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A Review of Haptic Technology Applications in Healthcare

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Abstract

Regaining lost abilities via the formation of new neural pathways as a result of extensive practice and retraining is a key feature of the rehabilitation process. However, patient boredom is a big issue in rehabilitation owing to the extensive practice that is necessary. Awareness of the value of haptic (touch-enabled) interfaces in computer applications has grown because to the emergence of games with buzzing joysticks and consumer electronics with touchpads. Some forms of haptics, however, are paving the way for cutting-edge computer-based rehabilitation solutions, such as "serious games," which are only one use of haptics' potential to enhance clinical treatment. In this paper, we aim to review the methods and technologies of haptic feedback that are used for medical treatment and rehabilitation. Developing and innovating better haptic feedback technology has the potential to expand and improve access to virtual healthcare such as the doctor being able to "feel" a patient's tumor from miles away by being paired with robotic devices.

Keywords

Haptic, Healthcare, Virtual Reality, Videogame, Serios Games, Technology

1. Introduction

In virtual gaming and robotics, haptic technology is advancing quickly. In the latter, haptic devices detect the user's physical movement and manipulation of the haptic device in order to offer lifelike tactile sensations, which in turn trigger an organized robotic movement. Touch screen technology, which detects touch input in order to operate the digital environment, is only one kind of haptic technology; more complex force-feedback haptics integrate kinaesthetic motions with tactile feedback. In a video game, for instance, the player may control the location of virtual objects and experience their effects by manipulating a robot's end point. To do so may include stroking, pressing, pulling, or picking up an item.

The study of touch encompasses not only tactile but also kinaesthetic reactions. Touch-screen haptics, like those found in MP3 players and mobile phones, utilize tactile haptics, which involves vibrations responding to low-threshold mechanoreceptors in the finger pad, and therefore do not provide feedback to the body on the movement and position of the limbs, or the associated forces received and exerted by the limbs. Force feedback haptics, on the other hand, uses both touch and movement to simulate a more human-like feeling of touch, such as the devices shown in **Figure 1**. Through physical contact with the body, haptic devices and software that supports haptics can exchange information with the nervous system. They can both send information to and receive information from the body [1].

Haptics is the way that information is passed along through touch [2]. The outcome of controlling a force-feedback haptic device, which provides resistance to body movement or directly moves the body using physical force, is returned to the user in the form of force information. These devices are often constructed of motors or actuators [3]. Research into haptics, particularly as it relates to virtual reality, has seen a surge in popularity in light of recent technological advancements. Through a combination of auditory, visual, and interactive feedback systems that immerse the user through the various forms of stimulation and interaction made through the simulated environment [4], virtual reality environments can provide experience that generally cannot be achieved through regular means.

Companies like Facebook, Google, Samsung, HTC, and many more are spending millions on VR R&D, with the technology's current focus being on entertainment purposes like gaming and interactive media. A huge number of open-source software, like Unity3D and Vuforia [5] [6] [7], has contributed to the broad use of VR systems outside the realm of entertainment. One such field is the medical [8] [9] [10] field that have experienced substantial expansion in recent years.

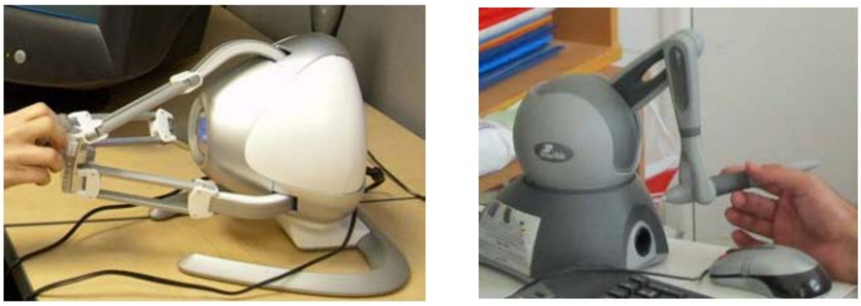

Figure 1. Haptic technology in medicine.

