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High Definition 3D Telemedicine: The Next Frontier?

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Abstract. Evidence from the literature indicates that the degree of immersion often referred to as the “sense of being there” experienced by clinicians and patients is a factor in the success of tele-health installations. High definition and 3D telemedicine offers a compelling mechanism to achieve a sense of immersion and contribute to an enhanced quality of use. This article surveys HD3D trials in tele-health and concludes that the way HD3D is integrated into telemedicine depends on the clinical, organisational and technological context. In some settings real time HD3D is not so desirable whereas asynchronous transmission of HD3D images and videos is highly desirable.

Keywords. HD3D, telehealth

Introduction

Currently telemedicine installations based on 2D video conferencing are becoming increasingly prevalent, particularly in localities where fast, high bandwidth networks are available in addition to business models that entice health care professionals, organisations and patients to adopt the new technology [1]. While this trend can be expected to lead to an increasingly wide range of clinical installations, an open question exists regarding the benefits and need for 3D and high definition telemedicine installations. High definition images are generally regarded as those that involve at least 1280*720 pixels (720p) per frame resulting in a fine-grained image and high-quality viewing experience. The 3D effect involves the rapid presentation of slightly different images to both eyes to generate the impression of depth and realism.

Although the use of HD3D is in its infancy, insights from emerging installations suggest that HD and 3D telemedicine applications have a place in telemedicine installations. Investigations suggest that ‘immersiveness’ experienced by clinicians and patients in addition to the extent to which health records can be integrated into a tele-health consultation are important determinants of successful tele-health installations [2]. Similar sentiments are expressed by Broens et al., (2007) [3] following a review of the literature.

The main claim advanced in this article is that the way HD3D is integrated into telemedicine depends on the clinical, organisational and technological context. HD3D

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requires more bandwidth and faster networks than 2D conferencing so real-time consultations are not plausible over some networks. However, as discussed below, in some settings such as wound management, work flow issues preclude real time HD3D from being desirable but the facility to view an image in high definition and 3D asynchronously enhances the consultation for wound specialists.

Some time ago, Jennett et al., (1998) [4] identified that tele-health impacts at three levels: the health system level, the program level and the patient encounter level. As Le Rouge et al., (2007) [5] conclude, this multi-level impact makes it difficult to predict successes and failures in tele-health and results in a paucity of frameworks for doing so. These authors advance the concept of *Use Quality* to reflect the effectiveness of the actual technological use in its full organizational, clinical and social context. *Use Quality* encompasses technology, medical procedures, decision-making and human interactions in a holistic, integrated view of the system. What is desired is not more use of a tele-health technology but an enhancement of the quality of experiences and outcomes when a technology is used. This perspective enabled them to explore critical success factors for *Use Quality* from subjects who had experiences with a range of tele-health installations as patients, providers and clinicians. The three categories of *Use Quality* factors found were:

- **Technological Aptitude** i.e. how easily the technologies could be used. This involved training, and useability
- **Orchestration** of the tele-health involving a mix of in-person and tele-health consultations, the coordination of the medical team around the patient
- **Communication Skills**. This includes three components. Telepresence— the sense of being there in the same room, access to health records—that the clinician in a tele-health encounter actually accesses the patient's health record and the professionalism exhibited by the nurse accompanying the patient.

Telepresence was a single but important factor identified by Le Rouge et al., (2007) [5]. However, experience from virtual reality studies illustrates that this factor can be primal, perhaps a prerequisite for use quality. Many virtual reality environments aim to induce a sense of presence within the participant. A sense of presence has been defined as the subjective impression of being there in the virtual environment or as the illusion of being unaware of the medium used to create the immersion [6]. Evidence from human computer interaction studies demonstrate that the realism of 3D environments leads to cognitive immersion and a sense of ‘being there’ [7]. Applications of virtual reality immersive environments to health and well-being exemplified by Kurillo et al., (2011) [8] reinforce the view that the engagement inherent in these environments leads to compelling outcomes.

In this article, HD3D technology as it applies to tele-health is described with a survey of emerging applications. Though few studies have yet demonstrated the benefit of HD3D, indications are that the heightened telepresence enhances *Use Quality*. However, the introduction of HD3D video conferencing to replace 2D video conferencing in all situations is not, in itself, likely to lead to *Use Quality*. Rather, the specific context of each use must be explored in order to determine the best way to integrate HD3D with other tele-health facilities given organizational constraints, clinician and patient preferences, workflow demands and technical limitations. These points are made with insights from a HD3D trial involving Tele-dentistry, Tele-wound management, Tele-psychiatry and Tele-oncology currently being implemented in Victoria, Australia.

