Integrating haptic-tactile feedback into a video capture based VE for rehabilitation

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Abstract

Video capture 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. The paper describes the system, the guidelines of its design, and the ongoing usability study.

Keywords: haptic, rehabilitation, vibration, virtual reality, video capture

Introduction

Applying Virtual Reality (VR) technology in the field of rehabilitation has been gaining popularity in recent years. The variety and sophistication of VR applications has been increasing thus allowing healthcare professionals to add VR applications to their clinical toolbox. 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 into an existing virtual environment (VE) that has already been applied in rehabilitation. We aim to explore whether providing simple vibratory feedback will enhance the intervention. Further, we plan on doing so while employing moderately priced haptic hardware, rendering it affordable for wide clinical use. 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 HMD and desktop platforms in wider use (Weiss et al., 2004). 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 virtual environment, and their own natural movements entirely direct the progression of the task, i.e., the user's movement is the input. The user's live, on-screen video image responds at exactly the same time to movements, lending an intensified degree of realism to the virtual reality experience. Typically, video capture VR provides both visual and auditory feedback both of which appear to enhance the users' sense of presence.

A major development in this field occurred with the release of VividGroup's Mandala Gesture Extreme (GX) platform (www.vividgroup.com) in 1996, together with a suite of interactive, game-type environments. This platform makes use of a chroma key-based setup so that the real-life background is replaced by a simulated background. GX VR has enjoyed considerable success around the world in numerous entertainment and educational facilities including science museums and entertainment parks. During the past five years it has also begun to be adapted for use in rehabilitation and has generated great interest in clinical settings (see below). GX VR, and its companion rehabilitation oriented interface, IREX VR, currently offer a wide variety of gaming applications including, Birds & Balls, wherein a user is required to touch balls of different colors; if the touch is "gentle", the balls turn into doves whereas an abrupt touch causes them to burst. In another application, a soccer game, the user sees himself as the goalkeeper whose task it is to prevent balls from entering the goal area (see Figure 1).

Figure 1: Individual with a stroke performing within the Soccer environment using the VividGroup GX system.

During the last decade several other commercial companies developed video-capture gaming platforms, such as Reality Fusion's GameCam and Intel's Me2Cam Virtual Game System, whose production was discontinued. More recently Sony developed its very popular EyeToy application designed to be used with the PlayStation II platform. Although the latter systems differ from the GX/IREX VR systems (See Weiss et al., 2004 for a review), they all have several advantages as rehabilitation tools. The ability to interact within a VE without wearing any display or tracking gear makes a significant difference when applying video capture systems to many types of patient populations.

The potential of these platforms for rehabilitation was readily apparent despite the fact that they were originally developed for entertainment and gaming purposes. Indeed, VividGroups's GX platform was first applied without adaptations within a clinical setting by Cunningham & Krishack (1999), who used it to treat elderly patients who were unstable and at high risk for falling. However, the inability to grade these platforms to levels suited for patients with severe cognitive or motor impairments initially limited the application of these environments in clinical settings. In order to broaden the potential clinical applications of the platforms, our research group adapted the GX VR platform (e.g., Kizony, et al., 2003). VividGroup developed, and now also markets, a version of the GX platform, known as IREX (Interactive Rehabilitation EXercise) platform (www.irex.com) which enables therapists to adapt levels of difficulty and record performance outcomes (Sveistrup et al., 2003). Sony's EyeToy has also been examined in terms of its potential for use as a rehabilitation tool for older patients with stroke; although the ability to adapt this system is limited, it is suitable for some rehabilitation populations (Rand, et al., 2004)

Rationale for Multimodal VEs

We perceive stimuli in the environment through our sensory channels. Neuroanatomical and neurophysiological studies (e.g., Driver & Spence, 2000) suggest that early processing is modality specific, and that later on the unimodal data are integrated into a complete description of the world. Studies in various disciplines have demonstrated that the modalities may interact. This interaction may take place at different levels of processing, and may be manifested in several ways. Contradicting tactual and visual information, for example, may hinder the proper cross-modal integration thus causing perceptual illusions (e.g., Botvinick & Cohen, 1998). Cross-modal interactions are found even at earlier levels of processing. Auditory stimuli may effect visual processing (e.g., Shams, et al., 2000), and visual information may modulate somatosensory processing (e.g., Taylor-Clark, et al., 2002). The different modalities may influence each other even prior to the appearance of stimuli, as manifested in the control of attention. Behavioral studies have shown how shifting attention in one modality caused a shift of attention in another modality (e.g., Spence, et al., 2001). Similar findings were also found in patients with sensory extinction where a visual stimulus may produce tactile neglect (e.g., Maravita et al., 2000). Longer lasting effects appear in cross-modal transfer (CMT), where knowledge acquired in one modality, improves performance when employing another modality. Rats trained in a maze showed bi-directional CMT between visual and somatosensory modalities (Tran et al., 1994), as well as auditory and visual modalities (Delay, 1986). This phenomenon is found in humans as well (Krekling, et al., 1989).

