Design and Development of Virtual Reality Based Perceptual-Motor Rehabilitation Scenarios

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Abstract—**Virtual Reality technology may provide new options for conducting perceptual-motor assessment within simulated 3D environments for persons with a wide range of disabilities. This paper outlines our work developing a series of game-like VR scenarios to assess and rehabilitate eye-hand coordination, range of motion and other relevant perceptual-motor activities. Our efforts have focused on building engaging game-based stereoscopic graphic scenarios that allow clients to participate in perceptual-motor rehabilitation by interacting with 3D stimuli within a full 360-Degree space using a head mounted display or by way of a "face-forward" format using 3D projection displays. Exploratory work using multiple video sensors to detect and track 3D body motion, identify body postures and quantify motor performance is also described.**

Keywords—**Virtual Reality, Perceptual-motor Rehabilitation, Vison-Based Tracking**

I. Introduction

Virtual Reality (VR) provides numerous assets for rehabilitation beyond what is currently available with traditional methods [1-2]. One of the cardinal assets for this form of advanced simulation technology involves the capacity for systematic delivery and control of stimuli. In this regard, an ideal match exists between the stimulus delivery assets of VR simulation approaches and rehabilitation requirements. This "Ultimate Skinner Box" asset can be seen to provide value across the spectrum of rehabilitation approaches, from analysis and training at an analog level targeting component cognitive and physical processes (i.e., selective attention, grip strength, etc.), to the complex orchestration of more complex integrated functional behaviors (e.g., planning, initiating and physically performing the steps required to prepare a meal in a distracting setting). This asset can also be seen to allow for the hierarchical delivery of stimulus challenges across a range of difficulty levels. In this way an individual's rehabilitation can be customized to begin at a stimulus challenge level most attainable and comfortable for them, with gradual progression to higher functional difficulty levels based on the individual's performance. Another primary strength that VR offers rehabilitation is in the creation of simulated realistic environments in which performance can be tested and trained in a systematic fashion. By designing virtual environments (VEs) that not only "look like" the real world, but actually incorporate challenges that require real world functional behaviors, the ecological validity of rehabilitation methods could be enhanced. As well, within a VE, the experimental control required for rigorous scientific analysis and replication can still be maintained within simulated contexts that embody the complex challenges found in naturalistic settings. Thus, VR derived results could have greater predictive validity and clinical relevance for the challenges that clients face in the real world.

Our recent work has focused on the development of a series of PC-based VR perceptual-motor rehabilitation scenarios that can be delivered via a stereoscopic Head Mounted Display (HMD) or by way of standard monitors and projection displays. These applications are currently being tuned to foster interaction in a series of game-like scenarios to assess and rehabilitate eye-hand coordination, range of motion and other relevant perceptual-motor activities. Significant effort is being put into the interface design that will allow a therapist the capacity to easily configure the stimulus presentation parameters in advance or in real time, according to the needs of the client to promote optimal perceptual-motor action based on both therapeutic need and/or the specific research question.

Within this context, we are also experimenting with the use multiple video sensors to detect and track 3D body motion, identify body postures and quantify perceptual-motor performance within "first person" VEs. One advantage of markerless vision-based sensing, compared to encumbered, wired magnetic tracking methods, is that it allows the client to move more freely during interaction training sessions. This may provide a better understanding of the client's range of motion, movement speed, muscle strength, endurance, dexterity and accuracy. This paper will discuss our rationale, scenario/interface design, and vision-based video tracking system that we are developing.

II. Clinical Rationale

Perceptual-motor impairments are commonly seen as the natural effects of the aging process and in a wide range of disabling conditions (i.e. spinal cord injury, traumatic brain injury, stroke, Parkinson's disease and other neurological conditions). These groups currently make up a large segment of the world population and the numbers are increasing as the Baby Boomer cohort ages. For example, falls and instability are among the most serious problems facing the elderly population. They are major causes of morbidity, mortality, immobility and premature nursing home placement. Approximately 90% of hip fractures in the elderly are caused by falls. Of those elderly people who were functionally independent before a hip fracture, 25% remain in long-term care for more than a year afterwards, and another 35% must depend on mechanical aids or people for mobility. Therefore, there is a great need to identify the causes of falling in the elderly and to develop strategies for preventing these falls [3].

