step from an early fitment and usability evaluation of both the Xtion Pro Live and the Microsoft Kinect (Section 11).

Figure 10.9 Asus Xtion Live Pro

http://www.asus.com/media/global/products/hahEFPMWY9UVDL7z/P_500.jpg

11 Experimental Interfaces - VR-I Module Prototype 2

It should be noted that the following two interfaces were neither implemented nor were installed during usability testing. Instead they were utilised during periods of downtime with the VR-I Modules to enable the testing of concepts of motion tracking, specifically limb tracking. The idea was to informally test the how well the depth sensor and camera could identify key sections of the human skeletal form, together with obtaining some idea of the levels of accuracy and consistency during tracking. The reason for using the hospital as a "backdrop" for these particular evaluations was to be able to assess how, when deployed within an environment characterised by specific light types, furniture and ancillary equipment, the hardware and software solutions performed when compared to that of a controlled laboratory environment.

11.1 Microsoft Kinect

The Microsoft Kinect (Figure 11.1) was initially supplied for use with the Xbox 360 gaming console. It was subsequently made available for PC use by way of a series of third-party drivers. Microsoft introduced an official Kinect Software Development Kit (SDK) package in 2011. Appendix 1.7 contains a data-sheet that illustrates the technical specifications for the Kinect.

Figure 11.1 Microsoft Kinect mounted atop the VR-I Modules Display.

11.2 ASUS Xtion Live Pro

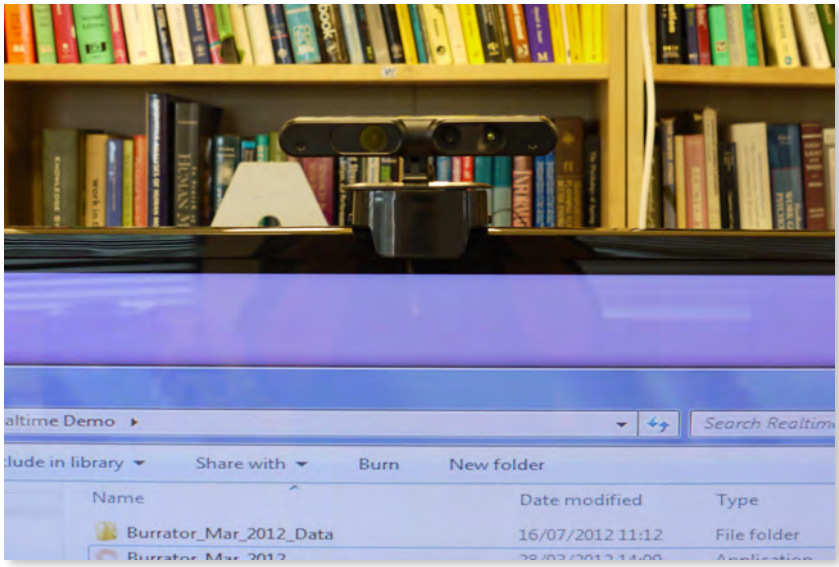


Figure 11.2 Asus Xtion Pro Live mounted atop the VR-I Module display.

A second camera, the ASUS Xtion Live Pro, was also evaluated. This camera essentially uses the same internal components as the Kinect but is USB powered, as opposed to the mains connection demanded by the Kinect. The Xtion is significantly lighter than Kinect weighing around 227g compared to the 1360g (Figure 11.4). The weight saving arose in part due to the lack of a tilt motor. The field of view (FOV) was marginally better (Figure 11.3) although the depth camera resolution was identical. Appendix 1.8 contains a data sheet that lists the technical specifications for the Xtion.

Field of View (FOV)	
Microsoft Kinect	
Horizontal FOV	57 degrees
Vertical FOV	43 degrees
ASUS Xtion Live Pro	
Horizontal FOV	58 degrees
Vertical FOV	45 degrees

Figure 11.3 Comparison of the the Field of View between the Kinect and the Xtion.

Depth Sensor Comparison Microsoft Kinect vs ASUS Xtion Live Pro		
Device	**Pros**	**Cons**
Microsoft Kinect	▪ High quality of device drivers ▪ Stable work with various hardware models ▪ Has motor that can be controlled remotely by iPi Recorder application: this makes device positioning more convenient	▪ Bigger size (30cm x 8cm x cm against 18cm x 5cm x 3.8cm) ▪ Higher weight (1360grams against 227grams) ▪ Require ACDC power supply ▪ Higher interference with another Kinect sensor in "Dual depth sensor" configuration ▪ Lower RGB image quality in comparison with MS Kinect
ASUS Xtion LIve Pro	▪ More compact (18cm x 5cm x 3.8cm against 30cm x 8cm x 5cm) ▪ Lighter weight (227grams against 1360grams) ▪ Does not require power supply except USB ▪ Better RGB image quality	▪ Less popular device ▪ Lower drivers quality ▪ Does not work with some USB controllers (especially USB 3.0) ▪ No motor, allow only manual positioning

Figure 11.4 The above table details the Pros vs Cons of the two leading motion tracking cameras.

11.3 Flexible Action and Articulated Skeleton Toolkit (FAAST)

The “Flexible Action and Articulated Skeleton Toolkit” (FASST) is a dedicated software library / driver that facilitates full-body control in VR applications and works in tandem with the Open NI (Open Natural Interaction) SDK in the case of the ASUS Xtion (a similar device to the Kinect), or the Microsoft Kinect SDK. Developed by Suma et al. (2013) the toolkit allows for the emulation of keyboard and mouse inputs triggered by body posture and specific gestures, in much the same way as Xpadder does for keypad-mapped interfaces.

Sensor	Joint		Sensor	Joint
0	Head		12	Right Elbow
1	Neck		13	Right Wrist
2	Torso		14	Right Hand
3	Waist		15	Right Fingertip
4	Left Collar		16	Left Hip
5	Left Shoulder		17	Left Knee
6	Left Elbow		18	Left Ankle
7	Left Wrist		19	Left Foot
8	Left Hand		20	Right Hip
9	Left Fingertip		21	Right Knee
10	Right Collar		22	Right Ankle
11	Right Shoulder		23	Right Foot

http://projects.ict.usc.edu/mxr/faast/

Figure 11.5 FAAST provided the scope to assign up to 23 body movements / gestures to keyboard / mouse inputs.

The rationale for testing motion tracking provided by these technologies was to establish if a lower-leg amputee could interact with the “Virtual Burrator” environment (as described in Section 7) such that articulated motion of the amputee’s hip joint and stump could be translated into in-game movement, and with prolonged use, may deliver a beneficial effect by minimising muscle atrophy that may occur during the time between sustaining the injury and being transferred to a rehabilitation centre, such as Headley Court. Providing some form of “motivational exercise” using these input devices would, it was hypothesised, be reflected in better rehabilitation outcomes through a rebuilding of depleted muscle mass to such a level whereby the limb would be able to accommodate a prosthetic device. There was also a suggestion that such a development would also do much to avoid patients having to endure further periods of time in a hospital environment.

With reference to Figure 11.5, during the evaluation, both the Left Knee (Sensor 17) and the Right Knee (Sensor 21) were mapped to the “W” key. This meant that, no matter which knee was raised, the player would move forward in the game or Virtual Environment. A series of variables were fine-tuned such that when a knee was raised, it would only trigger a single key press. Therefore, for the user to move forward over a large distance, there would be a need for some form of continuous limb or stump motion input such as that provided by a form of pedalling.

To change the participant’s viewpoint from left to right, Sensor 8 and Sensor 14 were mapped to the mouse-look function. The act of raising either hand upwards would trigger a turn and would only stop when the hand was lowered.

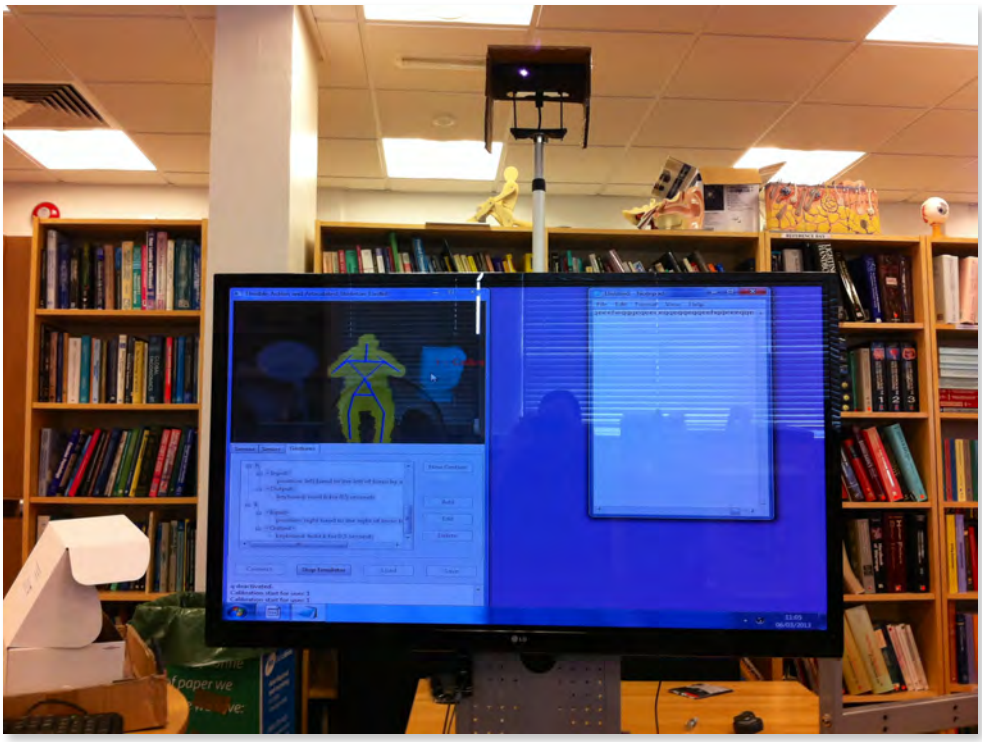


Figure 11.6 The FAAST output window and the Asus Xtion.

During the evaluation of the tracking capabilities of both the Kinect and the Xtion, a number of pressing issues arose. The first of these related to the both of the camera's depth sensors. When participants were in a standing position, with no other significant objects impeding the sensor's field of view (FOV), the camera's were able to correctly identify and track the human form. Figure 11.6 shows the output window of FAAST, notice how the body (in the standing position, shown in yellow) has a complete blue wireframe, this shows that the camera is accurately tracking the human skeleton. However, when lying down on a hospital bed (e.g. Figure 11.7) or sitting upright in a high-back arm chair (Figure 11.8) the software skeletal representation of the human participant could not be reliably displayed as a set of linked objects, independently from the background imaged scene.

Figure 11.7 Skeletal tracking on a treatment bed - Queen Elizabeth Hospital Physiotherapy department.

Figure 11.8 Skeletal tracking from a high back armchair - Queen Elizabeth Hospital Physiotherapy department.

Further tests were conducted to identify if the bedding material was absorbing the infrared emissions of the sensors. Using a sheet of aluminium foil, and a black bed sheet all provided the same negative results, to confirm that it was the inability of the two cameras' to capture depth data from two objects so close together, (i.e. a patient lying on a bed), a weightlifting bench (Figure 11.9) was introduced into the testing schedule. The width of the bench used was very similar to the average width of the human form and so, it was hypothesised, its occlusion by that human form would highlight the limitations of the depth sensor, as there would now be a clear unobstructed view of the ground.

Figure 11.9 Skeletal tracking on a weight lifting bench - Queen Elizabeth Hospital Physiotherapy department.

Just as with the standing position, there were no significant issues found in displaying a reliable and consistent skeletal form whilst lying on the weight lifting bench. The FAAST

output window on Figure 11.9 shows a full and stable skeletal form. Both the Kinect and Xtion were able to accurately determine the depth parameters of the whole scene, as the sensor had an unimpeded view of the participant and the surrounding area.

The second issue regarding the two cameras' was inconsistent tracking, particularly when simulating an amputee by attempting to track his or her knee joints and translating these into game or Virtual Environment movement. The tracking process was seen to work up to a to point but then anomalies would begin to appear, For example, at any given time, if both knees stopped moving, then movement in the game would suddenly advance albeit in a stuttered fashion. For a "new" (post operative) amputee, this may have the potential to induce considerable anxiety, rather than fostering early confidence in the first steps towards rehabilitation.

The final issue of concern related to the inability of the two systems to consistently replicate results in terms of accurate limb tracking. One simulated run may be flawless and achieve 100% accuracy then the subsequent run may fail to track and be no more than 50% accurate.

Touched upon earlier was an issue with the camera being unable to display a reliable skeletal representation whilst the participant was in close proximity to another surface - major limitation of the depth sensor. During the evaluation, both the cameras were mounted on the top edge of the display (Figures 11.2 and 11.6) which allowed for a maximum tilt angle of forty-five degrees. The problem with a forty-five degree angle at such a low elevation (1520mm) meant that parts of the participant were out of the vertical range of the of the camera and therefore tracking failed.

Due to the diminutive size of the Xtion (180mm x 55mm x 38mm) and weight (227g), it was possible to create a custom telescopic mount which, at the lowest set point positioned the camera 400mm above the display and at the highest point 690mm, see Figure 5.22 in section 5. With the mount fully extended, the camera could now handle a seventy-five degree tilt, an improvement of thirty degrees. The increased height also meant that the camera had a greater chance of tracking the human form from almost square on.

Unfortunately, the greatly elevated position of the Xtion and the increased angle of the camera failed to make any headway with regards to skeletal tracking with participants laying on a hospital bed, it did however allow for slightly better performance with the participants sitting in a hospital chair. The camera was able to sporadically pick up the participants' limbs, but would then tracking altogether. This was an improvement, but still unacceptable for long term participant use.

In the end the evaluation of this type of motion-sensing device was abandoned, despite the use of two types of camera. Yet in spite of the many variations to the cameras height and tilt angles the results were still inconsistent and, it was decided, would actually prove more of a hindrance to the participant. What worked up to a point in a laboratory setting using non-medical grade furniture failed to work consistently enough to warranty escalation to a testing strategy in a hospital environment.

12 Critical Care Unit

As a result of the experiences and usability study outcomes with the first prototype VR-I Module on the Military Ward of the QEHB, generating modifications that led to the second prototype VR-I Module, the decision was taken to investigate if the system could be employed in a demanding civilian medical setting, namely the Hospital's Intensive Unit (ICU). The patients in the ICU present a more demanding challenge than those in the Military Ward, as they are often very frail after significant surgery and then having quite traumatic initial recovery periods, especially given the numerous life support systems to which they may be attached, including the use of breathing support provided by mechanical ventilators.

Figure 12.1 An example of a typical Critical Care Unit bed space, Queen Elizabeth Hospital Birmingham.

The reason for the location change was that, due to the winding down of UK military operations in Afghanistan, a welcome gradual reduction was noted in the numbers of returning service personnel who had sustained the types of injuries that warranted the original motivation for a VR-based rehabilitation system. Permission was granted by the mains sponsors of this work - the Royal Centre for Defence Medicine - to switch the focus from military to civilian research.

Figure 12.2 VR-I Module prototype 2 undergoing an installation test at the Intensive Care Unit, Queen Elizabeth Hospital Birmingham.