These findings as well as other empirical evidence indicate 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. This may lead to better performance in various tasks and actions.

Furthermore, neurophysiological data have demonstrated how cross-modal interactions occur even in virtual environments (Iriki et al., 2001).

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. Some researchers have designed and built the required haptic displays, such as the Rutgers Master Glove (e.g., Burdea at al., 1992; Bouzit et al., 2002). Other studies have employed off-the-shelf products such as Sensable's Phantom (http://www.sensable.com) used in studying stroke patients (Broeren, et al., 2004).

These initial studies have encouraged the rehabilitation community to gain a greater appreciation for the feasibility of integrating haptic technologies into VR clinical intervention. In particular, there appear to be two key routes of interest. The first is related to the clinical application of VR technology to specific populations where haptic feedback plays the primary means of the intervention. Previous applications of haptic interventions include those targeted at strengthening muscles (e.g., Deutsch et al., 2001), or perceptual training for children who are blind (e.g., Colwell et al., 1998). The second is that the addition of an extra channel of information may produce a more realistic environment and increase the level of presence, which consequently, may enhance the efficacy of VR-based interventions (Durfee, 2001).

There is a third reason which motivates researchers to incorporate haptic feedback in clinical interventions which stems from the aforementioned cross-modal interactions. It seems that multimodal information may facilitate the user's performance. For example, visual displays have been shown to influence the perception of haptic stiffness (Srinivasan, et al., 1996), audio cues have been shown to influence the perception of haptic stiffness, and visual and haptic information combine to create better estimates of size and texture (DiFranco, et al., 1997). From a clinical point of view it may be hypothesized that supplying multi-modal information may produce a redundancy gain leading to better performance. Connor and colleagues (2002) have initiated some preliminary work to pursue this approach employing visuo-haptic feedback using methods of errorless learning.

The important role of cross-modal interactions may carry some perils as well. Major aspects of rehabilitation intervention are rooted in known neurophysiological effects such as the understanding of multimodal processes. A key concept is that of plasticity in the central nervous system. It is well documented that denervation causes changes to sensory and motor maps in the brain, thus reducing the representation of the damaged organ. These changes may start soon after the lesion (e.g., Calford, 2002). Significant efforts by clinicians are concerned with not only not losing but even regaining the altered areas in these maps. Acknowledging the importance of this issue, much research has focused on exploring potential mechanisms and ways to harness the plasticity effects and direct them for the benefit of the patient. The common "use-related" approach (e.g., Irvine & Rajan, 1996) contends that specific stimuli and training causes reorganization in the sensory and motor regions of the cortex. This also implies that not using the affected limb leads to "learned non-use" even beyond the actual constraints imposed by the lesion. Many patients with stroke, for example, suffer from both motor and sensory deficits. They may benefit from haptic feedback as a component of their therapy aimed at restoring tactile and proprioceptive functions. In such cases, it may be argued, that audio-visual non-haptic VR therapy may actually lead to deterioration and "learned non-use" of the affected limb.

This type of reasoning should motivate the clinical VR community to further explore the role of haptic feedback in rehabilitation (Feintuch et al., 2004). Such research will provide important information concerning when the use of haptic information may facilitate performance, when it is not helpful from a clinical point of view, and perhaps most importantly, when the lack of haptic feedback may actually harm the rehabilitation process.

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.

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 so that it can be used by patients who have very little strength 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 be easily cleaned to comply with hygienic standards. Another important aspect relates to the properties of the "hosting" platform, e.g., a video capture system. One of this platform's features which makes it so appropriate for rehabilitation, is its relative lack of encumbrance. Video capture systems are not only HMD-free but also cable-free. The advantage of free motion is not one that should be easily relinquished when adding the haptic hardware.