Another significant cause of perceptual-motor impairment is spinal cord injury (SCI), a devastating condition that often results in loss of sensation and voluntary activity below the level of the injury. The incidence of traumatic spinal cord lesions varies from 10 to 60 per million. The prevalence of traumatic SCI in USA has been estimated to be 721 per million. SCI is associated with a severe functional deficit and causes an abrupt change in the quality of the client's life. Clients with spinal cord injury lack the normal postural synergy of the lower extremity that regulates the upright position. Therefore, they must develop compensatory strategies to maintain balance, including muscle activity in the trunk, neck and upper extremity prior to the postural activity. Poor balance and the need to support oneself with the upper extremity limit those functional activities that require standing upright [4].

Stroke is also a major cause of disability in older adults, and can result in various motor/cognitive impairments and functional disability. Almost half of all clients who have had strokes retain substantial disability that affects performance of daily activities such as bathing and dressing and meal preparation [5-6].

An essential part of the rehabilitation process for physical dysfunction is the remediation of perceptual-motor deficits. Remediation aims to improve the functional ability of the client, and to enable him or her to live as independently as possible. Conventional therapy focuses on muscle strengthening, increasing joint range of motion and improving balance reactions. These interventions tend to be tedious, monotonous and provide little opportunity for systematic grading of difficulty level and concurrent performance measurement [7]. Indeed, one of the major challenges facing clinicians in rehabilitation is identifying intervention methods that are effective, motivating, and that transfer to the ability to function in the "real" world.

The use of VR to provide game-based rehabilitation to address these objectives makes intuitive sense. Continuing advances in VR technology along with concomitant system cost reductions have supported the development of more usable, useful, and accessible VR systems that can uniquely target a wide range of physical, psychological, and cognitive rehabilitation concerns and research questions. A compelling clinical direction may involve leveraging gaming features and incentives for the challenging task of enhancing motivation levels in clients participating in rehabilitation. In fact, one possible factor in the mixed outcomes found in rehabilitation research may be in part due to the inability to maintain a client's motivation and engagement when confronting them with a repetitive series of training challenges, whether they be cognitive or physical activities. Hence, the integration of gaming features in VR-based rehabilitation systems to enhance client motivation is viewed as an important direction to explore. Thus far, the integration of gaming features into a VE has been reported to enhance motivation in adult clients undergoing physical and occupational therapy following a stroke [8-9]. Strickland [10] also reports that children with autism were observed to become very engaged in the VR safety training applications that her group has developed which incorporate gaming features.

Our efforts in this area have focused on system design and development in three main directions: 1. Building engaging game-based VEs for perceptual-motor rehabilitation. 2. Creating intuitive interfaces that allow a therapist to intuitively control the delivery of stimuli in real time. 3. Experimentation with Vision-Based tracking methods. These efforts will be detailed in the following sections.

III. VR SCENARIO AND INTERFACE DESIGN

Our VE design and development has focused on building engaging game-based stereoscopic graphic scenarios that will allow clients to participate in perceptual-motor rehabilitation by interacting with 3D stimuli within a full 360-Degree space using a head mounted display. Alternatively, our scenarios are capable of being delivered in a "face-forward" format via the use of 3D projection displays. We have created three proof-of-concept prototype environments to serve as exploratory user-centered test beds for evolving these applications (see Figure 1).