A brief overview of HD3D technologies is presented in the next section. Following that, the HD3D trials in Victoria and other related trials are surveyed in the next section before concluding remarks.

1. Overview of HD3D technology

Real and simulated 3D visual experience in humans (and other animals) exploits biologically evolved mechanisms of monocular and binocular visual processing conducted in stages along the visual pathway within the brain [9]. The retinal image is a projection of the 3D world onto a 2D surface, the information on the third dimension, i.e. depth, is lost at the very first stage of vision. The perception of depth, or stereopsis, however, can be attained by combining information from two eyes. Stereopsis refers to our ability to appreciate depth, that is, the ability to distinguish the relative distance of objects with an apparent physical displacement between the objects. It is possible to appreciate the relative location of objects using one eye (monocular cues). Several strong monocular cues allow relative distance and depth to be judged. These monocular cues include relative size, interposition, linear perspective, light and shade and monocular movement parallax.

Stereoscopic brain processing is due to the separation between the retinal images of objects (retinal disparity) which is different in the left and right eyes, depending on the separation of the objects in depth. Binocular stereo resolution is extremely fine; a difference in depth of one millimetre can be perceived at a distance of one metre. Hence with binocular stereo vision, there is the ability to perceive an object as solid in three spatial dimensions—width, height and depth, or x, y and z. Thus, we can see where objects are in relation to our own bodies with much greater precision—especially when those objects are moving toward or away from us in the depth dimension, as well as perceive and measure ‘empty’ space. Clinical occupations, such as a surgeon or a dentist, rely on binocular stereo vision to assess, diagnose and treat.

2. Overview of HD3D Telemedicine Applications

The infrastructure that is now being built in Australia, such as that arising through the implementation of the national broadband network (NBN) offers a range of features such as ubiquitousness, affordability, low latency, high speed and high capacity. It will potentially link millions of devices, as well as people, that will enable a more efficient and effective management of our environment, healthcare infrastructures and our society as a whole. In 2010, a worldwide total of over 5 billion mobile connections from portable devices such as handheld computers and cell phones existed [10].

Recent history has shown that innovative application development is preceded by increases in bandwidth. Subsequently mobile devices are rapidly becoming an important platform for health care because they offer a number of benefits including low costs and widespread usage and additionally mobile devices can provide quick access to expert care even in remote or rural locations. These advantages have led to the development of health care applications for patients and providers using mobile devices as a platform. In this context, the health applications that require next generation access broadband remain forward-looking, but many are beginning to be offered today, such as HD3D television and related capabilities.

Some identified tele-health services enabled by next generation applications that could provide incremental benefits over current-generation broadband are increasingly within the scope of realization, such as:

- HD3D simulation and training of surgeons, clinicians, nurses and other healthcare professionals
- HD3D video consultation and/or diagnostic-focused interaction between patient and doctors
- HD3D video monitoring & vital sign tracking of remote patients.

Aspects of delivery of these services are coalescing under a recent Victorian State funded initiative entitled: Broadband 3D Tele-health applications for the empowerment of patients in health care facilities and the home [http://www.mmv.vic.gov.au/BEIPRound1]. This project represents a collaboration comprising proof-of-concept trials with over eight sites and over 12 health organisations within Victoria. Partners include the University of Ballarat (lead), University of Melbourne Psychiatry, University of Melbourne School of Dentistry, Ballarat Health Services, Northern Hospital (Epping), the Institute for a Broadband-Enabled Society (IBES), Grampians Rural Health Alliance (GRHA) and the Victorian eResearch Strategic Initiative (VeRSI).

The rationale for this project is to advance the use of ICT tools in clinical settings to increase the provision of specialist medical and allied health services to Victorians living in outer metropolitan, regional and rural areas, and elderly patients in an aged care setting. One of the primary objectives is to accurately simulate a face-to-face clinical-patient consultation over a broadband network, i.e. the NBN. This consultation would include incorporating as many diagnostic resources as the clinician would usually have access to in a face-to-face consultation.

Several applications, designed and integrated with new clinical processes, are being developed as part of the proof-of-concept project. The contexts of health care selected are:

- tele-dentistry and tele-geriatrics for patients in residential care
- tele-oncology
- tele-wound management
- tele-psychiatry.

The use of high quality HD3D technology in these healthcare scenarios can potentially allow for a very immediate and realistic experience for specialist, clinical and nursing staff, for many different assessments and treatments. HD and 3D technologies in combination may also improve the specialist's ability to observe patient health and function, stress, wounds, oral pathologies and adverse reactions resulting from chemotherapy treatment in order to diagnose and recommend patient treatment based on more accurate observations to improve health outcomes.

