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Integrating Haptic-Tactile Feedback into a Video-Capture–Based Virtual Environment for Rehabilitation

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ABSTRACT

Video-capture virtual reality (VR) systems are gaining popularity as intervention tools. To date, these platforms offer visual and audio feedback but do not provide haptic feedback. We contend that adding haptic feedback may enhance the quality of intervention for various theoretical and empirical reasons. This study aims to integrate haptic-tactile feedback into a video capture system (GX VR), which is currently applied for rehabilitation. The proposed multi-modal system can deliver audio-visual as well as vibrotactile feedback. The latter is provided via small vibratory discs attached to the patient's limbs. This paper describes the system, the guidelines of its design, and the ongoing usability study.

INTRODUCTION

APPLYING VIRTUAL REALITY (VR) technology in the field of rehabilitation has been gaining popularity in recent years. However, this trend is commonly limited to audio-visual VR systems, which do not provide haptic feedback. The goal of the present study is to integrate simple haptic-tactile feedback, provided by moderately priced hardware, into an existing virtual environment (VE) that has already been applied in rehabilitation.[1] This paper depicts the rationale behind our study, as well as the design of the system and the research paradigm.

VIRTUAL REHABILITATION USING VIDEO CAPTURE

Video-capture VR consists of a family of camera-based, motion-capture platforms that differ substantially from the head-mounted display (HMD) and desktop platforms in wider use.[2] When using a video-capture VR platform, users stand or sit in a demarcated area, viewing a large video screen that displays one of a series of simulated environments. Users see themselves on the screen, in the VE, and their own natural movements direct the progression of the task entirely (i.e., the user's movement is the input). The user's live, on-screen video image

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responds at exactly the same time to movements, lending an intensified degree of realism to the VR experience. Typically, video-capture VR provides both visual and auditory feedback, both of which appear to enhance the users' sense of presence. The platform employed in this study is GestureTek's Gesture Extreme (GX) platform (<www.gesturetek.com>). In the soccer application, for example, the user sees himself or herself as the goalkeeper whose task it is to prevent balls from entering the goal area (Fig. 1). As described previously,[1] our research group has adapted some of the VEs offered by GX and employed them in clinical settings. In our adaptations, the therapist may both control various parameters, such as the number and velocity of the balls, and monitor the patient's performance as measured by the system.

RATIONALE

We perceive stimuli in the environment through our sensory channels. Neuroanatomical and neurophysiological studies[3] suggest that early processing is modality specific and that later the unimodal data are integrated into a complete internal description of the world. Converging evidence indicates that the sensory modalities interact at several levels. The outcome of these interactions may be short or long termed. One such influence may produce improvement in learning and retrieval of representations due to multiple coding.[4] This may lead to better performance in various tasks and actions.

FIG. 1. Individual with a stroke performing within the soccer environment using the VividGroup GX system.

Furthermore, neurophysiological data have demonstrated how cross-modal interactions occur even in VEs.[5]

Until recently, one of the major components lacking in many VR simulations has been the provision of haptic feedback. In the absence of haptic feedback, users reach out to touch a virtual object, only to place their hands right through the object without feeling it. In recent years, haptic feedback displays have been introduced to the VR community in order to facilitate the sense of presence and improve performance. Some researchers have designed and built the required haptic displays, such as the Rutgers Master Glove.[6,7] Other investigators have employed off-the-shelf products such as the Phantom[8] manufactured by Sensable <www.sensable.com> or even low-cost haptic joysticks commonly used in the gaming industry.[9,10]

These initial studies have encouraged the rehabilitation community to gain a greater appreciation for the feasibility of integrating haptic technologies into VR clinical intervention. However, the role of haptic feedback in virtual rehabilitation has not been clarified yet, and a systematic investigation is required in order to establish its contribution. Unfortunately, the financial and technical burdens associated with haptic systems pose major obstacles for creating multimodal VEs. The proposed system aims to bridge this gap for certain types of interventions. Moreover, it aims to provide haptic feedback with minimal encumbrance for the user.