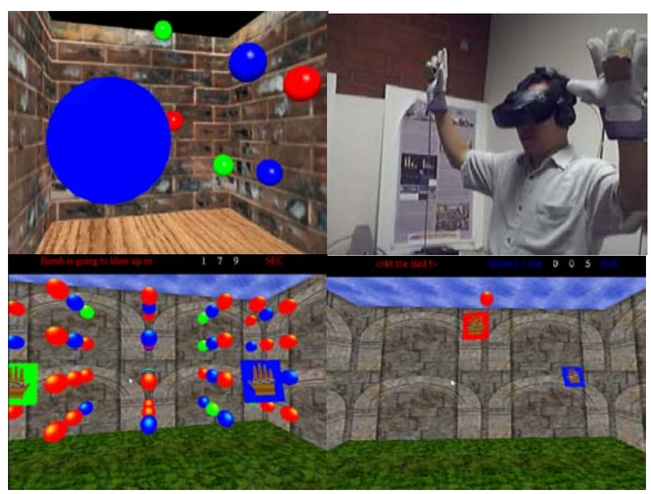

Figure 1. Prototype 3D Virtual Environments for perceptual-motor rehabilitation and a test "user".

These game-based scenarios are being developed for both assessment and rehabilitation purposes. Preliminary evidence from a 2D VR video-projected system indicates that gaming environments cause clients to be more motivated to perform and to achieve significantly higher movement metrics than during conventional therapy [9,11]. We are currently using Ascension "Flock of Birds" magnetic tracking of users' hand and head movements in these initial prototypes. The data from magnetic tracked performance is also being compared with simultaneous multiple camera vision-based capture in a constrained test setup using the approach discussed in the next section. Within each scenario, users' motor movement in full 6-degree of freedom space is tracked and quantified as they interact with the reaching and targeting challenges presented. The scenarios are comprised of scenes within which static or dynamic 3D stimuli are presented, and users are encouraged to interact "physically" within a game-like format. Two of the game scenarios have similar action requirements as would occur in real world handball or participating as a soccer goalie. A third scenario requires the user to make specific reaching movements to hit a target object, while avoiding contact with other non-target objects. A cognitive component can be introduced by changing the color of the user's hand representation in the VE which signals what color objects have now become the target. Immediate feedback of performance outcomes is intuitively obvious to users by way of their success/failure in their interaction with targets, as well as by way of a scoreboard, both during and at the end of each test trial. The presentation of the stimuli can be hierarchically graded (*e.g.* number, speed, directionality, spatial contiguity, etc.) with preprogrammed trials or can be adjusted in real time by the therapist.

The control of stimulus delivery parameters in real time by a therapist is essential for optimal orchestration and pacing of perceptual-motor action needed to attain therapeutic treatment goals. Judicious placement of target objects by a therapist (a la Wizard of OZ) can serve to support errorless training approaches, constraint-induced therapy and be used to prevent the client from becoming discouraged by performance targets that he cannot yet achieve. One method that we are designing to serve real time stimulus control purposes allows the therapist to use a mouse to strategically place stimulus trajectories in positions around a representation of the users' tracked body position (see Figure 2). This is enabled on a separate monitor with intuitive keyboard actions controlling the speed of the target movements.

Figure 2: Therapist views of different stimulus delivery control panels.

IV. VISION-BASED TRACKING

Recent efforts incorporate a single camera "fixed-plane," and vision-based approaches have appeared in the literature in this area and have shown promise [9,11]. These applications use a single camera vision-based tracking system that produces a representation of the user embedded within a two dimensional flat screen display environment where they can interact with graphical objects. However, existing systems have significant limitations; quantifying and understanding 3D body motion from a single visual system is inaccurate since only a 2D projection of the body motion is captured by the camera. Moreover, approximately one-third of the body joints are nearly unobservable due to motion ambiguities and self-occlusion. Multiple views are therefore required to quantify, disambiguate and identify the 3D human body motion. Within this context, our goal is to use video sensors to accurately detect and track 3D body motion, identify body postures and recognize user gestures.

Identifying body posture from its 3D shape is challenging, as the 3D description of the shape has to account for shape variability in characterizing a posture. Indeed, several people will perform similar posture differently and therefore identifying a posture from the 2D/3D shape descriptions will require a learning step. We present an appearance-based, learning formalism that is viewpoint independent and uses a 3D shape descriptor of the visual-hull for classifying and identifying human posture [13]. The proposed method does not require an articulated body model fitted onto the reconstructed 3D geometry of the human body. In fact, it complements the articulated body model since we can define a mapping between the observed shape and the learned descriptions for inferring the parameters of the articulated body model. In the following section we will present the shape descriptor considered and the learning algorithm based on Support Vector Machine (SVM) [14]. An overview of the proposed approach is given in Figure 3.