Evidence of these improvements and other benefits provided by the application of 3D and HD3D in tele-health systems is being gathered over the duration of the two year project. There is already known precedence in the application of 3D and HD3D tele-health technologies, across clinical training scenarios; Tele-surgery, and Tele-wound, among others, which are informing the Victoria pilot as it evolves.

2.1. Tele-surgery

A 1998 study focusing on 3D video-endoscopic systems to enhance depth perception during minimum-access surgery was undertaken by the University of Dundee [11]. The findings suggested that with the technology at the time, 3D systems based on sequential imaging showed no advantage over 2D systems in the conduct of laparoscopic cholecystectomy. A decade later and there is evidence of several pioneering hospitals undertaking 3D laparoscopic procedures in Europe and the USA, with a growing breadth of such operations in the UK [12]. The Royal Surrey County Hospital in Guildford (UK), for example, began using 3D endoscopic cameras to give surgeons performing keyhole surgery a better sense of depth when moving their instruments around inside a patient. A procedure was presented at the 3D Laparoscopic Surgery Symposium held in December 2010. The new system surveys the abdominal cavity using a camera that sends back two live video feeds from different angles. The two signals are polarised in opposite directions and the resulting image is then displayed as alternating rows of pixels on a high definition television screen. By wearing polarised glasses to view the screen, surgeons are given an impression of depth, as well as height and width. This can allow for more accurate cutting and stitching. The Royal Surrey have since undertaken hernia repairs, coloresections, hysterectomies, thoracic operations, urological and prostate operations, all in 3D. Because stereoscopic laparoscopy surgery is fairly new, however, there remain unanswered questions about its use and application.

The Minimal Access Therapy Training Unit (MATTU) of Surrey University's Postgraduate Medical School is leading on studies looking at novice surgeons using 3D versus 2D techniques, and the place of 3D for trainees for surgical skills as it may reduce errors and time taken [13]. One of the questions arising is that of visual negative effects that were identified early in the 1998 study by Hanna et al., [11] and whether, for instance, the stereopsis (each eye being presented with a separate image) can cause eye fatigue or visual inattention.

Other examples of hospitals that are adopting HD3D technologies include Barcelona’s Hospital Clinic that is trialling HD 3D technology for laparoscopic surgical interventions [http://www.catalannewsagency.com/news/society-science/catalan-hospital-first-one-world-practicing-surgery-assisted-hd-3d-technology] and surgeons at the Manchester Royal Infirmary (MRI) who have used 3D technology to assist in a laparoscopic radical prostatectomy. Dan Burke, the Consultant Urologist at MRI is quoted:

> *‘We are already excited at the potential this technology has, not just for us but for our many colleagues in the Trust in performing keyhole surgery. The equipment can be moved easily between theatres so any specialty could benefit. Ultimately we are aiming for a better patient outcome at a cost that will benefit the NHS.’* [2]

The direct application of 3D technology in surgical training and simulation has been achieved through various other initiatives outside of Australia. Surgeons are able to

[2] http://www.cmft.nhs.uk/media-centre/latest-news/surgeons-at-manchester-royal-infirmary-first-in-the-country-to-use-first-standalone-3d-system-for-prostate-cancer-surgery.aspx

practise keyhole surgery to remove tumours on a 'virtual 3D liver' before doing it in real patients as part of the pan-European EUREKA Odysseus project [http://www.eurekanetwork.org/], which aims to reduce risks to patients and also enable surgeons to take expert advice before doing operations. Critically the project has developed software for 3D-imaging of the blood vessels of a patient's liver which has materially advanced medical understanding of how the liver is segmented. Medical imaging of organs and tissues has contributed greatly to diagnosis and therapy planning, especially in the treatment of cancers. However, the 2D scanning images possible until now have been difficult to interpret and it has not been possible to consult remote clinicians. The Odysseus initiative and supporting PASSPORT [http://www.passport-liver.eu] project have specifically developed systems to construct 3D images of individual patients' livers, with their tumours or other pathologies, from MRI or CT-scans. The reconstructions can be transmitted to external experts in any location, for consultation in real-time prior to surgery. Simulation of laparoscopic and robotic surgery, with tissue resistance, has been further developed to practise the exact surgery proposed for an individual patient, or for training several surgeons simultaneously.

The thrust of the claims made here is that HD3D telemedicine can make a contribution to tele-health when installations are carefully designed, taking full account of the whole of context use quality. This is described with reference to HD3D in tele-wound management, tele-oncology and tele-psychiatry.