The ICU is a very high dependency ward, meaning that, often surrounding every bed (Figure 12.1) is a vast array of medical equipment that can be called upon at a moment's notice, should the need for rapid patient intervention be called for. It was, therefore, important that whatever system was to be introduced into the ICU setting, it had already benefitted from a stringent installation test and evaluation in a hospital setting. Figure 12.2 illustrates the VR-I Module being installed at the foot of a bed within the QEHB ICU. The

Figure 12.3 VR-I Module prototype 2 undergoing user evaluation patient evaluation. Queen Elizabeth Hospital Birmingham.

custom Xtion motion sensor mount was removed in this setting, as - in contrast to other control devices - it was unlikely to be used by those patients being presented by the clinical team as appropriate for involvement in the study. Including the Xtion could also pose a danger to overhead cabling as during emergency extraction from a patient cubicle.

12.1 Evaluation Summary and Results - Intensive Care Unit

The location selected for the installation test was the ICU at the QEHB. ICU houses the hospitals most vulnerable patients who have at one stage been fighting for their lives, having spent time on mechanical ventilators and on copious amounts of medication. This combined with being confined to prolonged periods of bed rest (in the case of participant 1, 47 days at the time of testing) meant that the participant would be very weak and would have poor strength in their upper body. Approaching a patient with the aim of recruiting for

the evaluation the VR-I Module would need to be a collaborative effort, key of which would be the nursing staff who run the unit on a daily basis. To have a prototype system introduced into an already over-crowed bed space it was necessary to have them on-side. This was achieved by holding an open day whereby staff would be able to come and use the VR-I Module, ask questions and ultimately gain their technology acceptance and go ahead. Next was to find a participant who was well enough and would consent to using the system, this was met with mixed results, as the potential participant was in critical care their families would also be approached for permission. Some were dismissive as they feared that using the system could cause undue stress and fatigue. A element of patience was therefore required until a suitable participant would present themselves.

It was assumed that there was a need to provide the VR-I Module for use in the ICU to see if exposure to a Virtual Restorative Environment can provide an element of respite from the normal day to day routine of boredom and clock watching (Section 1, Figure 1.7). Although ICU is vastly different from the military ward in terms of the increased level of care provided, the lack of bed space and the increased amount of medical equipment at the bed side. Despite that, one key factor remained the same, the lack of any views on to the outside world. Figure 12.1 is of an actual bed space within the ICU at the QEHB, the reason for the beds facing inwards is so the patient can be observed at all times.

12.2 Results from the evaluation of the VR-I Module Prototype 2

Date: 12th February 2012

Location: Area A, Intensive Care Unit, Queen Elizabeth Hospital Birmingham

Patient: 1

The participant was a 71 year old female who is on Day 47 on ICU. She is Post op duodenal resection, bile leak from blown duodenal stump, roux-en-y gastrojejunostomy, foley catheter in duodenal stump. MOF. Tracheostomy with trachy mask. GCS 15. No signs of delirium. Mood appropriate. Brother and sister present.

Activity: The participant was given 15 minutes of free roam using the Virtual Wembury Environment with the VR-I Module Prototype 2. The interfaces evaluated were the microswitch joystick and the motion XS controller (as described in Sections 6.2 and 6.5). The interfaces were selected due to the ability to be controlled single handedly, allowing the non dominant hand i.e, the free hand not constraint by a cannula to cause any discomfort to the patient and interfere with any medical interventions.

In the case of the motion XS controller it was a thumb controller that could be placed in multiple positions depending on the orientation of the patients arm, the interface offered very limited resistance in its use which was considered a good fit given the frailty of the patient. The second interface was the microswitch joystick, the joystick was also able to be used single handed, navigation would be conducted by the participant pushing and holding the ball grip in the desired direction of travel.

Feedback quotes:

A number of comments were received following on from the evaluation of the VR-I Module, these related to the VR-I Module itself, the interfaces and also the Virtual Environment.

“It was a nice distraction and a nice change from watching television ”

“I think I would find it relaxing without the movement”

“The screen was too large”

“The small controller was easier to use than the joystick”

“The movement on the screen made me feel a bit sick, especially if my relatives were in control”

“I would have preferred to look at more greenery”

“I would be keen to try it again”

“I enjoyed the sounds via the headphones”

“I didn’t mind being able to hear background noises whilst I was using the headphones”

“I did find it very tiring to use”

“I liked that the time of day could change on screen according to the actual time of day”

12.3 Future Development

Based on comments gained during the participant evaluation a number of recommendations were made as to further iterate the VR-I Module’s design and usability to make it suitable for use within the confines of the ICU.

1. Reduction of display size

The size of the display was to imposing for such a confined bed space, so a reduction was deemed necessary. The issue of display size (as mentioned in Section 4) would again come into question, it was already established that the VR-I Module would be best placed at the foot of the bed to provide patient access in the event of intervention.

2. Offer a series of user selectable viewpoints

For the most frail of participants who would find even navigating around the Virtual Environment fatiguing, the idea of creating a series of pre-defined view points that could be easily toggled using a single handed lightweight interface device.

3. Include warnings about nausea

An issue that was observed was that relatives and even nursing staff were taking navigational control of the Virtual Environment away from the participant, this caused an issue as the display was facing the participant and the movement was causing disorientation and an element of motion sickness. This would need to be addressed during the participant briefing.

4. Offer alternative Virtual Restorative Environments

A comment received during the evaluation was that the Virtual Environment lacked in greenery, to that end Virtual Burrator (See Section 7) was readily interchangeable with Virtual Wembury and offered a more forest like scenario.

5. Disinfectant wipes essential for providing the best possible levels of hygiene for all equipment worked well for the VR-I Module's housing and all the interfaces, when used on the display led to significant screen smearing (which became very obvious when dusk and night settings were reached/selected (See Section 12.4).

6. As with the case of the Military Ward study, set-up procedures (by clinical or nursing staff) was being undertaken by leaning over into the participants bed-space, the idea of implementing a second display (See Section 10.4) would need to be revisited.

12.4 Discussion

An interesting phenomenon presented itself during the evaluation that was not present during the earlier usability testing in the QEHB Military Ward. Due to the positioning of the beds in either the single occupancy rooms or multi-occupancy rooms, the display was never ever placed opposite a window. In the ICU, however, the head of each bed was positioned in front of a window, (Figure 12.1) this caused the display to pick up reflections and impair the screen image (to illustrate the problem, see Figure 12.3). To the top right corner of the display a reflection of an interior light can be seen, and a little to the left a reflection of an exterior window is also visible.

Figure 12.4 The effects of residue using alcohol free wipes vs the effects of a alcohol enriched wipes.

The effect, also seen in Figures 12.4 and 12.5 (with additional problems caused by the use of ICU sanitising wipes in the case of Figure 12.4), is known as Veiling Glare. Veiling Glare occurs when stray light is reflected from an external source

(window, light) prohibiting a clear view of the target (display). It can be minimised by ensuring the target surface is well cleaned to reduce adverse glare.

The issue with the use of the alcohol-free medical wipes, came about as a result of the fact that the VR display was not exempt from being disinfected. However, as a result of wiping, the electrostatically charged panel became a magnet for dust particles (and, potentially germs) to adhere to the screen and possibly travel between participants. Greater care was taken during the preparation of the display surface. It became apparent that when disinfected and allowed to air dry, large streaks of residual detergent caused fogging. By using dedicated alcohol-enriched wipes, the residue fogging effect was minimised dramatically due to the evaporation of any cleaning agent.

Figure 12.5 example of veiling glare.

http://news.essilorusa.com/stories/detail/blinded-by-the-light-how-glare-affects-vision

Conclusion

Following the patient evaluations and demonstrations described above, it suggested that the 50-inch display was too imposing, both in terms of bulk and image size. This concern was also backed up by care professionals who commented that, as the ward was critical care focused, at times the environment could be personnel- and equipment-heavy, with cubical and side-room bed space often at a premium. Further issues relating to the health and safety risks of manoeuvring the VR-I Module between patients and in and out of position was also raised. The original justification for incorporating a 50-inch display in the original VR-I Module design was to provide the best levels of immersion from the minimal safe distance allowed from the participant, which was at the foot of the bed, a distance of 183cm. To introduce a smaller display whilst, maintaining the quality of immersion the idea of using a cantilever screen was put forward. This, it was argued would allow for a smaller VR-I Module and display combination, but would enable the display to be positioned closer to the participant.

13 Virtual Reality - Interaction (VR-I) Module Prototype 3

Based on the feedback and future development responses collated during the critical care unit evaluation and demonstration, a list of requirements were generated defining the fundamental changes needed to the VR-I Module's design and functionality. The idea of creating a more streamlined version of the VR-I Module that would be less intrusive (both in overall physical structure and display size) would allow for improved bed-space integration and provide less resistance during relocation. What follows is a description of the ground-up build of a completely new prototype VR-I Module (Figure 13.1), specific to the needs of the Critical Care Unit.

Figure 13.1 The unmodified component form of the VR-I Module Prototype 3.

Figure 13.2 Original stock display mount (left).

Figure 13.3 Cantilever mount modification to the VR-I Module (right).

The previous two prototype VR-I Modules each possessed a 50inch display that was installed at the foot of a standard hospital issue bed (Section 5.19, Figure 5.25). This allowed the display to leave either side of the bed free in the event of patient intervention. Participants based on the display usability results (Section 9.3) stated that the display was satisfactory in terms of size, field of view and position. Reducing the display size to 32inches would certainly help reduce the foot print of the new VR-I Module, but might potentially hinder usability as the display would be smaller, and therefore positioned at too great a distance from the participant, thus, potentially, allowing their attention to wander

beyond the confines of the virtual environment. Figure 13.2 shows the upper part of the original display mount procured; it provided only a minimal vertical tilt adjustment. What was needed was a cantilever mount (Figure 13.3) that would allow the display to be pulled closer to the participant in order to help counteract the shortfall in display size. The chosen cantilever mount, at maximum reach, safely accommodates a 60inch display weighing a maximum of 32kg, the selected 32inch display weighs 8.0kg, the model selected being the LG32LS3400.

Figure 13.4 32” LG display with pedestal mount.

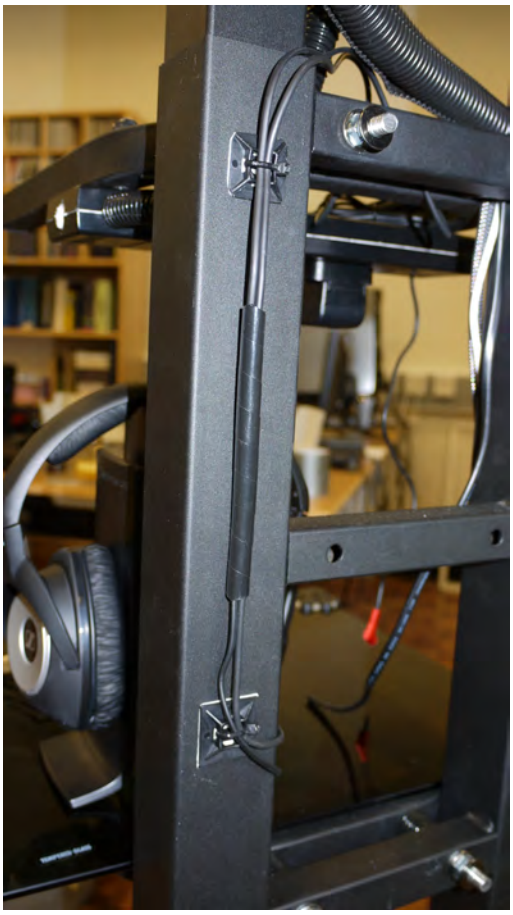
http://i.testfreaks.com/images/products/600x400/72/lg-32ls3400.33235528.jpg

14.1 Headphones

Figure 13.5 Sennheiser RS170 headphones.

An ergonomic issue raised in earlier (Section 12.3, point 7) regarding headphone comfort and ambient noise cancelation saw the type evolve from on-ear headphones (Section 5.9, Figure 5.17) to a pair of Sennheiser RS170s (Figure 13.5). The headphones feature the same Kleer technology as used with the previous type, but features full padded foam earphone covers to encapsulate the ear and provide minimal sound leakage, both external and internal. A key advantage over the previous type is that the RS170 is rechargeable, featuring 24-hour usage per charge and a docking cradle for safe storage.

Figure 13.6 The headphone audio / signal cable installation. The mains power block can also be seen mounted above the headphones.



A further change from the two previous VR-I prototypes concerns how the audio is delivered. Initially audio was routed from the PC to the headphones, which led to the tester having to ask the participant for level adjustments. For the new build, the headphones were wired to the display and the audio signal fed to the display via the HDMI cable from the PC. This allows the participant to self-control the audio levels using the display's remote control.

Figure 13.7 Headphones with disposable earphone protectors installed on the VR-I Module Prototype 3.

13.2 Laptop

During the modifications to the VR-I Module Prototype 2 the use of a second display had been investigated (Section 10.4). An issue of concern was the fact that the participant's personal space had to be "invaded" in order to administer test conditions or to make interface changes. The introduction of a laptop provided the much needed secondary display and also acted as an uninterruptible power supply during participant changeovers.

Figure 13.8 Laptop installed and running.

13.3 USB Hub

Figure 13.9 USB 3.0 Hub mounted to the display.

Now that the display was able to be repositioned independently of the frame, it proved beneficial to mount a USB 3.0 hub to the rear of the display (Figure 13.9). This meant that only one USB cable was required to be connected to the laptop for ease of setup following a period of storage. A second advantage came from keeping interface cabling to a minimum.

13.4 Interface Technology

Genius Ring Mouse

Figure 13.10 Genius Ring Mouse and USB dongle.

One of the feedback comments gained from the Critical Care Unit Demonstration was the request to have a series of pre-defined view points that the participant could access or “jump to”, simply at the press of a button. The Genius Ring Mouse (Figure 13.10) allowed just that. By clicking the top right corner of the mouse, the viewpoint could be altered; thumb-swiping in any direction across the surface of the mouse would provide a shift in mouse look so that the viewpoint could be tailored to suit the participant’s needs.

13.4 Completed VR-I Module Prototype 3

What follows is a series of images that depict the final VR-I Module as used by participants in the Critical Care Unit, at the QE Hospital. Figures 14.10, to 13.14 are images taken from the actual unit undergoing evaluation at the QEHB at the time of writing.

Figure 13.11 (left) The front of the VR-I Module.

Figure 13.12 (right) The rear of the VR-I Module.