The objective of this paper is to do a comprehensive examination and evaluation of the current state of haptic technology and its applications in the healthcare field. The paper also provides an overview of the various types of haptic technology currently available and their potential uses in healthcare, such as in medical training, rehabilitation, and telemedicine. Also, we have discussed the challenges and limitations of haptic technology in healthcare, and its future prospects. Additionally, the paper has also explored the gaps in the current research on haptic technology and healthcare, and suggests areas for future research.

2. Literature Review

2.1. Haptic Technology in Medicine

According to studies on the development of motor skills, the brain sends a sequence of messages to the relevant muscles before any movement can occur. These instructions specify the muscles that must be clenched and the precise type of the motion to be performed. The chosen program is then executed, and the resulting muscle contraction is observed [11]. Schmidt advised that the operator provide parameters such as the time, speed, force, and magnitude of the planned movement in order to execute the program. A suitable action can be taken after these parameters are entered into the larger program. Movements are mostly within the control of the performers.

In a nutshell, haptics is the science of feeling and manipulating through touch, and it's what makes it possible for a user to have a feel for a virtual reality (VR) environment or an actual faraway object. The latest generation of computational models, which rely on sight and sound, may now incorporate this sense. By requiring the user to respond to actions in a virtual or remote environment, haptics facilitates communication in both directions. Operators can feel input from computer programs in the form of sensations anywhere on their body thanks to equipment like joysticks, data gloves, etc. Training for operations like surgery and spacecraft maneuvers that require hand-eye coordination might benefit from haptics technology when combined with a visual display [12].

Actuators allow for haptic feedback. Actuators, which provide forces for haptic feedback and controls, are devices that when an electric current is sent through the actuator, the mechanism within moves. In the past, only electromagnetic devices were in use. These electromagnetic motors give powerful feedback and normally work at resonance, but only provide a narrow range of feelings. Electroactive polymers, piezoelectric, electrostatic, and subsonic audio wave surface actuations are just a few examples of the next generation of actuator technologies that offer faster reaction times. This mechanical stimulation may be utilized to provide real-time visual and tactile feedback to the operator, making it easier for them to remotely manage equipment and machines and aiding in the construction of virtual items in a computer simulation [13]. Patient safety, procedure success rate, and the ease of medical and clinical training are all improved when robotic accuracy is added to the expertise of a clinician through the acquisition of real-time information [14].

As a profession, medicine has always relied on physical contact between doctors and patients. The doctor-patient relationship has been revolutionized by modern technology. Haptics is becoming an increasingly viable option as medical treatments continue to advance thanks to advances in technology. It has been suggested that simulation is the natural next step in health science teaching [15]. Thanks to advancements in computing power, extensive simulation can now take place in simulated environments. The technology behind virtual reality makes it possible for users to navigate their way around an artificial environment in a manner that is very comparable to the way they would navigate the real world. VR's 3D haptic technology has just lately been offered as a potent tool for the training of medical practitioners. Examples of virtual reality systems that have benefited the medical and dental communities include the virtual haptic back [16], the shadow hand [17], and the periodontal training simulator (Periosim) [18] [19].

Operational exposures in neurosurgery for residents have been reduced due to a confluence of political, economic, and societal factors. We need to create neurosurgical simulations that are sufficiently realistic that they may be used to practice complex procedures without worrying about the health of the patient. A computer-based virtual reality platform simulates the transit of a ventriculostomy catheter through the brain parenchyma and into the ventricle, complete with artificial resistance and relaxation. For example, G. Michael *et al.* [20] developed a high-quality VR neurosurgical training simulator using haptic feedback. As a first module, they have recreated a significant part of the ventriculostomy implantation process. Task simulation using this method may be built up in a modular fashion, allowing for the recreation of full neurosurgical operations [21].

The use of virtual reality (VR) settings in rehabilitation has been on the rise over the past decade, however its implementation into clinical practice has been minimal. Ilaria Bortone *et al.* [22] proposed a virtual reality (VR) rehabilitation training system equipped with wearable haptics for children with neuromotor impairments. The system's goals are to increase patient involvement and engagement, to provide consistent multi-sensory afferent feedback during motor exercises, and to take advantage of VR's adaptability to meet each individual's needs. To test the viability of the system and provide proof of concept, a rehabilitation session was done with children who have cerebral palsy (CP) and developmental dyspraxia (DD) as part of an experiment. Capabilities of people with CP/DD to those of normally developing children and adults were compared. The results illustrate the system's compliance with variable degrees of motor skills and the patients' ability to finish the experimental rehabilitation session, with performance changing between groups as predicted by motor abilities. The described approach has also inspired the development of a kinematic evaluation. The findings obtained mirrored the varying motor capacities of the patients and participants indicating the suggested kinematic evaluation is a viable outcome measure for motor function.