These guidelines, together with our goal to build an affordable system have major implications on the nature of the haptic feedback this system provides. Haptic feedback used in its broadest sense refers to both tactile and force feedback (Laycock & Day, 2003). The provision of full haptic feedback is analogous to the way developers strive to create visual VEs with greater resolution and graphic accuracy attempting to achieve lifelike stimuli. Although this is a worthy goal, satisfying this aspiration as well as this list of constraints, appears to be too demanding for the present stage of this project. For example, it would be difficult to mimic the real life force reflected from hitting a ball (as the ones delivered in the Soccer or Birds & Balls applications) without being bound to a desktop system (e.g., Sensable's Phantom; http://www.sensable.com) or being harnessed to an cumbersome exoskeleton (e.g. Immersion's CyberForce; http://www.immersion.com).

Instead we have chosen to limit the provision of haptic feedback to tactile vibratory feedback achieved with the aid of vibratory discs placed on the user’s limbs. A certain vibration is mapped to a natural haptic sensation such as the weight of a ball, or its velocity when colliding with the hand. This raises the issue of finding the most appropriate sensation to be replaced by vibration. It is likely that subjects may accept more favorably certain such replacements than others. For example, a subject may find it more intuitive when the buzzing sensation that replaces the collision felt upon hitting a virtual ball (weak sensation=slow ball; strong sensation=fast ball). On the other hand, substitution of the ball's texture by vibration (weak sensation=smooth surface; strong sensation=rugged surface) may not be easily perceived by the user.

These issues should be addressed via empirical study and via perusal of the literature related to the perception of vibration which is the interpretation of patterns of impulses transmitted to the brain by the quickly-adapting large myelinated (group A-beta) fibers. There is no separate “sense” of vibration the way there is for vision, smell, and hearing. Vibration is another form of touch. Vibration perception is transmitted through the nerve fibers in the skin and dermis (Dellon, 1997). Referring to the upper extremity, the nature of the vibration power transmitted to the palm is different from that into the fingers. The hand-arm system resonates mostly in the frequency range of 20 to 50 Hz, depending on specific test treatment and individual characteristics (for example, the size and the length of the hand-arm (Dong, et al., 2005). A major consideration when applying this system for rehabilitation will be to adapt its output to the treated population.

Tactile devices have been used since the early era of personal computers to serve as alternate presentation displays. For example, Vibrators have been inserted into a pair of shoes in order to transfer information about stock market performance as an alarm to alert the user in the case of the occurrence of a dramatic transaction (Fu & Li, 2005). In the realm of rehabilitation, vibration has often been used for people who are blind or deaf. Pointing devices such as Logitech's tactile mouse (iFeel MouseMan) has been used to control the desktop environment whereby the mouse vibrates as the user interacts with buttons and menus on the desktop and windows applications. Although some users find these vibrations to be unnatural to the windows environment, others claim that a variety of game applications is enhanced when such feedback is available (Laycock & Day, 2003).

Vibration has also been used to provide haptic feedback for rehabilitation intervention by several research groups. Boian et al. (2003) instrumented their Rutger's Ankle Haptic Interface to provide both force feedback and vibratory stimuli. They used the vibratory stimuli to supplement the force feedback felt by patients with stroke in several virtual environments. For example, a feeling of turbulence was presented to the participant who must control the position of a boat gliding over during stormy weather via low-frequency side-to-side vibrations of the platform. Different levels of turbulence were implemented via changes in vibration frequency up to a maximum of 1.5 Hz.

Figure 2: The vibratory discs

The Current System

The 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 (See Yang, et al., 2002 for details). Figure 2 shows two buzzers (shown next to 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 ten separate buzzers. Each one can be activated separately and do so within a range of 3 discreet 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 can interact with the VE. The scenario includes balls coming at him. In the current prototype whenever the user touches a ball he feels a vibration in his hand. The buzzers are attached to the user's hand using Velcro strips. The GX System is operated in its "Red Glove" mode, where the user wears two red gloves which allow the GX VR system to know 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 (See Figure 3).


[redacted]

Figure 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: Visual, Visual-Aural, Visual-Haptic, and Visual-Haptic-Aural. This way we can compare their performance and presence levels during various modes of feedback. To date, two VEs have been tested, Soccer and Juggler. In the former (See Figure 1), the subject is a goalkeeper blocking balls thrown at him. In the latter (See Figure 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 (in the visual-aural mode that is typically used in GX systems), each feedback condition is experienced for 90 seconds. 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 & Singer's (1998) Presence Questionnaire, and (3) Heart rate.

[redacted]

Figure 4: Screen shot of the Juggler application

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 evidence suggest haptic feedback may enhance clinical intervention. The proposed system aims to integrate simple vibrating feedback into a video capture system, and thereby producing 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 be perceived to be by abled-bodied and patient subjects.

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