Figure 13.13 Rear of the display featuring USB 3.0 hub and mount for Motion XS controller

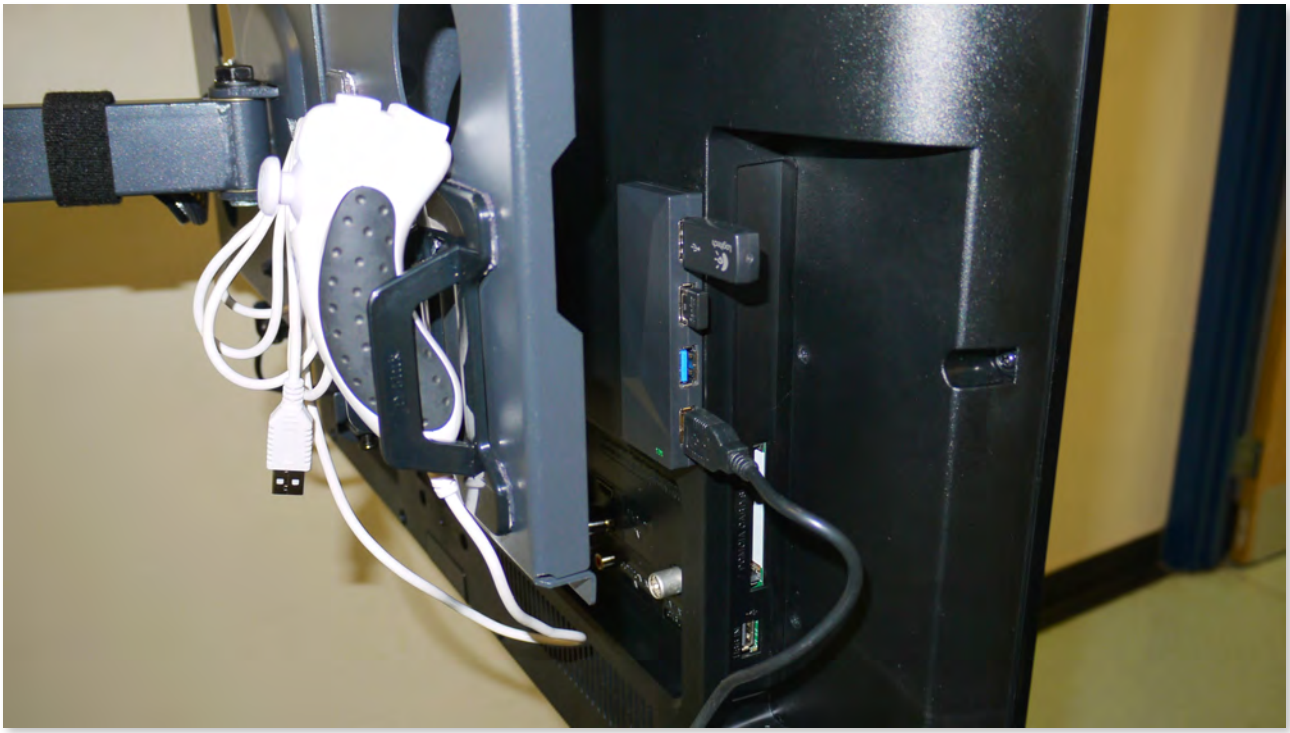


Figure 13.14 Dedicated keyboard storage, stable even during VR-I relocation.

Figure 13.15 Virtual Environment as seen by participants, note the clean look of the VR-I mount, with all the equipment located out of site.

Figure 13.16 VR-I Module undergoing testing in a ward setting. (display fully retracted)

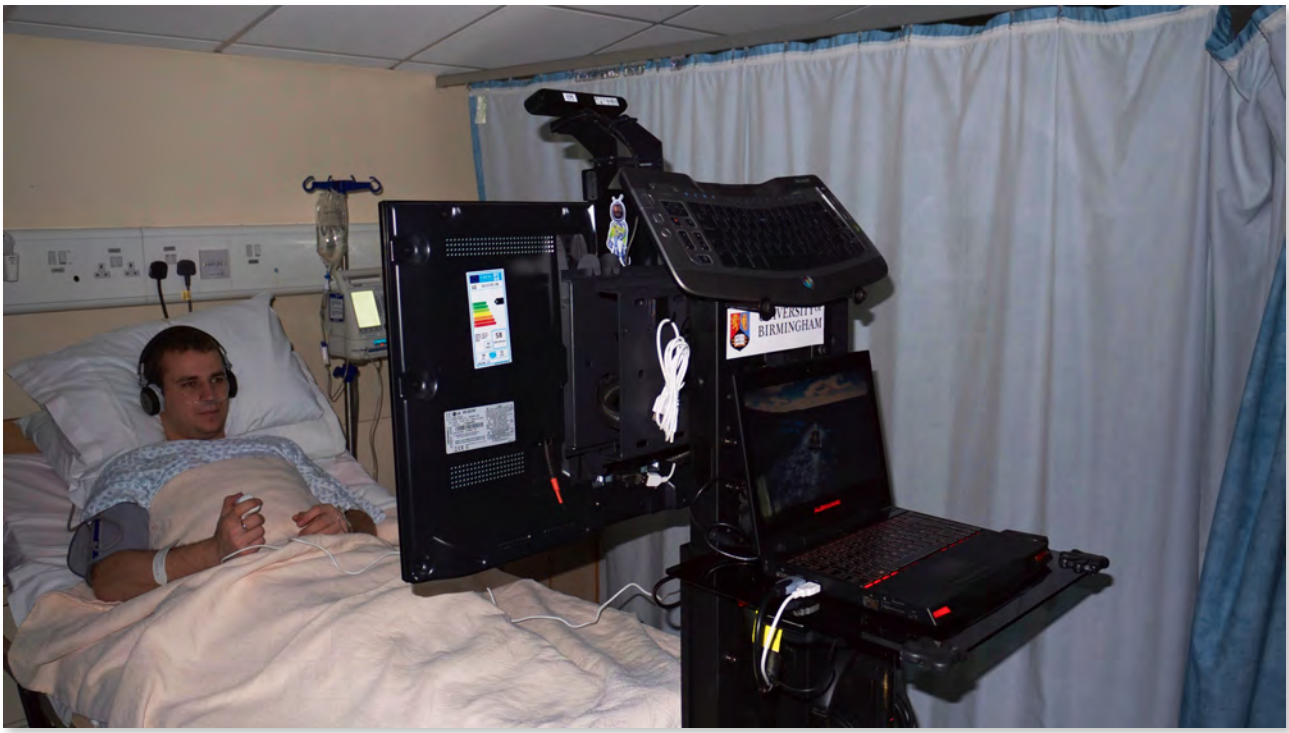


Figure 13.17 VR-I Module undergoing testing in a ward setting. (display fully extended)

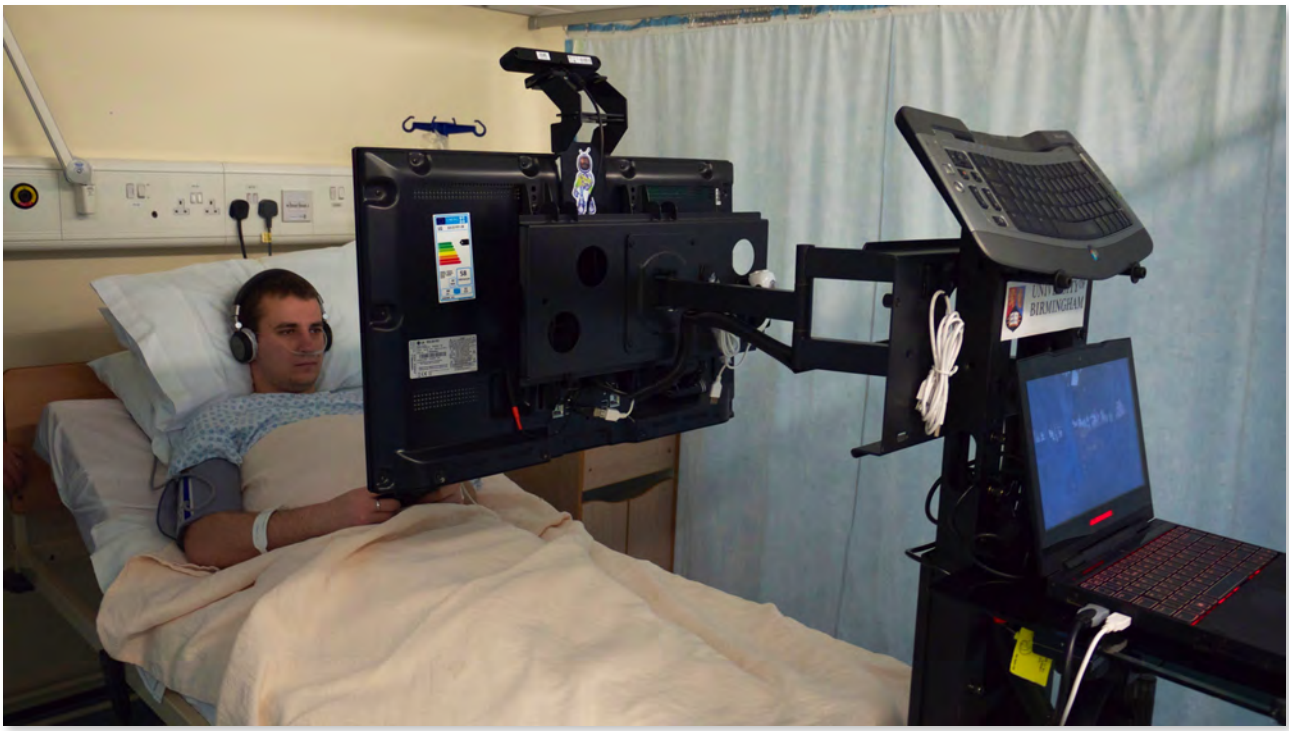


Figure 13.18 Virtual Environment running on VR-I Module, The Xtion motion sensor is attached but not active.

Figure 13.19 VR-I Module installed under hospital bed.

Figures 13.20 and 13.21 VR-I Module Prototype 3 undergoing evaluation by nursing staff during briefing session.

14 Conclusions

The research described herein has addressed the human-centred development of prototype hardware and commercial off-the-shelf technologies together with a bespoke 3D virtual environment of a nature scene, such as a forested region or costal path. To support the research, it was necessary to design and create a series of cost effective, reproducible and reconfigurable Virtual Reality Interaction (VR-I) Modules for use in the recovery and rehabilitation support of military and civilian hospitalised patients, such as those at the collaborating hospital, the Queen Elizabeth in Birmingham (QEHB).

The idea was inspired as a result of studies conducted by the 1980s by Ulrich, R. (1983; 1984) which suggested that exposing patients to views of real-world scenes of nature from their hospital beds (trees, gardens, etc.) positively influenced their recovery periods, reduced the need for analgesia and increased the perceived satisfaction of their hospital stay when compared to those patients with no such views.

As well as addressing the main human factors and ergonomic issues with regard to the deployment of interactive technologies within typical hospital ward and cubicle environments, the research has also focused on the more demanding environment supporting critical patient care, namely the Intensive Care Unit. Throughout the research, a strong human-centred approach has been adopted which, through close engagement with a range of stakeholders, from medical consultants, pain control specialists, physiotherapists and nursing staff to the patients themselves, and even, on occasions, their relatives, has helped to ensure that the evolutionary design of the VR-I Modules and their component interactive technologies has been undertaken both scientifically and sensitively.

Based on the research and knowledge gained, the first of three prototype systems were created and evaluated. The evaluation took the form of a usability study that investigated the use of a number of low-cost hand control interfaces that catered for the varying nature and severity of patients' injuries. The results suggested that the Xbox 360 controller provided the greatest usability for participants, although this finding was possibly more to do with familiarity due to prior gaming experience and the age demographic of participants, even though the controller was not always the most suitable option based on the types of injury sustained (i.e. the incapacitation of one hand). Recommendations were made to include a series of interactive technologies that addressed the problems encountered during testing (such as the increased shoulder and arm fatigue sustained by participants having to reach out to use table mounted interfaces, e.g. keyboard and mouse, or the harshness of the microswitches within the joystick, again increasing fatigue), but still would allow for greater comfort and therefore enhanced usability. Some of the recommendations made included, the use of a wireless keyboard and mouse to remove the tether of a usb cable therefore, increasing positional flexibility, and the experimentation of limb tracking to try and negate the need for physical controllers.

Following the usability testing of the first VR-I prototype, a question was asked by the medical stakeholders at QEHB as to how the VR-I Module or an evolutionary iteration might fair in a new medical environment. As well as suggesting that the study scope could be extended to assess how well the module design would support reconfiguration for multiple healthcare applications in the future. The main reason for this question came as a result of the gradual reduction in hostilities in theatres such as Afghanistan and the consequent reduction of military patients (i.e. potential participants) arriving at QEHB.

As a result of this challenge, the VR-I Module underwent an installation test and a period of evaluation at the QEHB's Intensive Care Unit. The early results of the evaluation, which included the VR-I Module itself and the 50inch display being too large for such a confined bed space laden with banks of specialist medical equipment, potentially making for an unsafe working environment for clinical staff. An issue as to health status of the patient and their inability to handle two handed controllers due to diminished levels of grip strength, even the joystick, due to the kinds of force required. which led to a total re-evaluation and re-design of the VR-I Module, taking into account the types of *civilian* patient who would now, in the main, be using the system, together with the new operating environment and the types of interfaces needed to provide even the frailest of patients with the chance to experience the virtual nature scenarios.

With the completion of the second and redesigned VR-I Module prototype, two complete modules were assembled and deployed within the QEHB's ICU. At the time of writing these modules are undergoing further evaluation, with specific reference to the impact of virtual scenes of nature on patients' sleep quality and delirium experiences. Indeed, this work is generating even more research opportunities, such as the re-adaptation of the VR-I Module for evaluation as a means of delivering Virtual Reality distraction therapy for burns patients undergoing lengthy and quite painful dressing changes.

15 Future Research

Throughout the execution of the present research, a wide range of issues were uncovered all of which warrant significant further study. Some of these issues demand the re-investigation of existing ideas, or issues only briefly considered herein, such as motion tracking/sensing for hospitalised patients, olfactory display systems to enhance the patient recovery process (through improved immersion or even as a result of aromatherapeutic effects of immunologic features of certain scents, such as pine (e.g. Li, 2010), and the evolution of the VR-I Module prototype to allow it to be integrated into other areas of medical research. New avenues for exploration include the evaluation of advanced forms of display technologies such as curved-screen monitors, 4K technologies, and head-mounted displays, all of which are possible options to help improve the experience for the participant and - potentially - an enhanced or accelerated path to recovery. These topics will now be discussed in slightly greater detail.

15.1 Motion Tracking

As discussed earlier within this thesis (Section11) the idea of accurate and reproducible skeleton tracking proved elusive, even with the advent of the second iteration of the Microsoft Kinect 2 system. According to the specifications for the Kinect 2, the Windows developer version offered a vast improvement in tracking with better horizontal and vertical fields of view and a full high-definition camera. Latency had also been improved, with a reduction of 30ms over the original sensor to 60ms.

Table 15.1 - Comparison between the Microsoft Kinect and Kinect 2.

Hardware comparison between Kinect and Kinect 2		
	Microsoft Kinect	**Microsoft Kinect 2**
		
Field of View (FOV)	57.5 Degrees Horizontal 60.0 Degrees Vertical	70.0 Degrees Horizontal 60.0 Degrees Vertical
Camera Resolution	640x480	1920x1080
Latency	90ms	60ms
USB	2.0	3.0
	n/a	Employs an IR stream to aid with better low light tracking

The subject of limb tracking could be re-investigated to identify if the advances in camera technology from VGA (Kinect), to Full HD (Kinect 2) can translate into more accurate and reproducible skeletal tracking within a patient rehabilitation scenario (See section 11.3). An approach by rehabilitation staff at the QEHB was made with a request to incorporate limb tracking with the use of a MOTOmed. A MOTOmed is essentially an exercise bike that the patient can operate whilst in bed, it can offer three modes of training, passive, motor-assisted or active, all depending on how advanced the patients recovery is.

