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Real-time Free-Viewpoint 3D Video for Wheelchair Seating Assessment: Preliminary Assessment for Local and Remote Applications

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Abstract *– Using video-conference-based telerehabilitation technology to provide valid wheelchair assessment results can be a difficult task for occupational therapists (OT) due to the necessity of working on a 3D task within a 2D video-based screen. New virtual reality (VR) technology could improve this process by providing a real-time, 3D representation of the client and their wheelchair that can be remotely manipulated by the rehabilitation specialist. This pilot study examined the potential of combining the Zaxel Virtual Viewpoint™ System (ZaxelVV) with the TightVNC application sharing software as a mean to improve visualization during an on-line wheelchair assessment. Following evaluation by two OT's, the current system was found to be appropriate for assessing overall posture in the wheelchair and wheeling hand position while a series of recommendations were also made before such a system could be used clinically. We also discuss the advantages and potential of the 3D approach including the possibilities for 3D measurements as well as automated assessments by a virtual therapist.*

Keywords *– Virtual Reality, Wheelchair, Assessment, Telepresence, Telerehabilitation*

I. INTRODUCTION

An interactive wheelchair seating evaluation between an experienced occupational therapist and a patient should provide the most appropriate wheelchair seating system. An occupational therapist's expertise regarding proper positioning is to maximize functional abilities, prevent contractures and pressure sores, as well as assistance with management of pain. After the patient's current wheelchair evaluation, recommendations are made regarding possible modifications, repairs, and/or additions. The traditional evaluation process can be time and cost consuming as the therapist and the patient must be in the same location. Physical measurement is performed by the therapist moving around the wheelchair as many observation viewpoints are necessary for the evaluation and the measurements.

Telerehabilitation involves the evaluation of a patient by a therapist (or several therapists) where the patient and/or rehabilitation specialists are at different locations. Using conventional video conferencing, where the therapist and patient communicate via simple video and audio streams, therapists must adapt to dealing with 3-dimensional problems within 2-dimensional video space. While video conference systems provide clear images, 3D manipulation such as moving the camera's viewpoint, moving around the patient, and obtaining accurate measurements of the patient and wheelchair are not provided.

Research involving wheelchairs and VR have largely been focused on training wheelchair users to navigate through various environments (home, school, workplace, etc.) [1-3]. Few telerehabilitation VR implementations have been successful due to technical requirements, resource issues, and difficulties in maintaining a sense of presence [4].

A true interactive 3D medium for completing wheelchair seating assessments could improve decision making and enhance clinical efficiency. Therefore, a 3D based wheelchair seating assessment system connected via a network to the remote location that provides omni-directional 3D observation and enhanced 3D measurements would be desirable.

II. METHODS

To achieve the objective of providing an interactive, remote 3D assessment environment, appropriate VR and communication technology must be combined that achieve the following goals:

- Provide a 3D, to scale, representation of the client and wheelchair
- Provide sufficient viewable area for static and dynamic assessment
- Allow the OT to view the client from any direction
- Potential for linear, angular, and circumferential measurements
- Low-latency, high frame-rate system control and visualization over an IP-based network

A. Technology

The Zaxel Virtual Viewpoint™ System (ZaxelVV - http://www.zaxel.com) [5] provides an interesting environment for live rendering of a person within a 3D virtual environment. This tool captures a subject using several surrounding cameras and converts the video images into 3D geometrical and textural information, then generates a new arbitrary viewpoint in 3D space based on an operator's input, all in real time (Figure 1).

The ZaxelVV system used in this study consisted of 12 cameras mounted on four walls enclosing an area of approximately 4m x 4m (Figure 2). Three groups of four cameras are each connected to individual "slave" computers in charge of the synchronized capture of the 2D video streams of the surrounded subject. These three slave computers are linked to a master control workstation. This control computer uses Zaxel provided software for the 3D-visualization, directing the slave computers to the different computational tasks needed for the generation of specific 3D views.

Figure 1: ZaxelVV real-time representation of a person in a wheelchair.

Many application sharing software options exist to allow the use of applications on remote computers over IP-based networks. After evaluating a range of products, TightVNC (http://www.tightvnc.com/) [6] emerged as a viable option for initial testing since TightVNC provides various functions to fine tune the performance of the end-to-end system; such as (i) choice of compression algorithm, (ii) choice of shared screen area, (iii) remote mouse and keyboard control, (iv) one-to-one communication as well as one-to-many communication, (v) open source code for customization. In our testing TightVNC was capable of sharing full-screen, real-time, wheelchair seating pressure graphics. Seating pressure maps are very graphical intensive since the entire window consists of varying coloured squares, displaying real-time pressures between the patient and their wheelchair seat. Since few areas on the screen remain unchanged, seating pressure analysis is very demanding for application sharing systems. Application sharing software for business typically cannot handle this type of data.