To better engage the user and encourage motor skill relearning, virtual hand (VH) embodiment by the user is widely considered crucial for VR-based hand rehabilitation applications. In particular, the VH needs to be able to exhibit interaction behaviours ranging from stiff to soft, depending on the nature of the work at hand. Although humans naturally possess this skill through the modulation of hand stiffness and haptic interactions, it has not been effectively replicated by VH in previous research hence Hong *et al.* [23] demonstrated the use of myoelectric control of VH in a virtual reality setting that incorporates biomimetic stiffness modulation and wearable finger force feedback. The biomimetic stiffness modulation makes it easy for VH to match the user's hand in real time, effectively mimicking the hand's stiffness profile. However, the wearable finger force-feedback technology creates an accurate simulation of external force on the fingertip, allowing the user to better comprehend their surroundings and better control their stiffness. Eight healthy volunteers completed two tasks that required different degrees of stiffness to assess the advantages of the proposed integrated system. The results are compared to those obtained by using simplified versions of the integrated system in which either biomimetic impedance control or wearable force feedback were removed. According to the findings, the proposed integrated system allows the user to adaptively control VH's stiffness via the perception of contact torques and vision, leading to task-dependent behaviours ranging from rigid to soft for VH.

Most individuals with hand dysfunction struggle with rehabilitation training. It has been shown via relevant research that the central nervous system is capable of reorganizing its structure and function following injury, suggesting that this damage can be healed through nervous system plasticity. Chen *et al.* [24] developed a brain-computer interface-based virtual reality system for hand soft rehabilitation. VR and BCI integration into the hand rehabilitation system has the potential to not only make what was once a passive procedure into an active one, but also to increase the patient's motivation and interest in the training process. The practicability and efficacy of the suggested hand soft rehabilitation method was confirmed through a series of studies. The results of the trials show that the system is able to boost patients' motivation for rehabilitation, which is crucial to the success of the process. Indicators of patients' hand-movement abilities in the virtual reality billiards game indicate that virtual reality can increase patients' rehabilitative potential.

As the eHealth Industry ecosystem continues to grow, haptic perception services that rely on accurate haptic signal reconstruction for an immersive experience are becoming more and more important. However, most of the currently available techniques for haptic signal reconstruction are inefficient as a result of requiring either exceedingly complicated processes or poor feature representations. Ang Li *et al.* [25] proposed a long short-term memory-based force reconstruction network (LSTM-FRN) to solve this problem by developing a novel sparse attention module for low-latency reconstruction and a novel metric learning-based constraint for high-precision reconstruction, resulting in a good compromise between computational complexity and feature representation. A massive data collection of acupuncture needle insertions accompanied by synchronized needle motion signals and haptic signals was built to train data for the network. Finally, augmented reality (AR), the LSTM-FRN-based haptic reconstruction, and a skill evaluation subsystem were integrated to establish an interactive needle insertion training system (HapAR-NITS). Extensive trials showed that the suggested combination of technologies makes it possible for our HapAR-NITS to deliver an immersive experience and pleasant manipulation effects.

According to research, including haptic input into virtual reality telemedicine consultations improves therapeutic results. Haptics can contribute useful information to two-dimensional scan images, such as tissue hardness or softness. It can also create lifelike simulations for surgeons and improve access to healthcare for those with impairments.

2.2. Haptics Technology Used in Serious Games

Instead of being played for pure entertainment, "serious games" are played with the intent of solving a problem. They share their medium with casually played video games. Serious games, on the other hand, may keep learners engaged long after they've learned the material and help them master complicated skills [26].