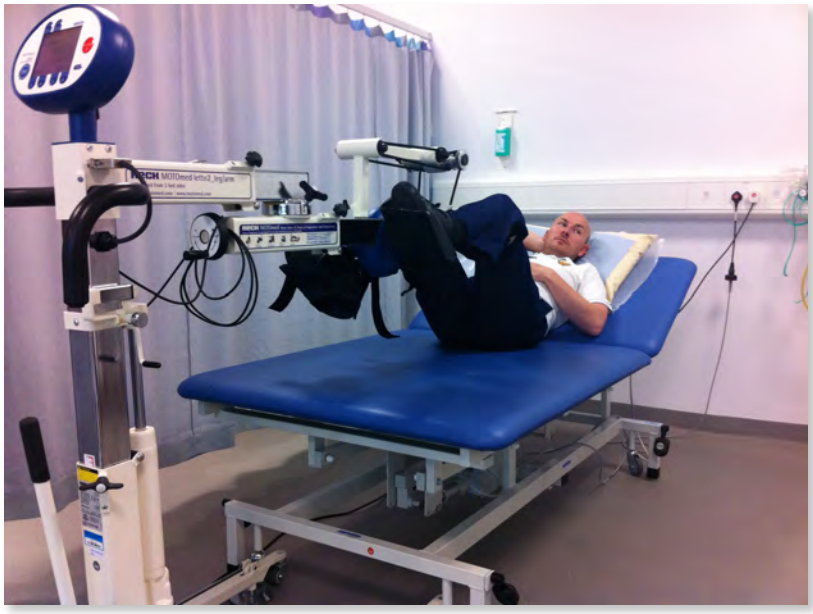


Figure 15.1 The MOTOmed movement trainer.

At present the MOTOmed has the patient using the system with no visual feedback or motivational cues, the idea of using the Kinect 2 with a further iteration of the VR-I Module could potentially allow for the rotational action of the feet operating the pedals to be translated into game movement. This potentially could lead to a study to investigate if visual feedback through the use of a VR-I Module with motion tracking could provide greater levels rehabilitation (be it motivation or distraction) than the current method of timed usage with limited feedback.

15.2 Olfactory Systems

The evaluation of the Scentscape scent delivery system (described in Section 5.8) proved problematic, as the system was an early prototype and one of the very first to be delivered to the UK. The issues with the cross-contamination of dispersed scents in the atmosphere together with the noise of the unit whilst in operation brought a premature end to any evaluation, simply because of the distractive nature of these unacceptable olfactory display features. For olfactory displays to become an acceptable, unintrusive form of display technology, future work is essential in order to evolve the present, very immature prototypes into a more integrated system such as a custom HVAC - (heating, ventilation, and air conditioning) based system, a system that (Figure 15.2) can be plumbed into an existing ventilation system to provide greater and more even scent dispersal without the need to have equipment attached to the VR-I Module (See Figure 5.16).

The upper section of the image in Figure 15.2 presents the individual cartridges that contain the various scents; below that is a control module that can be interfaced to a game engine to allow for automated scent dispersal when the user enters a pre-defined zone in the virtual environment.

Figure 15.2 Custom scent delivery system.

http://www.scentair.com/why-scentair-solutions/#scentwave

15.3 VR-I Module Evolution

During the execution of the present research, there had been an evolutionary change to the VR-I Module prototype, from the original 50-inch display that saw use in the military ward or the QE Hospital to the subsequent demonstration in the ICU that saw the prototype evolve into versions two and three (described in Sections 10 and 13). As a result of the evolutionary development of these modules and the regular exposure of the results, not only to the ICU clinical specialists and nursing teams, but also to “visiting” specialists from other medical sectors of the QE Hospital, it was inevitable that another evaluation opportunity would arise. One such sector was that of the Hospital’s Burns Unit, where interest was shown in the adaption of the interactive display modules to help with patient

distraction therapy during the very challenging, and often distressing procedure of dressing changing.

Figure 15.3 A re-adapted VR-I being evacuated in the Burns Unit QEHB

Image courtesy of Dr Charlotte Small

As early system based on the VR-I Module prototype 3 (Figure 15.3) was developed and installed in the Burns Unit were it is, at the time of writing, undergoing patient evaluation at the QE Hospital. One of the early issues to arise form using this system related to how the prototype and its main interface components can, in the future, be made water resistant without adversely affecting usability, thereby allowing patients to continue to have their dressings changed during water treatment, which is an essential aid to pain relief and helps to reduce the odours that typically accompany such a trauma.

15.4 Display Technology

15.4.1 Curved Display Technology

During interactions with the medical stakeholders and collaborators with the present research, one suggestion that has been raised relates to an investigation to see whether or not the next generation of curved display technology can have an effect on levels of immersion (Shupp et al. 2009), either as a single or combined to form an enclosure (Figure 15.4).

Figure 15.4 The 55” curve display from LG.

http://www.lg.com/au/images/pressrelease/lg-oled-tv-curved-screen.jpg

15.4.2 4K Display Technology

Another development worthy of future investigation (and this applies not only to hospital interactive 3D modules, but to general display usage in Virtual Reality and simulation as well) would be an investigation into the use of ultra-high definition display technology and whether or not such definition can improve the perceived levels of realism and therefore increase both immersion and, possibly, health restorative effects.

What is 4K?

A High Definition display featuring 1080p resolution is composed of two million pixels (1920x1080), a 4K display, referred to as *Ultra High* Definition has over eight million pixels (3840x2160). Therefore 4K boasts around four times the resolution than 1080p and, thus provides for a far superior picture. It has been suggested that the clarity and definition of the image might even negate the need for 3D technology. This suggestion has been partly backed up by the fact that mainstream content providers (such as Sky and the BBC) have discontinued 3D services.

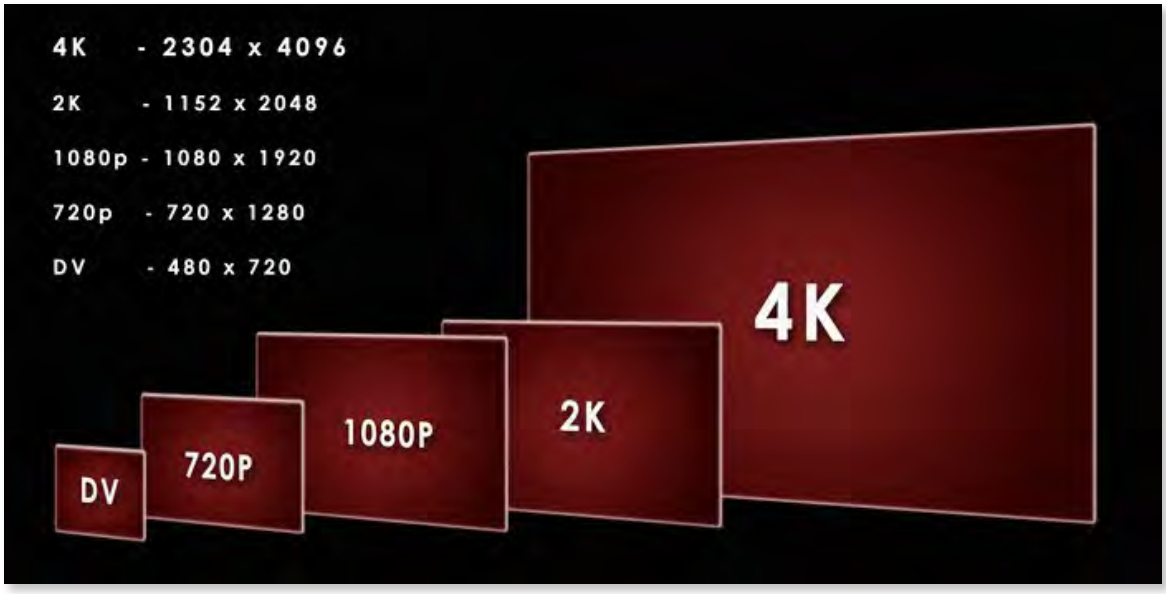


Figure 15.5 Current resolutions for display technologies.

http://www.seanjvincent.com/2011/11/4k-vs-1080p-or-just-good-film.html

Throughout the present research, the display type used was a 32-inch High Definition (1080p) display. Section 9.3 demonstrated that participants during the usability study found the 1080p display to be suitable in terms of size and Field of View (FOV). A study could be undertaken to investigate if other types of display technology such as 3D or 4K can offer an improvement in levels of usability.

15.4.3 Head Mounted Displays

Figure 15.6 (above) Informal test of the Sony HMZ-T1 head mounted display.

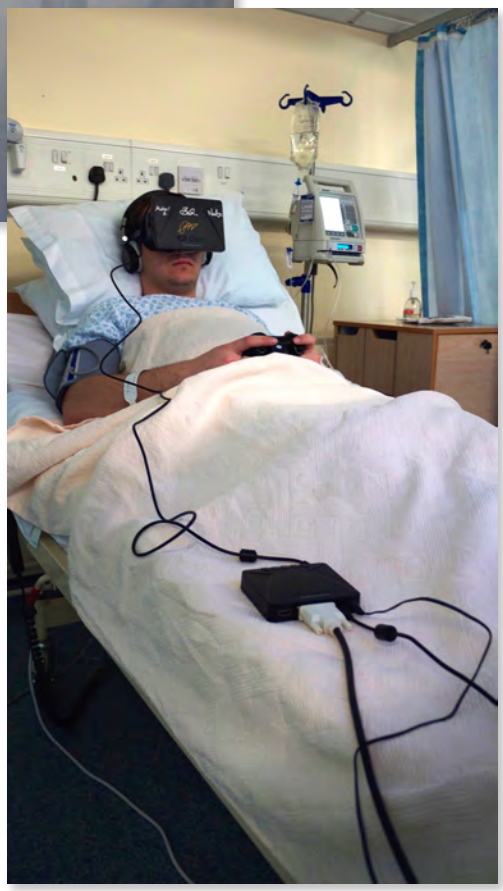


Figure 15.7 (right) Informal test of the Oculus Rift dev kit 1.

Future research in the field of potential exploration of head-mounted display (HMD) technologies in hospital settings centres on whether or not there is a need to pursue more wearable, lightweight, wireless devices to support increased levels of immersion (and, thus, possible distraction effects) for hospitalised patients.

Early informal evaluations had indicated that motion sickness and eyestrain can occur, and, given some of the related “cybersickness” effects noted with even large-screen implementations of the VEs studied during this research (where some patients complained of disorientation and early symptoms of nausea), testing with patients may prove unwise, or will have to be undertaken with considerable care. Nevertheless, with the ever-evolving nature of HMDs the importance of increased immersion for patients with traumatic injuries may warrant further reviews and investigations, especially from a pain management or pain distraction standpoint.

15.5 Interfaces

With the advent of the next generation of gaming consoles, such as the Xbox One and the PS4, there will be ample opportunities to re-run usability testing processes described herein to investigate whether or not they - together with the new and varied products emanating from crowd-sourced initiatives, such as Kickstarter or Indiegogo, may herald an improvement to the overall usability of the system.

Figure 15.8 (left) The controller for the Xbox One. (right) the controller for the PS4.

http://news.xbox.com/2013/06/xbox-one-controller-feature

http://us.playstation.com/ps4/ps4-accessories/

One example of a viable crowd-sourced interface is the Quadstick (Figure 15.9). This innovative device designed and built by Fred Davison. It features a joystick, four sip and blow sensors, a lip position sensor, and a push switch connected to a 32 bit ARM processor that converts the sensor inputs into USB and Bluetooth signals for host devices.

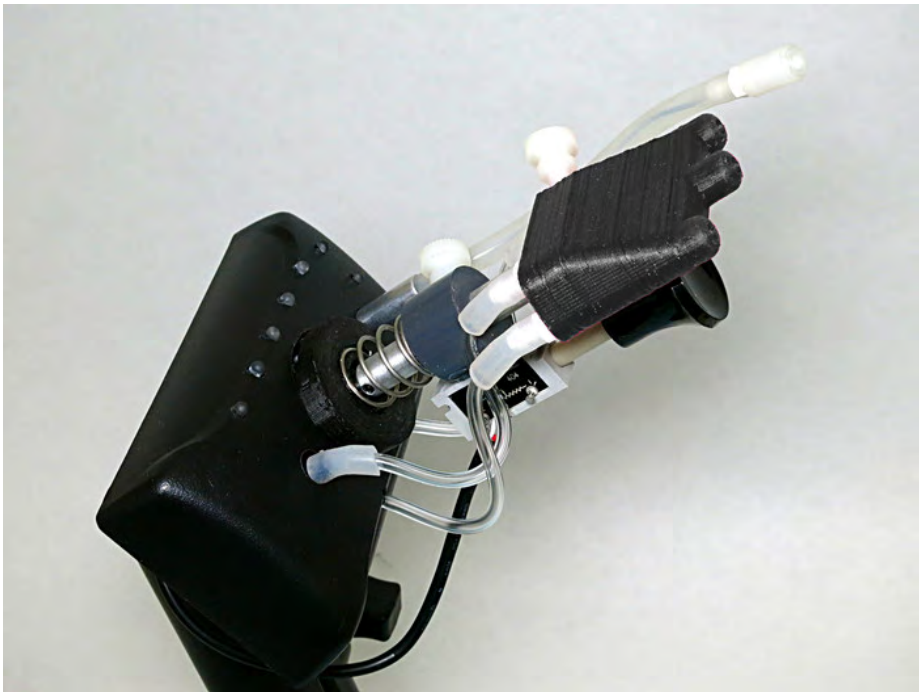


Figure 15.9 The Quadstick controller.