The combination of ZaxelVV and TightVNC provides a novel approach for 3D telerehabilitation. ZaxelVV provides real-time 3D shape and motion capturing and TightVNC provides real-time transferring of the 3D play window view with remote manipulation through mouse and keyboard manipulation. Since TightVNC runs on standard desktop/notebook computers, the clinician does not need a high-end graphics workstation to work with the data. 3D processing is handled at the ZaxelVV location.

Figure 2: ZaxelVV data capture area

Two experiments were performed with several subjects placed within the ZaxelVV viewable area (Discover Laboratory, U. Ottawa SITE building, Downtown Campus) while the therapists stayed at a remote site (The Rehabilitation Centre, Health Science Campus).

The TightVNC server software was configured on the master ZaxelVV control workstation to share the 3D-visualization window. A 2.8 GHz Pentium 4 computer at the rehabilitation centre site launched the TightVNC client program, connected via the Internet, and communicated with the TightVNC server using a relatively high-bandwidth connection (i.e., using minimum compression, maximum quality). Telephone was used for audio communication. The overall system diagram is shown in Figure 3.

Following the calibration to find the extrinsic parameters of the 12 cameras and the fine tuning of the background extraction settings, the subject sat in the wheelchair and followed instructions from an OT at the remote site to mimic a seating assessment. Using the application sharing software, the therapist was able to rotate and zoom the ZaxelVV real-time model using remote mouse and keyboard control.

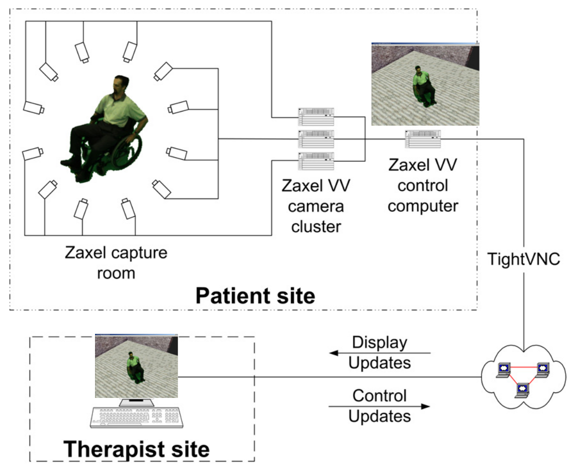

Figure 3: System diagram.

Following an accommodation period with the system, qualitative feedback from OT was obtained concerning system function, system requirements, and potential for future use. Bandwidth usage was monitored during each session.

The first test session was performed using the default ZaxelVV system configuration. All 12 cameras were located approximately in the range of 1.5m to 2m above the floor and evenly spaces around the video collection area. No effort was made to provide contrasting colours between the subject's clothing and the wheelchair. In the second test, one camera was positioned at floor level as shown in the left side of the subject in Figure 2 and the subject wore lighter colour clothing while in the black wheelchair.

III. RESULTS

The combination of ZaxelVV and TightVNC provided a real-time 3D model that was sufficient for evaluation purposes. As shown in Figure 4, image quality varied substantially based on camera/viewpoint location, subject clothing, and subject location within the Zaxel video field.

A. Bandwidth Requirements

The default rendering resolution for the ZaxelVV images was 1024x768. While running at the TightVNC "high bandwidth" setting, bandwidth peaked at 235.8 KB/s from the ZaxelVV site to the remote site and 70 KB/s from the remote site to the host site (subject not moving). When the subject maneuvered the wheelchair within the video field, bandwidth peaked at 390 KB/s. The video frame rate at the remote site in both test sessions was between 2 and 3 frames per second.

Changing the TightVNC setting to "normal bandwidth" did not create a perceivable decrease in image quality but lowered the peak bandwidth to 185 KB/s from the ZaxelVV site and 7.8 Kbps from the remote site. Slight improvement in remote frame rate was also noted.

Changing the ZaxelVV rendering resolution to 640x480 greatly increased the frame rate at the remote site (5-10 fps). Since bandwidth was not the governing factor for frame rate, the relatively poor frame rate performance for this application sharing could be attributed to lack of available processing power on the ZaxelVV systems to both render the 3D video data and compress/transmit the TightVNC images at full video data rates.