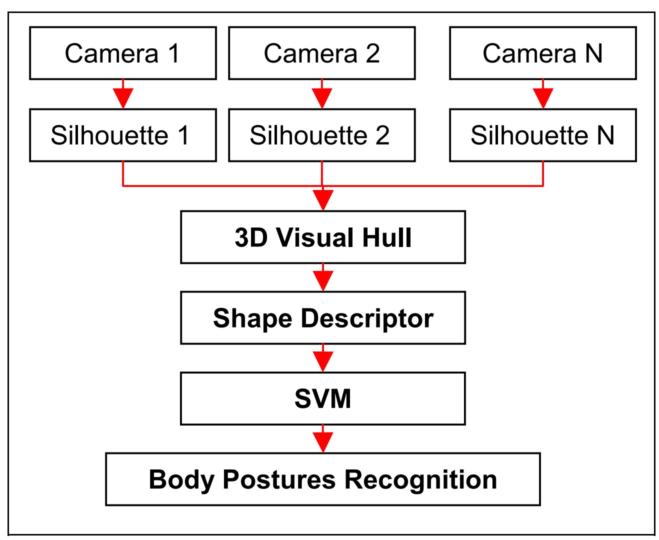

Figure 3: Overview of the proposed approach.

Our approach is based on the integration of 2D silhouettes captured by two or more cameras and the description of the human body shape using a 3D shape descriptor generated from the visual hull of the human body. Integrating multiple silhouettes acquired simultaneously from different viewpoints allows generating a 3D visual-hull of the human body. The visual-hull of an object is the closest approximation of the 3D object that can be obtained from the detected 2D silhouettes [12].

We have defined a shape description method that has the ability to characterize surfaces' local and global similarities, as well as comparing various 3D surfaces. The shape descriptor of a surface is defined by a distribution in the spherical coordinate space. Comparing shapes is therefore reduced to comparing the corresponding distributions. The 3D shape descriptors characterizing shape properties are used for training a SVM. The shape descriptor is inferred from the 3D visual hull obtained by integrating multi-view silhouettes acquired by 4 synchronous cameras. The shape descriptor is represented by a vector:

S= {(index of the bin, density of points in the bin)}.

The visual-hull corresponding to the detected silhouettes and their shape descriptors are computed at a frame rate of five frames per second. The system was trained on the chosen 12 postures by considering approximately 2000 samples per posture. The selected postures are displayed in Figure 4.

Figure 4: The set of 12 postures we defined in our system.

In Figure 5 we show the output of the system where the postures of person are recognized independently of the relative orientation of the person and cameras.

Further details on the game-based scenario development, therapist interface design and vision-based tracking progress will be presented at the conference.

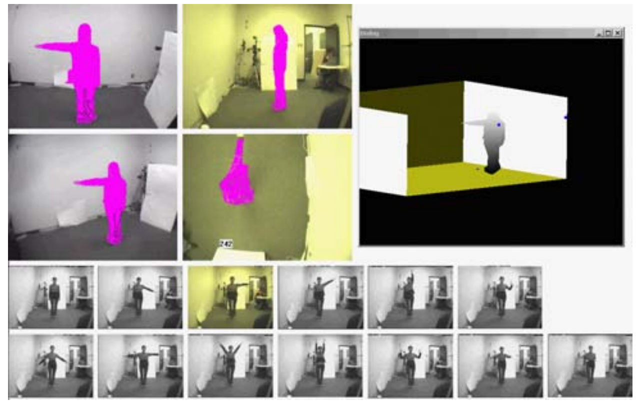

Figure 5: Illustration of the system's output. The thumbnail of the recognized posture is highlighted.

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