http://www.quadstick.com/gallery.html

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Contents - Appendix 1

Contents - Appendix 2

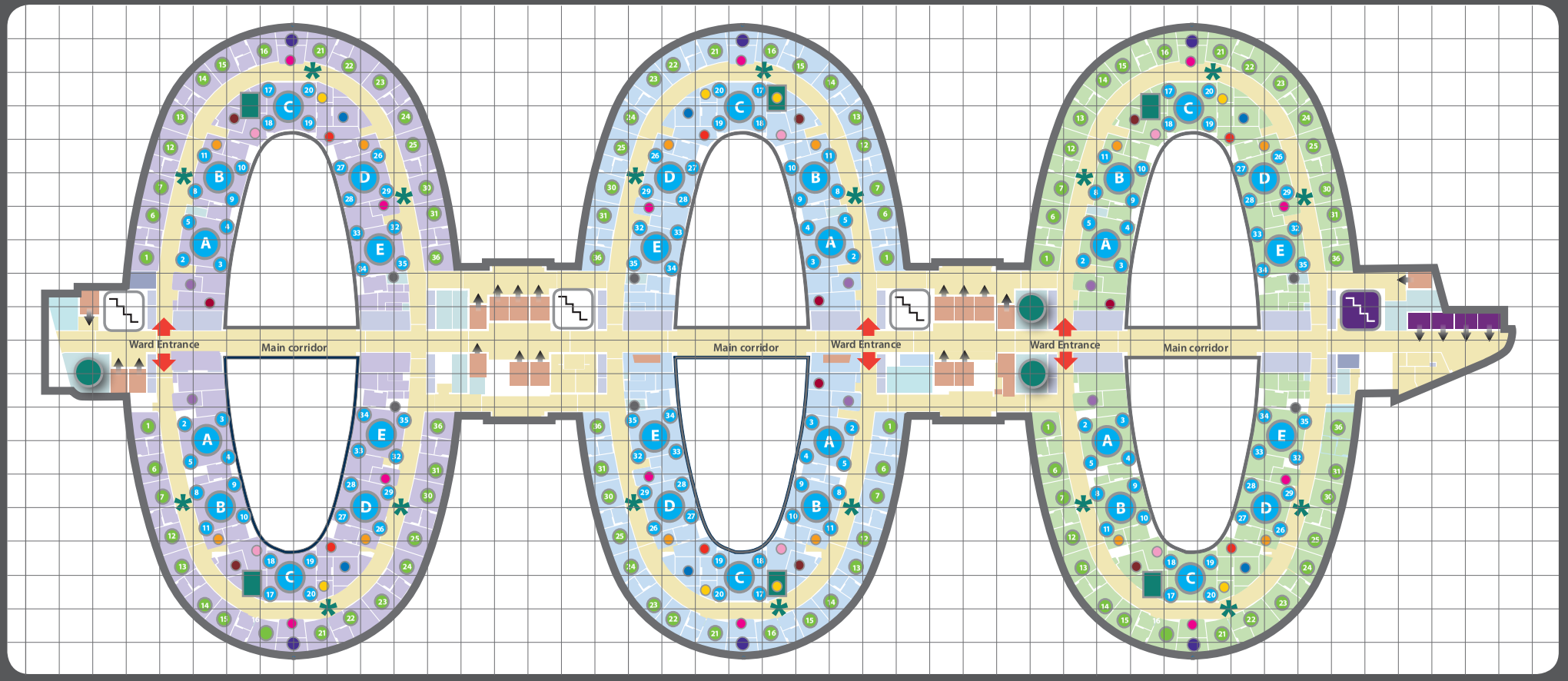
Section 17 - Appendix 1

General ward layout

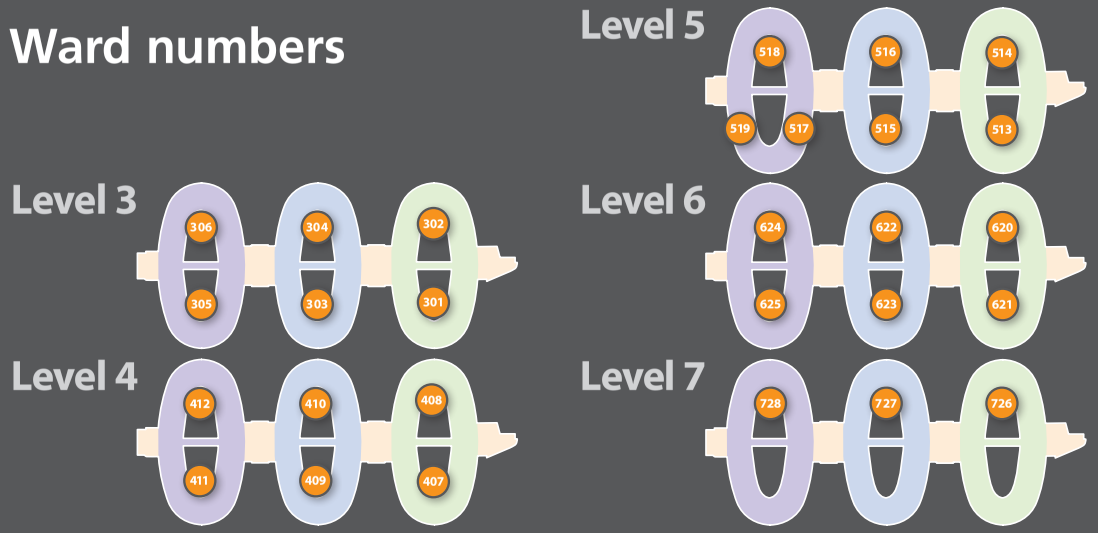
Queen Elizabeth Hospital Birmingham
Part of University Hospitals Birmingham
NHS Foundation Trust

Appendix 1.0

http://www.uhb.nhs.uk/Downloads/pdf/QehbFloorplanGeneralWard.pdf



Ward numbers



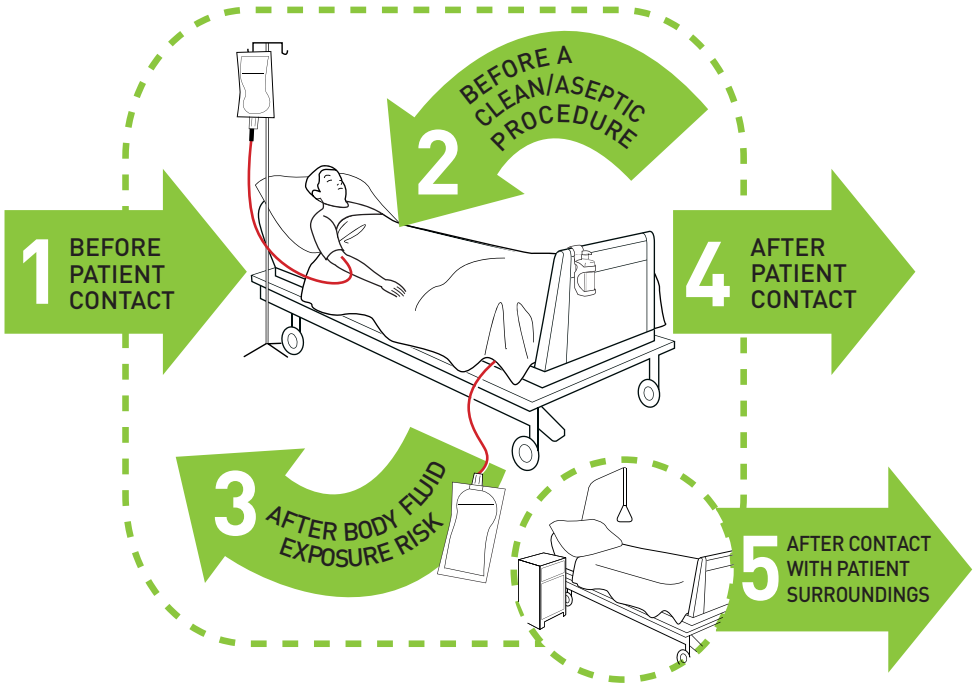
Key

- Reception
- Staff base
- 4 - Bedded rooms
- Single room
- Sitting bay
- Ward Sister's room
- Consultation room
- Used Linen
- Assisted bathroom
- Medication
- Clean utility
- Store room
- Clinical waste
- Regeneration Kitchen
- Pantry
- Service Locations
- Visitor Lifts
- Visitor Stairs
- Lifts
- Staff Stairs
- Ward Entrance

Appendix 1.1

NHS
National Patient Safety Agency

Your 5 moments for hand hygiene at the point of care



1 BEFORE PATIENT CONTACT	**WHEN?** Clean your hands before touching a patient when approaching him/her **WHY?** To protect the patient against harmful germs carried on your hands
2 BEFORE A CLEAN/ASEPTIC PROCEDURE	**WHEN?** Clean your hands immediately before any clean/aseptic procedure **WHY?** To protect the patient against harmful germs, including the patient's own, from entering his/her body
3 AFTER BODY FLUID EXPOSURE RISK	**WHEN?** Clean your hands immediately after an exposure risk to body fluids (and after glove removal) **WHY?** To protect yourself and the healthcare environment from harmful patient germs
4 AFTER PATIENT CONTACT	**WHEN?** Clean your hands after touching a patient and her/his immediate surroundings when leaving the patient's side **WHY?** To protect yourself and the healthcare environment from harmful patient germs
5 AFTER CONTACT WITH PATIENT SURROUNDINGS	**WHEN?** Clean your hands after touching any object or furniture in the patient's immediate surroundings when leaving - even if the patient has not been touched **WHY?** To protect yourself and the healthcare environment from harmful patient germs

Based on WHO poster 'Your 5 moments for hand hygiene' and reproduced with their kind permission

cleanyourhands® campaign

Appendix 1.2

How should a social hand wash be performed?

Social hand washing should take at least 30 seconds:

- Wet hands under running warm water.
- Dispense one dose of soap into cupped hands.
- Rub hands palm to palm.
- Right palm over the back of the other hand with interlaced fingers and vice versa.
- Palm to palm with fingers interlaced.
- Back of fingers to opposing palms with fingers interlocked.
- Rotational rubbing of left thumb clasped in right palm and vice versa.
- Rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa.
- Rinse hands with warm water.
- Dry thoroughly with paper towel. Cloth towels must not be used. Warm air hand dryers may be used in non-clinical areas.
- Turn off taps using a 'hands-free' technique (e.g. elbows). Where this is not possible, the paper towel used to dry the hands can be used to turn off the tap.
- Dispose of the paper towel without re-contaminating hands. Do not touch bin lid with hands.

Appendix 1.3

Virtual Reality Interaction Module

User Guide.

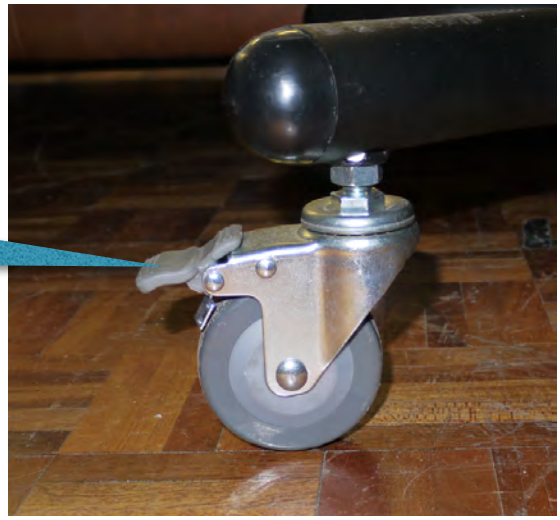
Instructions for setting up the VR-I Module prior to use

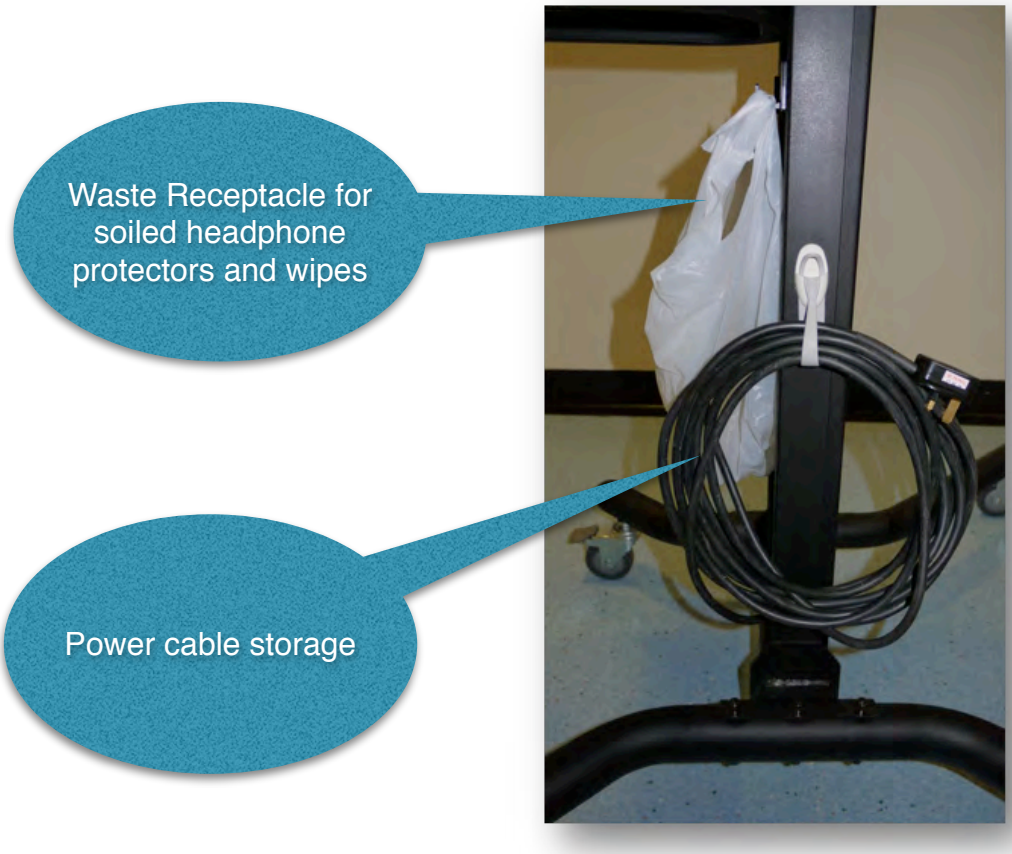
1. The two casters at the rear of the module are lockable (Figure 1) and so when correctly positioned depress the rocker switches to lock the wheel (Figure 2). Figure 3 shows the brakes disengaged.