B. Occupational Therapist Feedback

Positive comments regarding the use of this system for wheelchair assessments included the ability to rotate the 3D playing view in any direction and zoom for more detailed view using simple mouse manipulation and the TightVNC client software. This allowed the OT to work in a more familiar manner (i.e., move around the patient) and also provide unique views, such as directly above the wheelchair.

Based on the current image quality, both OT's would be able to make valid judgments on overall posture and overall wheelchair seating status. However, the current image quality was considered a problem for making more detailed clinical decisions.

The recommendations include that colour contrast between the client and the chair must be improved, that lower positioned cameras are required to enable wheel and foot-rest measurements and that 2 cm accuracy is needed. While the upper body detail was often very good, detail was often missing on the bottom section of the wheelchair, wheel hub area, foot – footrest interface, leg-frame interface, seat depth, and seat height.

Faster frame rates at the remote site would be necessary for live mobility analysis; however, the current application sharing system was considered adequate for quasi-static seating analysis. Increased frame rates would also make it easier for the therapist to make changes to the viewpoint and magnification.

Figure 4: Remote view screen capture from TightVNC client (top: optimized view, bottom: non-optimized view).

IV. DISCUSSION

As a pilot test, the combination of ZaxelVV and Internet-based application sharing technology showed great promise as the preferred tool of the future for wheelchair assessment. As a concept, clinical staff were able to see the value of having 3D visual control of the environment during a consultation. While measurement tools were not available in the current Zaxel viewing module, working from an accurate 3D model should provide better measurements than that can be obtained from 2D video systems.

While the future is promising, improvement must be made to the current technology and to the video capture environment. In terms of image capture, the subject must wear clothing distinguishable from the background (currently green) as ZaxelVV uses a color keying method to extract the background in the video data for generating its 3D model. Secondly the wheelchair and the patient on it must have high contrast in color for proper position visualization. In this experiment the wheelchair had black cushions and a dark frame, and the subject had dark pants, identification of body position below the waist was difficult while upper body imaging was considered satisfactory (the subject wore a light grey shirt that provided high contrast with the wheelchair). Problems with contrast between dark wheelchair components and dark clothing are consistent with other video-based telerehabilitation applications.

The wheelchair assessment application will require a modified camera setup, as compared with typical applications that put a person within a virtual space. A wheelchair adds a level of complexity since some cameras must be positioned at a low height to capture details of some areas that are captured at too low a resolution or are completely obstructed from ceiling height cameras. A combination of low and high position cameras are needed to provide valid visual information to a therapist when assessing foot/foot rest, rear wheel camber, wheel axle/body orientation, top-view body orientation, and to take accurate measurements. Positioning one camera 50cm from the floor during the second trial improved the images of some areas of the rendered model; however, more cameras at this height are required.

The application sharing approach was also viable as a mean of interacting with the main 3D system. Since 3D visual information of the specialist is not essential at the patient's end, application sharing was able to produce a telepresence effect without requiring Zaxel systems at each location. A major advantage of application sharing as the visual/control communication medium is that no additional software was required to work with the Zaxel system (i.e., dedicated communication code within the Zaxel software was not required). Within healthcare, application sharing software could be configured to interact with firewalls and other security systems to provide a common means of communicating within a telerehabilitation encounter. Most dedicated conferencing systems are blocked by hospital network security systems.

As expected, jitter and delay were only a concern during dynamic movements; such as, wheelchair translation and rotation. Improvements must be made in terms of frame rate before this system can be used for the full range of wheelchair assessment tasks.

Possible solutions include increasing the processing power of the control computer at the Zaxel location to offset the application sharing compression and transmission tasks from the main processor, experiments with improved TightVNC compression algorithms and settings, and/or reduce windows image size. While typical broadband bandwidth capacity in the community continues to increase, this system must work within a 256 kbps bandwidth ceiling.

Following graphical and application sharing improvements, the Graphical User Interface (GUI) must be enhanced to provide semi-automatic or automatic measurement on the 3D subject. 3D measurement is one of the distinguishable advantages of this 3D approach since telerehabilitation measurements will be more accurate where similar measurements in a 2D video conference is not possible. Typical requirements include linear (wheelchair diameter, speed of wheeling) and angular measurements (obliquity of upper limbs, lower limbs, shoulder and spine as well as joint angles, relative positions such as hand on rim, centre of gravity and rear axle, pelvis position, etc.) 3D measurement tools opens future possibility for Virtual Therapist which can perform Wheelchair Seating Assessment by comparing the ideal patient seating in more automatic and systematic manner.

V. REFERENCES

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