More advanced forms of engagement, such as haptic devices such as those shown in **Figure 2**, have recently been accessible for use in video game design. Six degrees of freedom (DOF) haptic devices allow the user to "feel" the virtual environment in the same way they would in the real world. More realistic and immersive virtual environments may be simulated with the help of 3-DOF/6-DOF haptic devices since they allow for more precise tactile manipulation of virtual objects with force/torque feedback. The use of haptic contact into the design of "serious games" is a promising new area of study. In a 3D virtual world, the user is able to "feel" the surfaces of objects as well as the complicated forces generated by their interactions. Xiyuan Hou *et al.* [27] present two such serious games that make use of haptics. The first "T Puzzle" game allows players to "feel" the weight of virtual items as they rotate and manipulate the 3D puzzle pieces. A player's spatial skills may be improved with the help of this game. The second "Mol Docking" game is a collaborative virtual environment where players may experience the forces of contact between molecular systems and understand the docking process.

Two haptic aided gaming apps, Haptic Handwriting and Ten Pin Bowling, were created by Xu *et al.* [28]. Post-stroke patients can utilize the games to rehabilitate their motor skills. As a means of therapy, the 3 degree of freedom Novint Falcon haptic device is used. The research shows that patients' motor skills, control, and hand-eye coordination can all benefit from the game's emphasis on

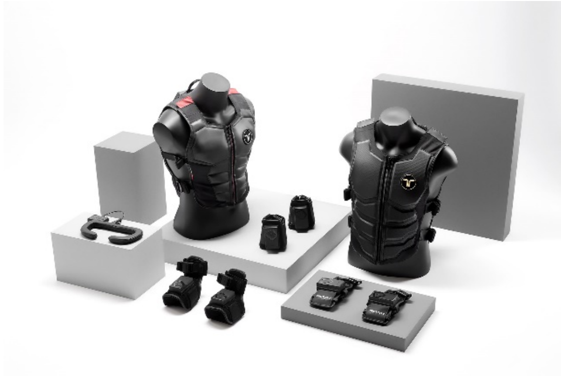

Figure 2. Haptic feedback devices used in gaming.

handwriting. HaptiCast, a first-person shooter-inspired 3D haptic game with 3-degrees-of-freedom, was proposed by Andrews *et al.* [29]. The dynamic movement of in-game objects is simulated using the Newton Game Dynamics [30]. Using the haptic device, the player may command a variety of virtual wands with which to explore the game's digital setting. Lifting, swinging, and throwing are just some of the haptic feedback options available for various wands.

A multiplayer network-based game called Haptic Battle Pong utilizing a 6-DOF haptic device was proposed by Morris *et al.* [31]. Each participant uses a Phantom haptic device to manage a virtual paddle in this cooperative game. The object of the paddle sport is to keep the ball within your own zone while keeping it out of your opponent's. Here, the velocity and penetration distance of the ball are ignored in the force computation in order to execute good haptic depiction. When the ball makes contact with the paddle, the player feels a steady force. For the purpose of instructing students in molecular docking, Sato *et al.* [32] created a docking system that makes use of a haptic device. They did the math to figure out how much force is exerted by one water molecule on another, so that students may experience haptic feedback representing the electrostatic and Van der Waals forces.

The impact of a haptic vest within a virtual reality system is tested and evaluated by Yoshimasat *et al.* [33]. Test subjects have been free to roam the Virtual Environment (VE) while receiving video, audio, and tactile inputs. Participants in the studies have responded to a questionnaire about their experiences with the haptic vest and the VE. Despite the differences in view among the experts, the responses reveal that most users think that the haptic vest is helpful in enhancing the performance of the VE. Subsequent findings corroborate this conclusion by demonstrating that professional users place less weight on thermal stimuli than they do on tactile and thermal stimuli, which are more abstract than real-world experiences. As a whole, it is important to note that the stimuli produced by the vest were sufficient in identifying the events that occurred in the VE in the vast majority of cases. The results of the questionnaire indicate that the haptic vest enhances the sensation of presence and realism in the VE.