Lockable Casters
Figure 1

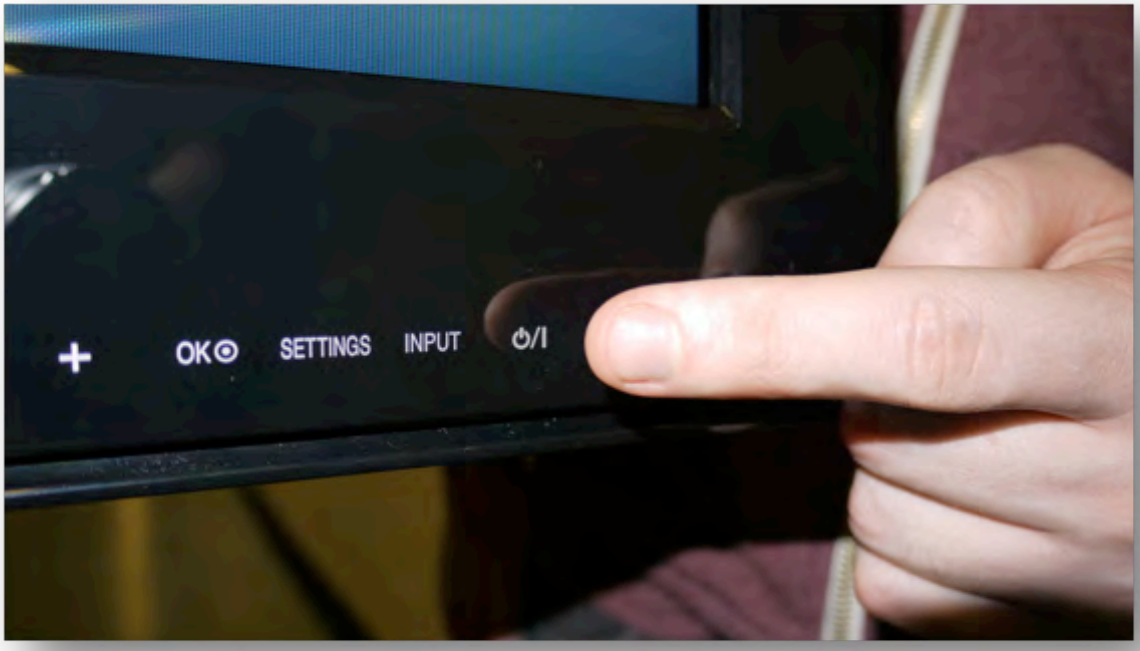
Caster in locked postion
Figure 2

Caster in unlocked postion
Figure 3



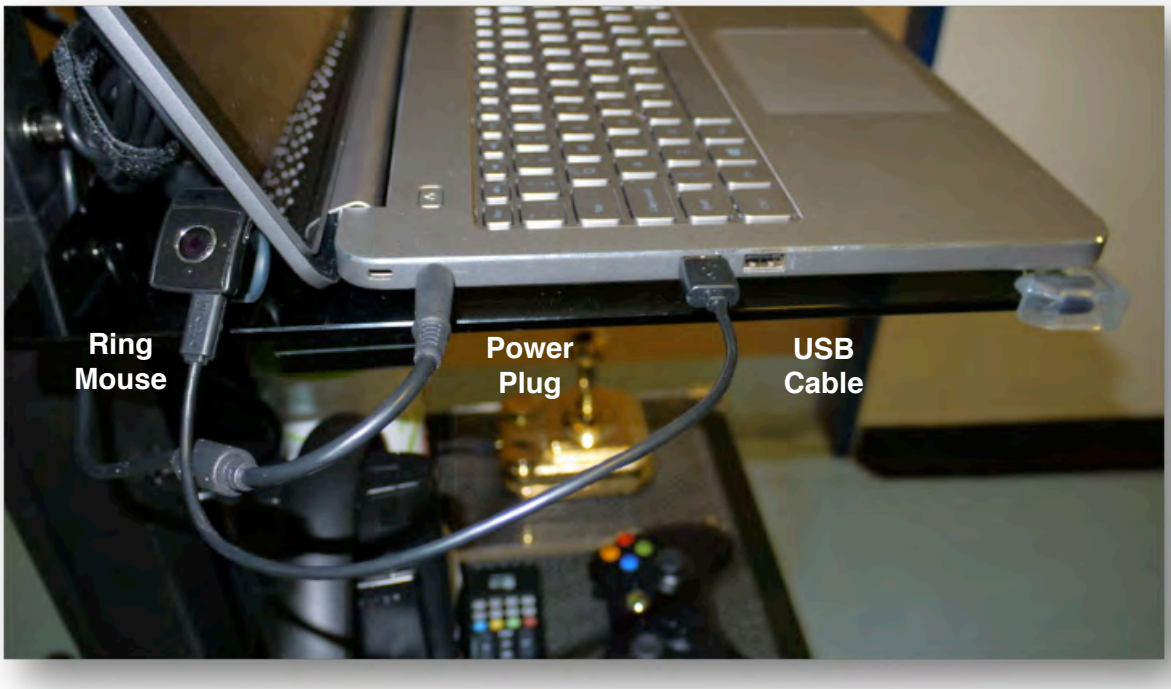


2. To power the display on / off, simply touch the symbol.



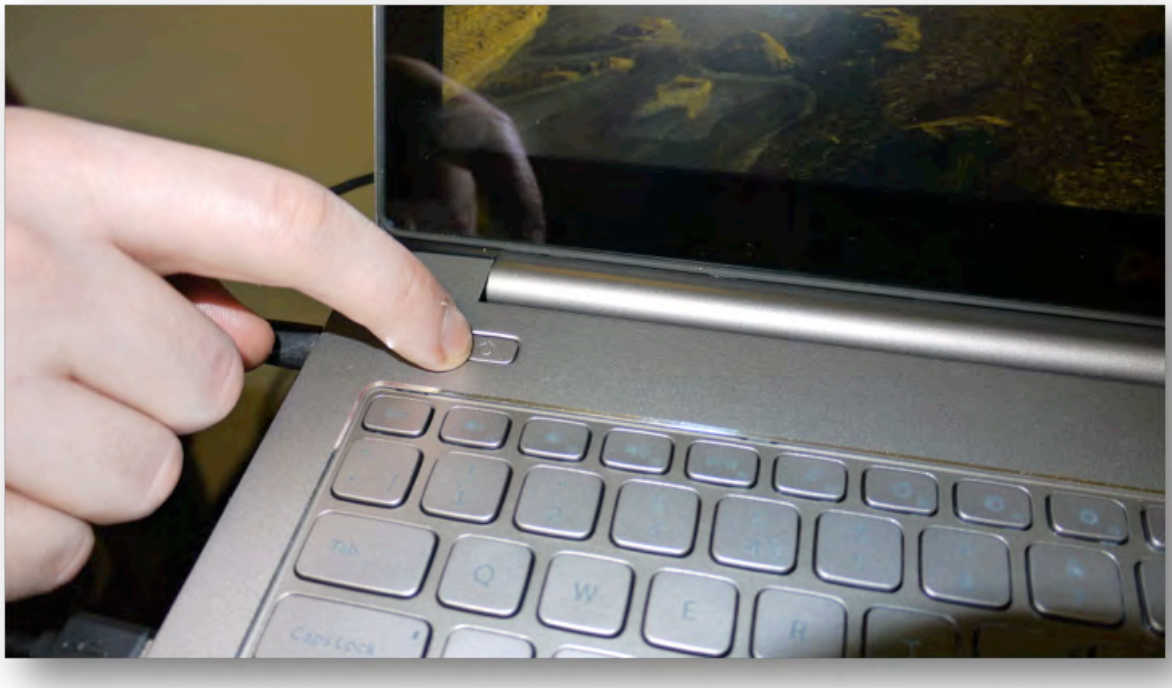
3. To connect the laptop to the VR-I Module place on the upper shelf and connect the four cables.

Lets look at the left side of the laptop (image below) there are two cables plugged in, to the left, the power plug and towards the centre a USB cable to recharge the Ring Mouse. (If you follow the cable you can see the Ring Mouse seated just behind the laptops display.

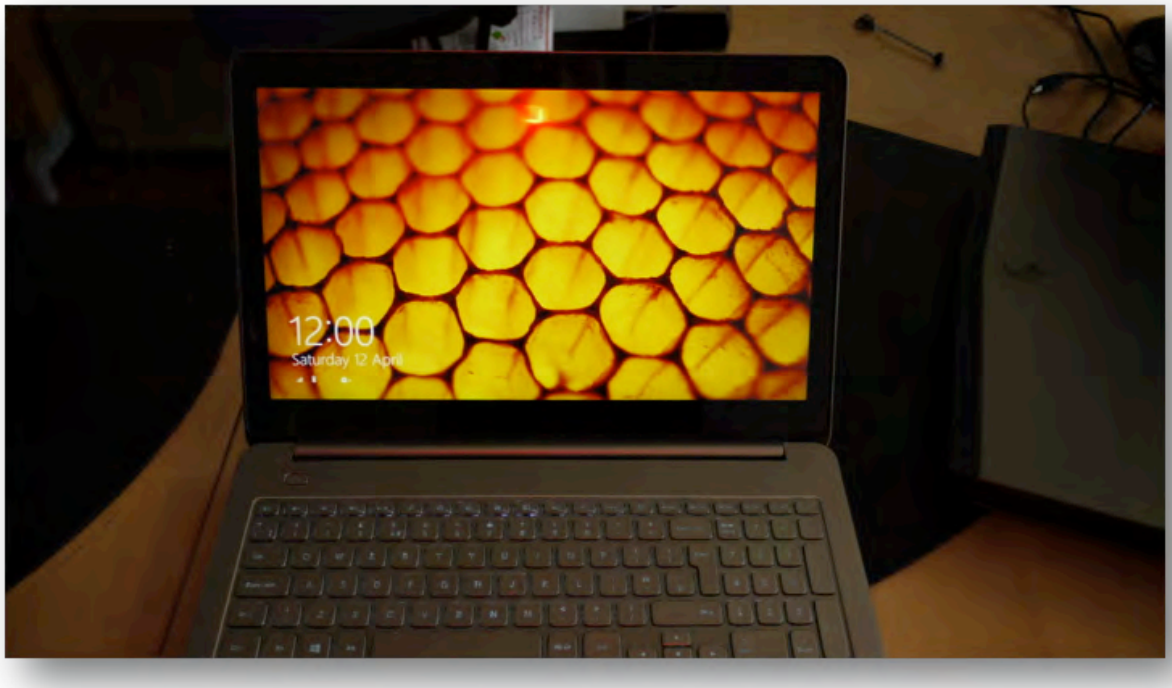


To the right of the laptop sits the HDMI cable, when connected provides an image of Virtual Wembury on the large display as well as on the laptop. The USB cable to the left leads to a USB Hub mounted behind the large display. The USB hub will provide the power to any controllers that are plugged into it.

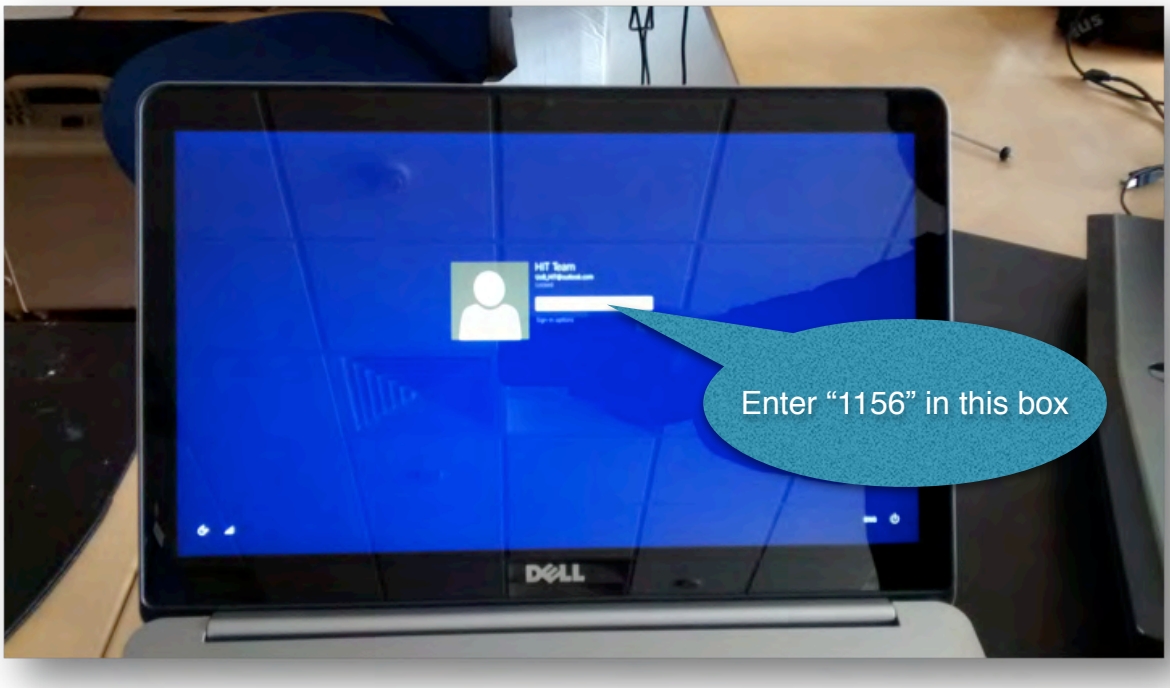
4. Power the laptop on / off



5. The laptop will boot up and load Windows 8.1. You will then be presented with a welcome screen, press any key to continue.



6. In the password box enter the numeric four digit pin “1156”



7. The following screen will be the Windows desktop. We are concerned with the icon half way down the screen and to the left called “Wembury”

8. Double click on the “Wembury” icon and you will be presented with a “Wembury Bay Configuration” window. Simply click on “Play” to start.

9. Virtual Wembury will start up and you will be able to offer a choice of controllers to the participant. These are explained on the “VR-I Module 32 User Guide - Interfaces” handout

10. Layout of the controllers, headphones and wipes.

11. Location of the wireless keyboard

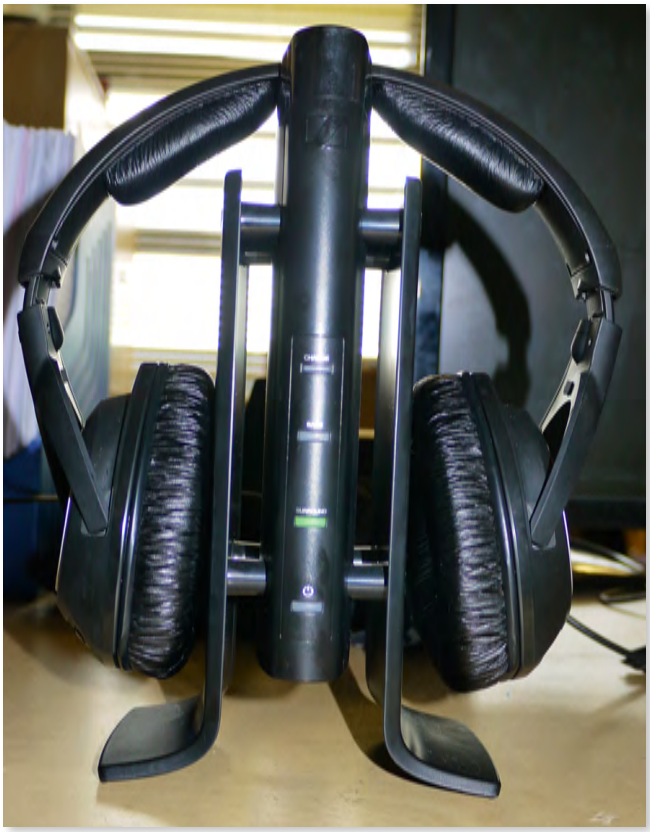
12. Location of the Motion XS thumb controller and USB Hub, notice that the dongles for both the wireless keyboard and mouse are installed as well as the ring mouse.

13. Audio

The audio is delivered through a pair of wireless headphones and the volume is controlled using the displays remote control. To use the headphone first press the power button on the docking station. The button will light up green.

Then press the power button on the headphones. A green light will flash to indicate that the power is on.

14. When the headphones are not in use please place them on the docking station to allow the batteries to recharge ready for the next participant.



14. Volume is increased or decreased using the displays remote control.

15. To shut the system down following testing, please refer to the Interface section that states, Press F9 on the keyboard to stop data capture before pressing F12 to exit Virtual Wembury. This is a crucial step as it will allow the system to store and date the path the participant travelled.

The laptop can then simply be powered off by pressing the power button (Number 2), the screen buy touching the power symbol (Number 4).