DESIGN PRINCIPLES

Our system design adheres to several constraints and guidelines. First and foremost, this is a rehabilitation tool meant to be used with a variety of patients suffering from various pathologies. It has to be lightweight and otherwise non-encumbering, so that it can be used by patients who have decreased strength and range of motion in the affected limb. The haptic feedback has to be adaptable, so that it can be administered in a range of intensity levels appropriate to the varying sensory thresholds of different populations. Also, since the system is expected to serve many patients, it has to be durable, easy to put on, and easily cleaned to comply with hygienic standards. Another factor derived from the system's clinical goals is the lack of encumbrance. Finally, it has to be affordable, allowing its wide distribution to clinics.

CURRENT SYSTEM

Our current system integrates the GX VR system with haptic feedback provided by vibratory discs attached to the users' hands (either the tips of the fingers or the palm). The equipment includes the typical GX VR setting (i.e., a standard PC, a video camera, a large monitor, and a chromakey backdrop). The haptic hardware consists of small, light, flat buzzers, similar to those found in cellular phones.[11] Figure 2 shows two buzzers (shown next to a hand for scale). Each buzzer is connected via a cable to the interface card installed in the computer. In future versions, the system will be made wireless. The system can support up to 10 separate buzzers. Each one can be activated separately, within a range of three discrete intensities, determined by the input voltage.

As is usual with applications of the GX VR system, the user stands in front of the camera and screen, where he or she can interact with the two-dimensional VE. In the current prototype VE, a ball floats towards the user; whenever he or she touches a ball, he or she feels a vibration in his or her hand. The buzzers are attached to the user's hand using Velcro strips (Fig. 3). The GX System is operated in its "Red Glove" mode, where the user wears two red gloves that allow the GX VR system to sense that contact with an object has been made by a hand, and not by other body parts. Thus, the haptic stimulation is delivered only when a virtual object is "touched" by the hands. Additionally, the user wears a Polar heart rate monitor <http://www.polar.fi> on the chest and wrist in order to obtain a simple physiological measure, possibly indicating the user's sense of presence.

FIG. 2. The vibratory discs.

FIG. 3. Subject wearing two red gloves with embedded vibrators on palmar surface and heart rate monitor.

USABILITY TESTING PARADIGM

Currently, we have started the initial phase of usability study. In this ongoing study, we present healthy subjects with various VEs. The subjects experience each VE in four feedback modes: (1) visual, (2) visual-aural, (3) visual-haptic, and (4) visual-haptic-aural. This permits comparison of their performance and sense of presence levels during various modes of feedback. To date, two VEs have been tested: soccer and juggler. In the former (Fig. 1), the subject is a goalkeeper blocking balls thrown at him. In the latter (Fig. 4), the subject uses one hand to juggle virtual balls in the air, not allowing them to fall to the ground. Following a short practice session (in the visual-aural mode, which is typically used in GX systems), each feedback condition is experienced for 90 sec. The outcome measures obtained after each condition include (1) performance—percent success based on the number of saves and misses; (2) Short Feedback Questionnaire (SFQ), a modified version of Witmer and Singer's[12] Presence Questionnaire, and (3) heart rate.

CONCLUSION

This paper discusses the potential contribution of adding haptic feedback to VR applications in the field of rehabilitation. Theoretical foundations as well as converging empirical evidence suggest haptic feedback may enhance clinical intervention. The proposed system aims to integrate simple vibrating feedback into a video capture system, thereby pro-

FIG. 4. Screen shot of the juggler application.

ducing an intervention tool of greater power and flexibility. Our main challenges stem from two constraints. First we wish to maintain the advantages of video capture VE, namely unencumbered and patient-friendly operation. We also want the system to be moderately priced and affordable for clinicians. These constraints have led us to implement the haptic feedback vibratory discs, delivering haptic-tactile vibratory stimuli. The system appears to be feasible for testing the relevance and contribution of the different feedback modes. In the next phase, we will apply the system to various patient populations, who may react differently to the various feedback combinations. Our ongoing experimental work will help to determine how realistic such stimuli will appear to both abled-bodied and patient subjects.

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