2.2. Tele-wound

Chronic wound infections are responsible for considerable morbidity and significantly contribute to the escalation in the cost of health care [14]. The effective management of chronic wounds involves making assessments of the nature and severity of a wound in order to determine optimal treatment regimes. This is challenging and involves specialist wound care expertise particularly as new treatments emerge frequently and evidence bases change often.

In Victoria, many patients with wounds are treated in the home by visiting general nurses who often need a wound specialist to review the wound. The cost and feasibility of transporting the patient is often prohibitive so a wound specialist typically makes a home visit. This is organizationally inefficient and can result in long waiting times that lead to sub-optimal care. In regional and rural areas in Western Victoria, visiting nurses send a photograph of the wound to a wound specialist to review at his or her first available opportunity. Workload demands on visiting nurses and wound specialists in most settings in Victoria are so high that a real time video consultation between a nurse in the home and a wound specialist to discuss the sent image is too difficult to schedule without large delays. Rather, the specialist uses the image to determine whether a home visit by a specialist is needed and if so, how urgently it is needed. The image resolution and realism is therefore very important.

Specialised 3D wound cameras have recently been developed (Eykona. www.3dwoundimaging.com). Clinical assessments performed remotely were compared with those made live on the same patients and concluded that assessments were similar [15]. The specialized camera and software uses sophisticated image processing to reconstruct a 3D model of the wound that was used to measure wound volume to automatically regulate treatment pharmaceuticals [15].

The *Use Quality* assessment in the Victorian HD3D trial identified that a specialized camera and software to digitally reconstruct a wound volume is too expensive and sophisticated for stretched health care budgets. Instead, a conventional off-the-shelf 3D camera and relatively simple software that implements polar geometry described by Ozbolat et al., (2012) [16] provides a measure of wound depth. Software that enables wounds from the same patients to be displayed in HD3D over time along with depth information is regarded by wound specialists associated with the trial to be feasible and sufficient to enable a wound specialist to far more accurately assess a wound and determine whether a home visit is required.

2.3. Tele-oncology

A tele-oncology application in Northern Australia where cancer patients attend a remote chemotherapy unit and, with a nurse practitioner, engage in a consultation with an oncologist thousands of kilometres away in Brisbane is described by Sabesan and Brennan (2011)[17]. This has been demonstrated to impact positively on patients and clinicians. A consultation in HD3D can be imagined to enhance the 2D video by enhancing the Telepresence sense of 'being there'. However, oncologists and nurse practitioners associated with the Victorian HD3D trial indicate that the success of an oncological consultation relies to a large extent on human to human interaction factors. Eye contact between oncologist and patient is important as is human touch for reassurance and connection. Body language cues between the patient and significant others is also important. A *Use Quality* assessment indicated that the presence of HD3D glasses donned by oncologists restricted eye contact and presented as a counterproductive reminder of the demarcation between oncologist and patient. The role of communication in medical consultations, so critical throughout history has diminished as empiricism and evidence-based practice has become prevalent [18]. The central role of patient to physician communication for therapeutic objectives is still very much apparent in oncology and palliative care.

Although HD3D glasses restrict a tele-consultation, a HD3D view of extravasation spills or rashes was considered very important to clinicians in the Victorian trial. This led to the possibility of a revised workflow that involved the nurse practitioner videorecording in HD3D all features of interest prior to the tele-consultation. This was seen to benefit the patient who could take their time undressing and benefitted the subsequent consultation by saving time and patient embarrassment.

2.4. Tele-psychiatry

The tele-psychiatry consultation requirement was for a HD3D synchronous video consultation. Unobstructed eye contact is not as critical in a psychiatric consultation as it was for an oncological consultation. Further, the majority of consultations involve the patient alone so interactions and body language with significant others is less pressing. Many psychiatric consultations involve assessments of fine motor movements to diagnose neurological conditions or to make an assessment of adverse reaction to pharmaceutical interventions. Workflow or other organizational issues did not preclude the use of synchronous HD3D for tele-psychiatry as it did for tele-wound. In summary, the *Use Quality* was optimally achieved with the introduction of HD3D video conferencing to replace 2D video conferencing. Trials are planned to investigate the extent to which the sense of being there is experienced by participants and is regarded to be beneficial.

3. Conclusion

Although still in its infancy, High Definition and 3D telemedicine installations have a clear role to play in the advancement of tele-health. Insights from existing trials of HD3D tele-health illustrate that the immersion experienced make tele-health consultations more compelling. HD3D Tele-surgery offers the surgeon a greater sense of realism that results in greater control of instruments. However, HD3D telemedicine is not limited to synchronous consultations that require high capacity networks. A focus on the quality of use of tele-health technologies requires a broad organizational, clinical and social assessment of the installation and often results in designs that integrate asynchronous HD3D via store and forward servers.

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