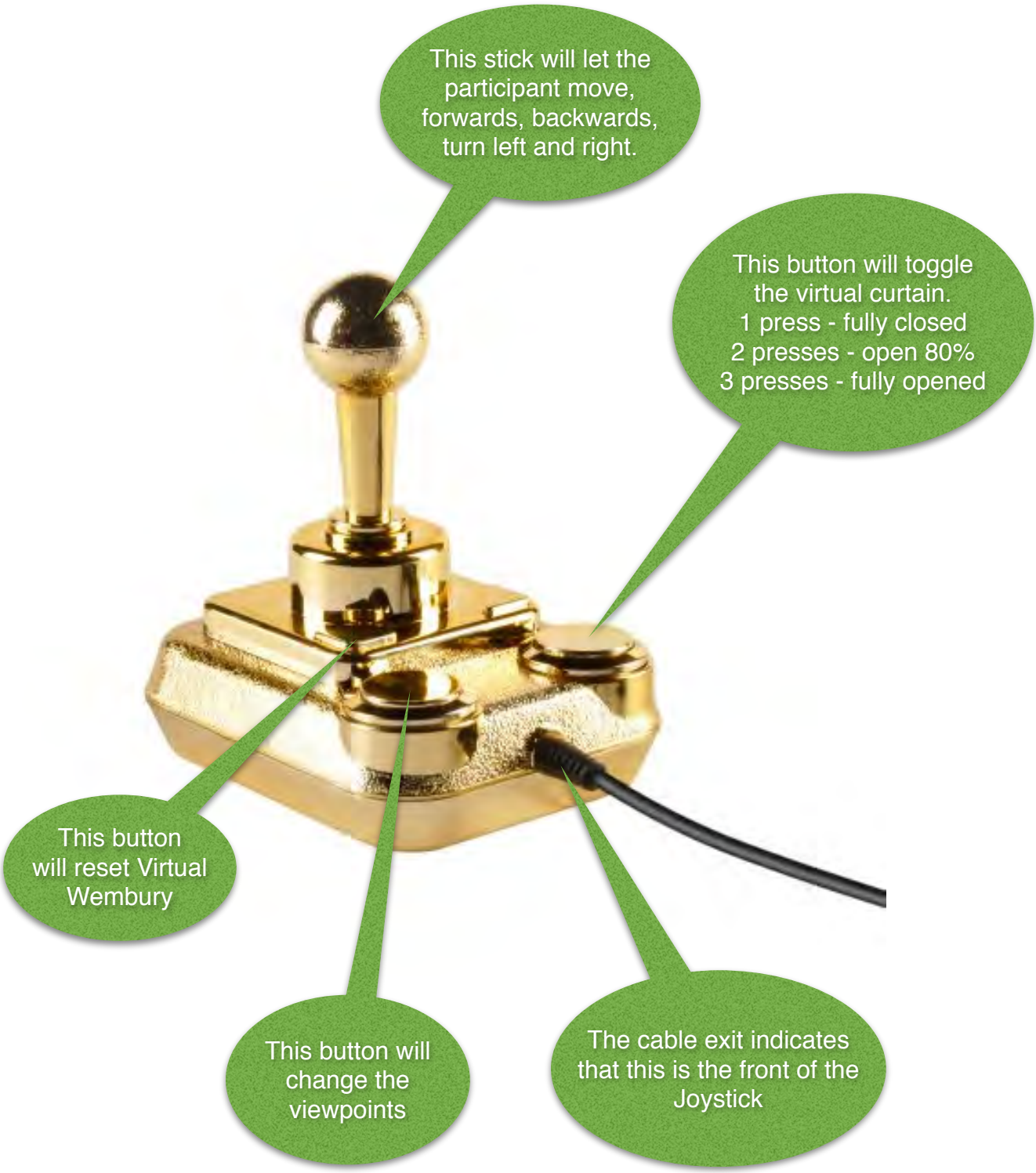
Appendix 1.4
Virtual Reality Interaction Module

User Guide

Controllers - Xbox 360

Motion XS thumb controller

Golden Joystick



Ring Mouse

The ring mouse has a usb dongle that is permanently fitted into the USB hub that lives behind the large display. The only thing that need attending to is the connection of the micro USB cable to charge the mouse.

Wireless Keyboard and Mouse

The list of key presses apply both to the wireless keyboard and mouse and the laptops keyboard and trackpad.

An important note when participant testing using any of the aforementioned interfaces, before exiting Virtual Wembury via the F12 key. Please press F9 to stop data capturing that records where the participant has travelled.

W = Walk forwards

A = Side step left

S = Side step right

D = Walk backwards

O = Toggle virtual curtain
- **1 press - closed**
- **2 presses - open 80%**
- **3 presses - open 100%**

M = Toggle view points

N = Enter / Exit cabin cruiser

F11 = Reset

F9 = Stop data capture (important to press this before exiting via F12)

F12 = Exit

Appendix 1.5

Discounted Interfaces

The following images depict the interfaces that were considered and then discounted based on the either the build quality or the difficulty levels in its usage.

Figure 1.5.1 An combination trackball / mouse

Figure 1.5.2 How the hand sat on the controller

Figure 1.5.3 A trackball with scroll wheel and trigger mouse button

Figure 1.5.4 Razer Hydra

Figure 1.5.5 An Ergonomic joystick-type hand held mouse

Figure 1.5.6 Zeemote ZS1 Thumb controller

Appendix 1.6.1 - Xbox 360

```
;--- Xpadder Profile File ---

DataType=Profile
Version=2012.01.19

[Profile Settings]

[Set Settings]

[Assignments]
Set1Button1Slots=N
Set1Button2Slots=M
Set1Button4Slots=O
Set1Button7Slots=F11
Set1DPadUpSlots=W
Set1DPadRightSlots=D
Set1DPadDownSlots=S
Set1DPadLeftSlots=A
Set1Stick1UpSlots=W
Set1Stick1RightSlots=Mouse Move Right
Set1Stick1RightMouseSpeed=46
Set1Stick1DownSlots=S
Set1Stick1LeftSlots=Mouse Move Left
Set1Stick1LeftMouseSpeed=46
Set1Stick2UpSlots=Mouse Move Up
Set1Stick2UpMouseSpeed=32
Set1Stick2RightSlots=Mouse Move Right
Set1Stick2RightMouseSpeed=32
Set1Stick2DownSlots=Mouse Move Down
Set1Stick2DownMouseSpeed=32
Set1Stick2LeftSlots=Mouse Move Left
Set1Stick2LeftMouseSpeed=32
```

Appendix 1.6.1 - Xbox 360

```
;--- Xpadder Controller File ---

DataType=Controller
Version=2012.01.19

[Button Locations]
Button1Location=16,96
Button2Location=46,96
Button3Location=76,96
Button4Location=106,96
Button5Location=136,96
Button6Location=166,96
Button7Location=196,96
Button8Location=226,96
DPadUpLocation=241,158
DPadRightLocation=273,190
DPadDownLocation=241,222
DPadLeftLocation=209,190
Stick1UpLocation=36,158
Stick1RightLocation=68,190
Stick1DownLocation=36,222
Stick1LeftLocation=4,190
Stick2UpLocation=446,158
Stick2RightLocation=478,190
Stick2DownLocation=446,222
Stick2LeftLocation=414,190

[Access]
DPadUpAccess=POV
DPadRightAccess=POV
DPadDownAccess=POV
DPadLeftAccess=POV
Stick1XAccess=Axis X
Stick1YAccess=Axis Y
Stick2XAccess=Axis RX
Stick2YAccess=Axis RY

[Names]
Button1Name=Button 1
Button2Name=Button 2
Button3Name=Button 3
Button4Name=Button 4
Button5Name=Button 5
Button6Name=Button 6
Button7Name=Button 7
Button8Name=Button 8
DPadName=DPad
DPadUpName=Up
DPadRightName=Right
DPadDownName=Down
DPadLeftName=Left
Stick1Name=Stick 1
```

Stick2Name=Stick 2
StickUpName=Up
StickRightName=Right
StickDownName=Down
StickLeftName=Left

[Image]

Appendix 1.6.2 - Joystick

;--- Xpadder Profile File ---

DataType=Profile
Version=2012.01.19

[Profile Settings]

[Set Settings]

[Assignments]
Set1Stick1UpSlots=W
Set1Stick1RightSlots=Mouse Move Right
Set1Stick1RightMouseSpeed=46
Set1Stick1DownSlots=S
Set1Stick1LeftSlots=Mouse Move Left
Set1Stick1LeftMouseSpeed=46

Appendix 1.6.3 - Motion XS

```
;--- Xpadder Controller File ---

DataType=Controller
Version=2012.01.19

[Button Locations]
Button1Location=16,96
Button2Location=46,96
DPadUpLocation=241,158
DPadRightLocation=273,190
DPadDownLocation=241,222
DPadLeftLocation=209,190

[Access]
DPadUpAccess=POV
DPadRightAccess=POV
DPadDownAccess=POV
DPadLeftAccess=POV

[Names]
Button1Name=Button 1
Button2Name=Button 2
DPadName=DPad
DPadUpName=Up
DPadRightName=Right
DPadDownName=Down
DPadLeftName=Left

[Image]
```

Appendix - 1.7

Microsoft Kinect - Technical Specifications

Sensor

Colour and depth-sensing lenses

Voice microphone array

Tilt motor for sensor adjustment

Field of View

Horizontal field of view: 57 degrees

Vertical field of view: 43 degrees

Physical tilt range: 27 degrees

Depth sensor range: 1.2m - 3.5m

Data Streams

320x240 16-bit depth @ 30 frames/sec

640x480 32-bit colour@ 30 frames/sec

16-bit audio @ 16 kHz

Skeletal Tracking System

Tracks up to 6 people, including 2 active players

Tracks 20 joints per active player

Appendix - 1.8

ASUS Xtion LIVE Pro - Technical Specifications

Field of View

Horizontal field of view: 58 degrees

Vertical field of view: 45 degrees

Depth Image Size

VGA (640x480) : 30fps

QVGA (320x240): 60fps

Resolution

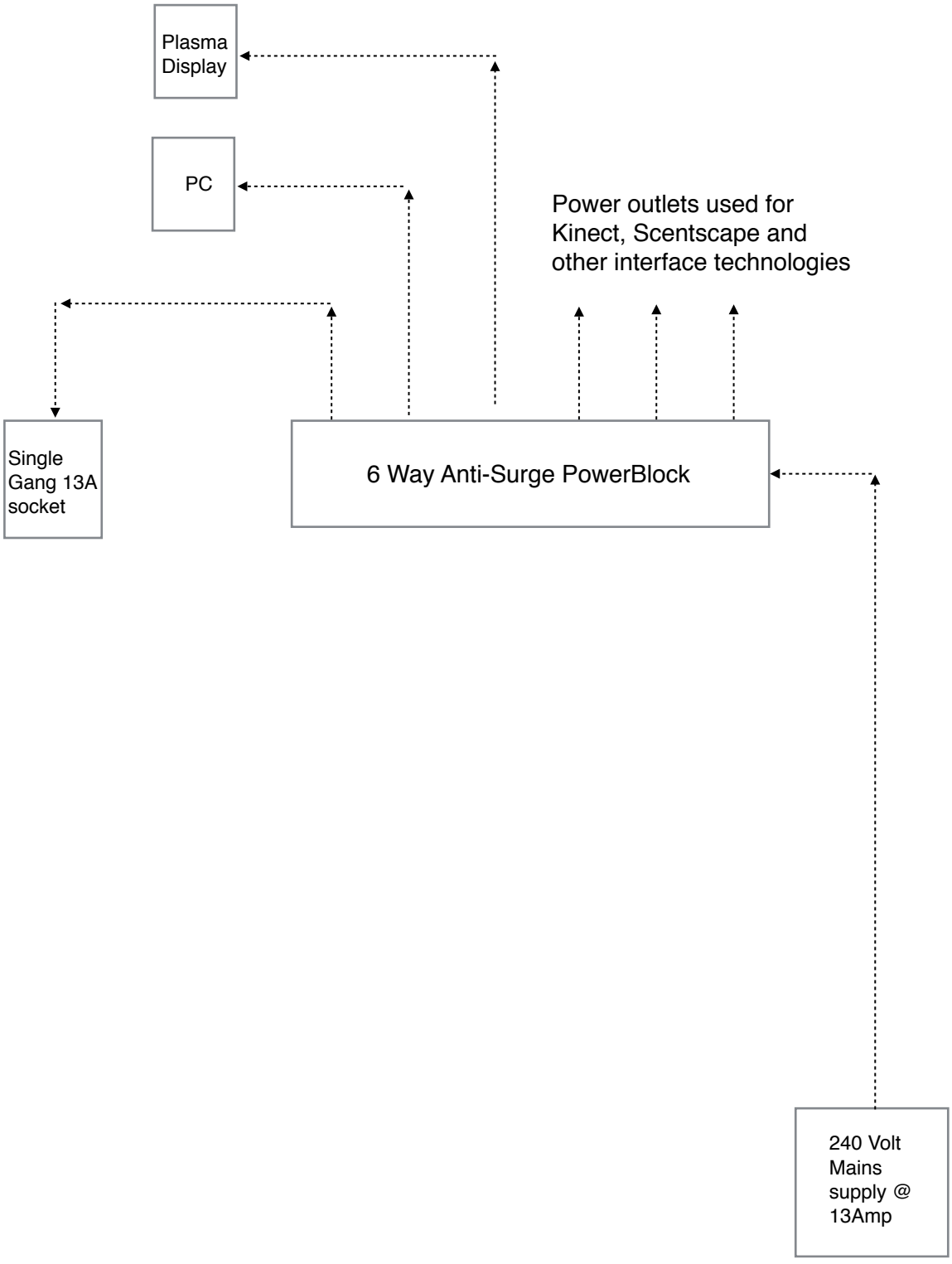
SXGA (1280*1024)