Nonfatal and fatal occupational injuries continue to be common in the construction industry. Working with heavy machinery in highly dynamic and constantly changing surroundings poses a variety of dangers. Many practitioners are concerned about the possibility of pedestrian employees being injured by overhead crane loads. Safety best practices advocate for the early deployment of adequate safety training in order to avoid harmful behavior. Serious games in Virtual Reality (VR) have shown to be effective for this aim since they engage and motivate users more than traditional techniques. Most VR experiences, on the other hand, are confined to one player, and tight roleplaying allows for little contact with the risks. The study presented by Ingvilds. M *et al.* [34] shows how an asymmetrical multiplayer serious game in virtual reality might depict a more realistic work atmosphere. The designed scenario includes numerous of the inherent dangers and unexpected human interactions associated in the specific use case of crane lift operations. Three players accomplish their separate job duties in virtuality, with two representing construction site laborers using head-mounted displays (HMD) and one operating a (gantry) crane using a remote desktop computer user interface. The findings of 18 volunteer users' tests suggest that receiving vibrotactile haptic input when presented with risks improves their hazard detection rate. User attentiveness increased by up to while minimizing time spent beneath a crane load.

2.3. Challenges and Limitations of Haptic Technology in Healthcare and Future Prospects

Haptic technology, which involves the use of touch and tactile feedback, has the potential to greatly improve healthcare by providing new ways for patients to interact with medical devices and for doctors to perform procedures. However, there are several challenges and limitations that must be overcome in order for haptic technology to reach its full potential in healthcare.

One major challenge is developing haptic interfaces that are both accurate and intuitive for users. This requires a deep understanding of human touch and perception, as well as the ability to create devices that can accurately mimic the sensations of touch and pressure. Another challenge is ensuring the safety and reliability of haptic devices, particularly when they are used in medical procedures. This requires careful testing and validation to ensure that the devices do not cause any harm to patients or interfere with the effectiveness of the procedure. A limitation is that haptic technology can be expensive and may be too expensive for widespread use in healthcare. There is also the need to address concerns about the ethics of using haptic technology in healthcare, as it could be used to manipulate patients or control their actions.

Despite these challenges, haptic technology has great potential in healthcare. It can be used to improve the accuracy and precision of medical procedures, such as surgery, and to create new ways for patients to interact with medical devices. It can also be used to improve physical therapy and rehabilitation, as well as to develop new treatments for conditions such as chronic pain. In the future, haptic technology is expected to play an increasingly important role in healthcare and medicine.

3. Conclusions

As well as generating neuroplasticity, video games have been proven to help patients with motor rehabilitation by offering settings for the practice of repeated, functionally relevant motions [34]. Rewards, goals, challenges, and the concept of meaningful play are all important to game design, and they are also crucial in the creation of games for rehabilitation. In addition, there have been a number of initiatives to forge a closer relationship between commercial game design and rehabilitative game design, with the former offering insight into variables that might boost motivation and involvement in the latter. Studies using commercial games in rehabilitation have yielded encouraging results, both individually and collectively, in terms of cost, safety, ability, and positive response and, by consequence, enjoyment. The developers of these games follow a number of tried-and-true guidelines in order to increase their chances of creating a product that will sell well and be enjoyed by a wide audience.

However, commercialized gaming systems sometimes lack the required degree of flexibility due to the elimination of medical considerations during development, despite being designed for a large target population. One possible option is to repurpose commercial games with more acceptable input methods such as haptic feedback input devices. The construction of custom-made games and game systems, developed to better fit patients' physical demands while concurrently giving games designed by the same principles, is a far more credible and widespread alternative. This might be crucial for generating patients who are as involved with rehabilitation games as "hardcore gamers" are with the most recent commercial games.

Current research on haptic technology in healthcare focuses primarily on the use of haptic devices for rehabilitation and therapy, such as in the treatment of stroke and spinal cord injury patients. However, there is still a lack of research on the use of haptic technology in other areas of healthcare, such as surgery and telemedicine. One area for future research could be the development of haptic technology for use in minimally invasive surgery, such as laparoscopic surgery. This could potentially improve the precision and accuracy of surgical procedures, as well as reduce the invasiveness of the surgery and recovery time for patients. Another area for future research could be the use of haptic technology in telemedicine, allowing doctors to remotely examine and treat patients using haptic feedback. This could greatly expand access to healthcare, particularly in remote or underserved areas.

Additionally, there is a lack of research on the potential long-term effects of haptic technology on human health and well-being. As the technology continues to advance, it would be important to conduct studies to understand any potential risks or side effects, as well as to ensure that the technology is being used in an ethical and responsible manner.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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