Interface

USB 2.0

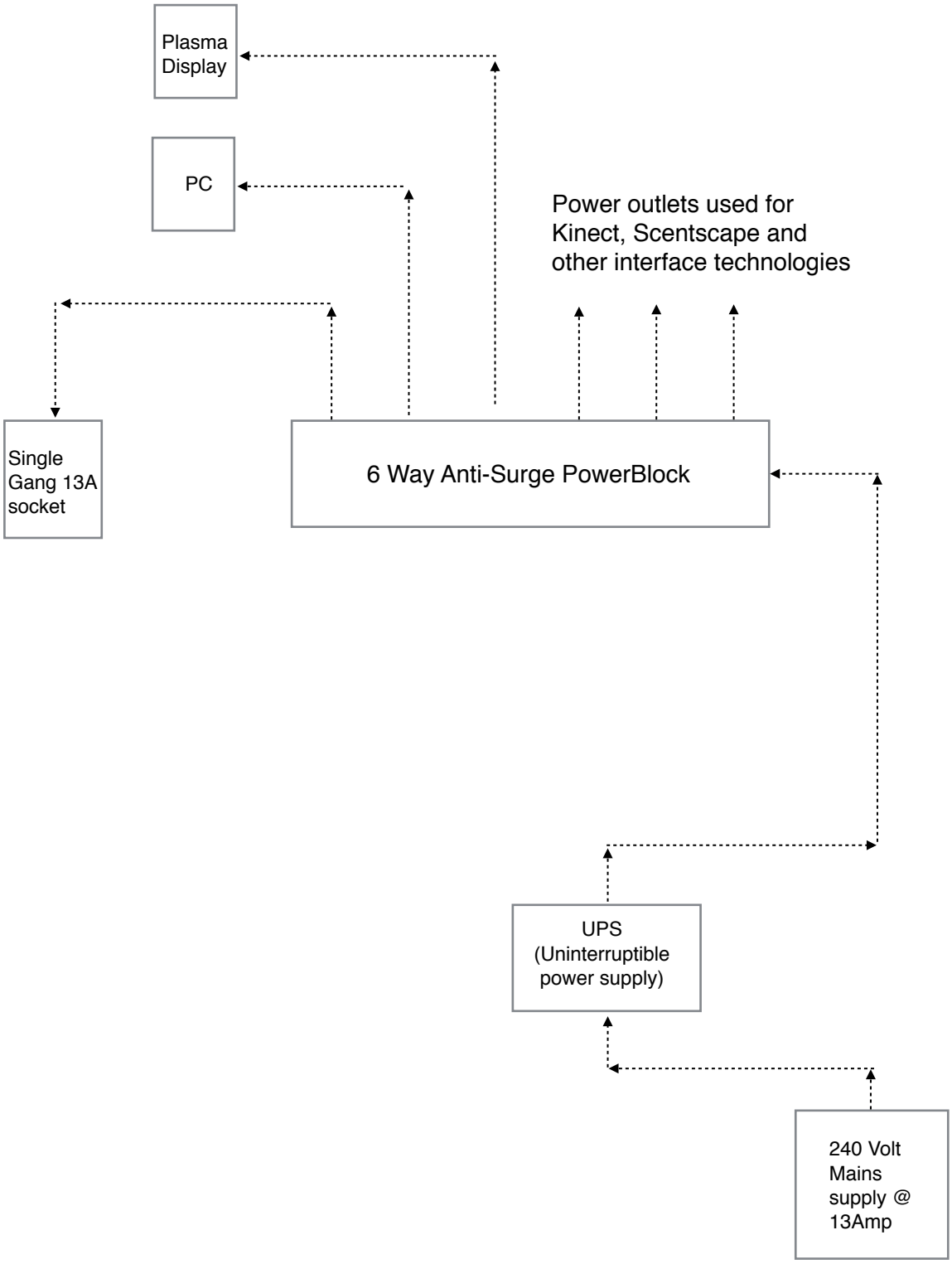
Appendix 1.9

Wiring schematic for Virtual Reality - Interaction (VR-I) Module Prototype 1



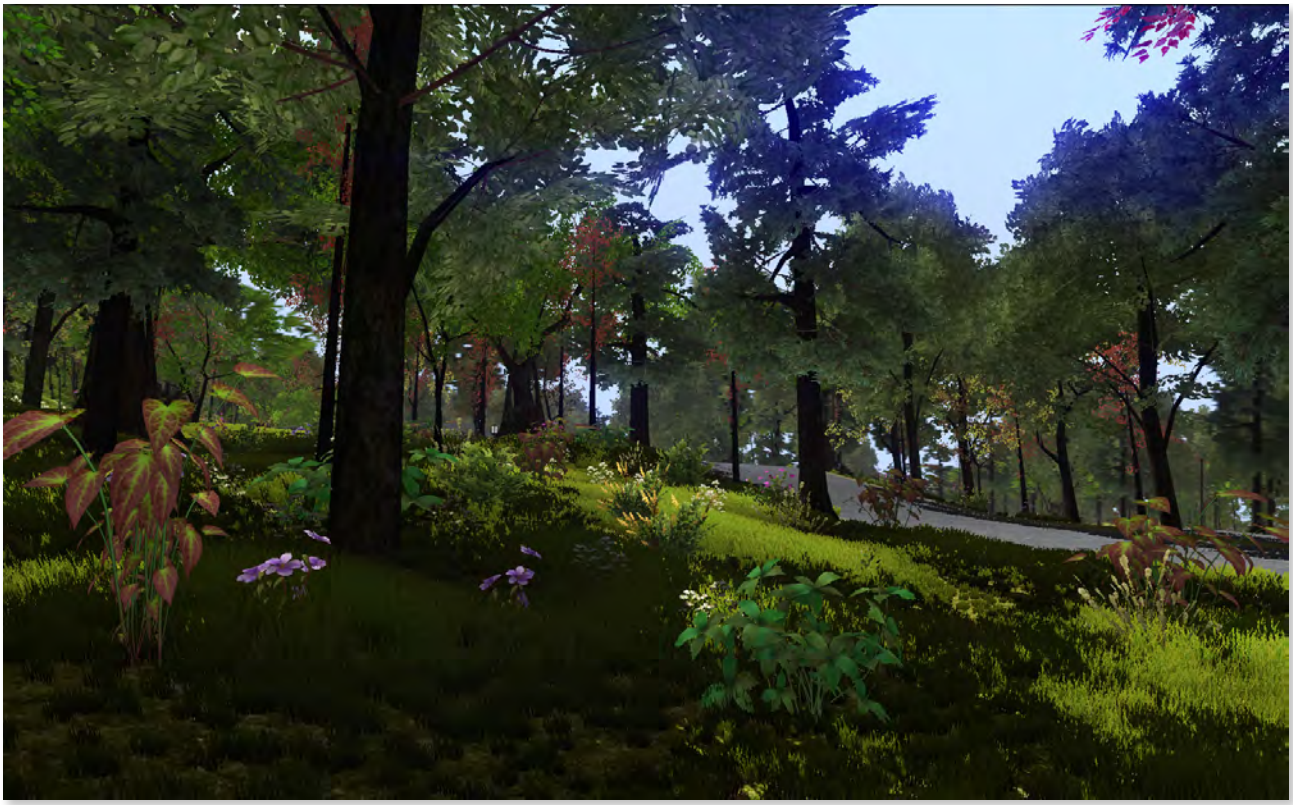
Appendix 1.9.1

Wiring schematic for Virtual Reality - Interaction (VR-I) Module Prototype 2



Appendix 1.10 - Images of the Virtual Burrator

The following series of images demonstrate the sheer scale of Virtual Burrator.



Section 18 - Appendix 2

Appendix 2.1

Participant	Condition			
	Xbox	Keyboard + Mouse	Thumb Controller	Joystick
	Keyboard + Mouse	Xbox	Joystick	Thumb Controller
	Thumb Controller	Joystick	Xbox	Keyboard + Mouse
	Joystick	Thumb Controller	Keyboard + Mouse	Xbox
	Xbox	Keyboard + Mouse	Thumb Controller	Joystick
	Keyboard + Mouse	Xbox	Joystick	Thumb Controller
	Thumb Controller	Joystick	Xbox	Keyboard + Mouse
	Joystick	Thumb Controller	Keyboard + Mouse	Xbox
	Xbox	Keyboard + Mouse	Thumb Controller	Joystick
	Keyboard + Mouse	Xbox	Joystick	Thumb Controller
	Thumb Controller	Joystick	Xbox	Keyboard + Mouse
	Joystick	Thumb Controller	Keyboard + Mouse	Xbox
	Xbox	Keyboard + Mouse	Thumb Controller	Joystick
	Keyboard + Mouse	Xbox	Joystick	Thumb Controller
	Thumb Controller	Joystick	Xbox	Keyboard + Mouse
	Joystick	Thumb Controller	Keyboard + Mouse	Xbox

Appendix 2.12

Questionnaire Reliability Analysis

Cronbach's Alpha	Internal consistency
a > 0.9	Excellent
0.8 < a < 0.9	Good
0.7 < a < 0.8	Acceptable
0.6 < a < 0.7	Questionable
0.5 < a < 0.6	Poor
a < 0.5	Unacceptable

Usability Section Reliability

Condition	N	Cronbach Alpha (N=17)
All	48	0.939
Joystick	12	0.965
Keyboard + Mouse	12	0.945
Thumb	12	0.801
Xbox	12	0.863

Display Section Reliability

Condition	N	Cronbach Alpha (N=8)	Q5 removed (N=7)	Q6 removed (N=7)	Q5 & Q6 removed (N=6)
All	48	0.644	0.751	0.713	0.769
Joystick	12	0.467	0.665	0.663	0.783
Keyboard + Mouse	12	0.628	0.869	0.521	0.828
Thumb	12	0.803	0.765	0.834	0.787
Xbox	12	0.622	0.71	0.732	0.789

Appendix 2.13

SPSS usability study output

```
GLM Joystic Key Thumb Xbox
  /WSFACTOR=interface 4 Polynomial
  /METHOD=SSTYPE(3)
  /EMMEANS=TABLES(interface) COMPARE ADJ(LSD)
  /PRINT=DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=interface.
```

General Linear Model

Notes

Output Created		16-APR-2014 14:27:56
Comments		
Input	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	12
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax		GLM Joystic Key Thumb Xbox /WSFACTOR=interface 4 Polynomial /METHOD=SSTYPE(3) /EMMEANS=TABLES(interface) COMPARE ADJ(LSD) /PRINT=DESCRIPTIVE /CRITERIA=ALPHA(.05) /WSDESIGN=interface.
Resources	Processor Time	00:00:00.00
	Elapsed Time	00:00:00.03

[DataSet0]

Within-Subjects Factors

Measure: MEASURE_1

interface	Dependent Variable
1	Joystic
2	Key
3	Thumb
4	Xbox

Descriptive Statistics

	Mean	Std. Deviation	N
Joystic	4.5683	1.37838	12
Key	4.3717	1.44483	12
Thumb	4.5158	.74069	12
Xbox	5.9308	.90508	12

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
interface	Pillai's Trace	.608	4.657[b]	3.000	9.000	.031
	Wilks' Lambda	.392	4.657[b]	3.000	9.000	.031
	Hotelling's Trace	1.552	4.657[b]	3.000	9.000	.031
	Roy's Largest Root	1.552	4.657[b]	3.000	9.000	.031

a. Design: Intercept
Within Subjects Design: interface

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser
interface	.453	7.688	5	.176	.724

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Epsilon[b] Huynh-Feldt	Lower-bound
interface	.908	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: interface

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
interface	Sphericity Assumed	19.056	3	6.352	4.180
	Greenhouse-Geisser	19.056	2.171	8.775	4.180
	Huynh-Feldt	19.056	2.725	6.993	4.180
	Lower-bound	19.056	1.000	19.056	4.180
Error(interface)	Sphericity Assumed	50.152	33	1.520	
	Greenhouse-Geisser	50.152	23.886	2.100	
	Huynh-Feldt	50.152	29.975	1.673	
	Lower-bound	50.152	11.000	4.559	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.
interface	Sphericity Assumed	.013
	Greenhouse-Geisser	.025
	Huynh-Feldt	.016
	Lower-bound	.066
Error(interface)	Sphericity Assumed	
	Greenhouse-Geisser	
	Huynh-Feldt	
	Lower-bound	

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	interface	Type III Sum of Squares	df	Mean Square	F	Sig.
interface	Linear	10.744	1	10.744	7.037	.022
	Quadratic	7.792	1	7.792	4.460	.058
	Cubic	.519	1	.519	.404	.538
Error(interface)	Linear	16.796	11	1.527		
	Quadratic	19.221	11	1.747		
	Cubic	14.135	11	1.285		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1127.529	1	1127.529	1416.499	.000
Error	8.756	11	.796		

Estimated Marginal Means

interface

Estimates

Measure: MEASURE_1

interface	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	4.568	.398	3.693	5.444
2	4.372	.417	3.454	5.290
3	4.516	.214	4.045	4.986
4	5.931	.261	5.356	6.506

Pairwise Comparisons

Measure: MEASURE_1

(I) interface	(J) interface	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	.197	.618	.756	-1.164	1.557
	3	.053	.377	.892	-.777	.882
	4	-1.363*	.491	.018	-2.444	-.281
2	1	-.197	.618	.756	-1.557	1.164
	3	-.144	.477	.768	-1.194	.905
	4	-1.559*	.639	.033	-2.965	-.153
3	1	-.053	.377	.892	-.882	.777
	2	.144	.477	.768	-.905	1.194
	4	-1.415*	.345	.002	-2.174	-.656
4	1	1.363*	.491	.018	.281	2.444
	2	1.559*	.639	.033	.153	2.965
	3	1.415*	.345	.002	.656	2.174

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.608	4.657[a]	3.000	9.000	.031
Wilks' lambda	.392	4.657[a]	3.000	9.000	.031
Hotelling's trace	1.552	4.657[a]	3.000	9.000	.031
Roy's largest root	1.552	4.657[a]	3.000	9.000	.031

Each F tests the multivariate effect of interface. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

Participant: Condition: Date:

Appendix 2.3 (BORG CR-10) Rating of Strain or Discomfort Using the Controller

0	Nothing at all
0.5	Very, very weak (just noticeable)
1	Very weak
2	Fairly weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very strong
8	
9	
10	Very, very strong (almost max)
•	Maximal

Using the scale above, please rate the intensity of any sensations of strain or discomfort you felt when interacting with the controller.

Fingers	
Hand	
Wrist	
Forearm	
Upper arm	
Shoulder	
Neck	
Other	

Comments:

Participant: Condition: Date:

Appendix 2.4.1

Controller

How often have you used, or do you use, this type of controller?

Never	
Little experience / Rarely	
Occasionally / Sometimes	
Often	
Frequently / Always	

Please rate your level of agreement to the following statements:

	Strongly disagree	Moderately disagree	Slightly disagree	Undecided	Slightly agree	Moderately agree	Strongly agree
I found the controller easy to use							
I would have preferred an alternative controller							
The response to my input was acceptable							
The controller was ideal for interacting with the virtual environment							
I kept making mistakes using the controller							
I had the right level of control over what I wanted to do							
The controller was too complicated to use effectively							
I found it easy to move or reposition myself in the virtual environment							
The controller gave me a feeling of smooth motion							
The controller behaved in a manner that I expected							
The controller was comfortable to use							
It was easy to grip/hold the controller							
The controls on the controller were easy to reach							
The controls on the controller were easy to actuate (i.e. press, move)							
Using the controller was awkward							
The move forward/back control was easy to use							
The turn left/right control was easy to use							

Participant: Condition: Date:

	Too low -3	-2	-1	OK 0	1	2	Too high 3
The force required for pressing buttons or manipulating the controls was:							
The sensitivity of the controller was:							

	Low 1	2	3	4	5	6	High 7
Overall ease of use of the controller was:							
My overall satisfaction with the controller was:							

Please add any comments you have about the usability of the controller:

Participant: Condition: Date:

Appendix 2.4.2

Display

	Strongly disagree	Moderately disagree	Slightly disagree	Undecided	Slightly agree	Moderately agree	Strongly agree
I found the display appropriate for the task							
The amount of lag (delay) in the image affected my performance							
The display resolution was adequate							
I was aware of distortion in the image							
The quality of the image affected my performance							
There were no glitches in the display							
Objects in the virtual environment were realistic							
I had difficulty getting used to the display							

	Too small -3	-2	-1	OK 0	1	2	Too big 3
The display size was:							
The image field of view was:							

	Too close -3	-2	-1	OK 0	1	2	Too far 3
The position of the display was:							

	Too low -3	-2	-1	OK 0	1	2	Too high 3
The position of the display was:							

	Low 1	2	3	4	5	6	High 7
Overall satisfaction with the display was:							

Please add any comments you have about the display:

Participant: Condition: Date:

Appendix 2.6 **Workload**

Mental demand

How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching etc)? Was the task easy or demanding, simple of complex, exacting or forgiving?

Physical demand

How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, stressful or laborious?

Temporal demand

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance

How successful do you think you were in accomplishing the goals set out by the experimenter. How satisfied were you with your performance in accomplishing these goals?

Effort

How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration

How insecure, discouraged, irritated, stressed and annoyed verses secure, gratified, content, relaxed and complacent did you feel during the task.