

Research on the Application of Haptic Devices into Virtual Reality

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Abstract. As an important part of virtual reality technology, haptic devices bring much better immersion and interactive to users. Haptic devices are continuously refined so they become more and more realistic with this technology's advancement. Multiple feedbacks, including the initial vibration feedback, advanced force feedback, electrotactile, and thermo-haptic feedback devices, are valuable because they help with complex surgical operations, create immersive gaming experiences, and provide practice-oriented education and training. This paper provides an in-depth analysis of the main applications of haptic devices into virtual reality. It is shown that while haptic feedback and user comfort have been widely applied in the field of highly realistic haptic education, many issues still have not been explored in other areas. Further exploration is needed in customization for specific user needs, the integration of multiple sensory feedback systems, and the reduction of latency to enhance the overall virtual experience. Research into lightweight, wearable haptic devices could also expand accessibility and usability across diverse fields.

Keywords: Haptic devices, Virtual reality, Reality feedback.

1. Introduction

A haptic device is a key component of virtual reality (VR) technology designed to simulate real-world haptic experiences to provide a more comprehensive interactive experience [1]. Haptic devices have been developing and evolving since the introduction of virtual reality technology. Early haptic devices carry out simple vibration functions, such as vibration feedback in gamepads. As technology advancements, modern haptic devices can be applied to simulate different types of tactile effects such as temperature changes, pressure, materials, and others. These devices are designed to apply a variety of advanced technologies, such as airbags, force feedback mechanisms, electrical stimulation, etc. Developing those devices aims to provide users with a more realistic haptic experience in virtual environments [2].

Haptic feedback is of great importance in touch virtual reality. Virtual reality technology provides users with a more immersive experience by simulating real-world scenes and sensory experiences. However, without haptic feedback, users may feel it unreal interactive [3].

Haptic feedback brings users with a haptic experience that is similar to the real world by simulating the texture, shape, temperature and strength of objects. For example, in virtual reality games, when users touch a virtual object, they can feel the object's hardness, smoothness and surface texture through haptic feedback. Such haptic feedback brings user's immersive experiences and increases their interest in the game. In addition, haptic feedback can help users perceive objects' position, distance, and motion in a virtual reality scene. For example, in reality-simulating training, the simulating military battlefields and weapon operations make users feel the presence and attacks of virtual enemies through haptic feedback. Hence, the authenticity and effectiveness of training can be enhanced [4].

2. Haptic Device Technology

2.1. Vibrotactile feedback system

Among haptic technologies, vibrotactile feedback systems are the applied more widely and present users with information through vibrations generated by a motor. This technology is advantageous in its simplicity and low cost. Due to those advantages, it can be applied widely in consumer electronics to provide intuitive physical feedback to the user. As an example, in a smartphone, vibratory feedback immediately alerts the user when a message or call is received. In game controllers, vibration feedback provides player with better gaming experience, such as simulating the recoil of a gun in a shooting game or the vibration of the road surface when a car is moving in a racing game.

As technology development, vibrotactile feedback systems can provide diverse vibration patterns. For example, Immersion Corporation, a haptic feedback technology company, has developed haptic feedback technology that can simulate various physical sensations users experience when they touch a screen, such as clicking, scrolling and rotating. The technology can simulate simple touch sensations and multiple physical sensations through complex vibration patterns. In virtual reality, vibrotactile feedback systems can provide users with a full range of interactive experiences in which vision and hearing are combined. For example, when a user touches a virtual object, the vibration feedback in HTC's Vive controller can provide real tactile sensations, which adds an important sensory dimension to the user's virtual experience.

2.2. Force feedback devices

Force feedback device is an advanced haptic technology that utilizes mechanical actuators, motors, or hydraulics to generate forces that allow the user to feel the sense of touch when interacting with a virtual environment. This technology is particularly important in the application of virtual reality, in which it is necessary to apply precise control because it can provide physical feedback that is almost indistinguishable from the real world.

First, force-feedback technology has been widely applied in the medical field in surgical simulators that help doctors train in a comprehensive simulation prior to an actual surgery. For example, in the da Vinci surgical robot, an advanced force feedback mechanism is applied to allow doctors to remotely control the robotic arm to perform delicate surgical operations. The surgeon can feel tissue resistance and different types of tactile sensations through force feedback, which is very important for successful surgery.

Second, force feedback devices play a key role in engineering and design. Taking automotive engineering as an example, engineers make the best of virtual reality systems with strong feedback to simulate the process of assembling parts of a car. Through such simulations, potential problems at the product design stage can be identified, thus the engineers save the time and cost as required for actual prototyping. For example, international automakers like BMW Group utilize force-feedback equipment for assembly line personnel training to improve assembly efficiency and safety.

Third, in the aerospace field, NASA and other aerospace agencies train astronauts to perform spacewalks using simulators with strong feedback. These simulators mimic the physical forces at work in the microgravity environment in space, giving astronauts a realistic training environment. In addition, this device is applied into military training to provide realistic force experiences of simulated combat or operating combat vehicles, helping soldiers adapt to the physical loads before attending actual combats.

2.3. Electro- and thermo-haptic feedback devices

At present, haptic and thermo-haptic feedback devices have been developed, which marks the beginning of a new stage of haptic technology development. The combination of these technologies not only brings realism to Virtual Reality (VR) and Augmented Reality (AR) in the fields of remote control, education, medical care, and literary creation, but also increases its value in the application into various fields. Haptic feedback technology refers to the interaction between users and electronic

devices by simulating tactile sensations. Various tactile sensors and actuators allow communication with the user through the tactile effects produced by an electronic device. This technology helps enhance the user experience when it is applied in virtual reality and gaming. Simulating physical touch can make users more immersive [5]. In addition, haptic feedback technology helps users operate electronic devices accurately. For instance, vibration feedback is applied to enable user complete responding operation by means of clicks or touches. In short, haptic feedback technology provides users with a more immersive and intuitive interaction experience.

First, electrotactile feedback, also known as electrically stimulated haptics, applies a weak electric current to directly stimulate the skin's nerve endings to produce tactile sensations. Compared to traditional vibrotactile technology, electrotactile feedback enables users to accurately control the type and allows intensive hand sensations to simulate more detailed tactile experiences, such as flicking, rolling, and pressure. Traditional touchscreen devices rely on visual and audio feedback. However, after application of electro-haptic technology, users can feel the physical properties and textures of different objects through the touchscreen. They can feel the surfaces of different materials, such as the smoothness of silk or the roughness of gravel. This technology helps expand the scope to apply touch screens.

Second, thermo-haptic feedback is a technology that simulates the sensations of heat and cold by modulating the temperature of the surface of the skin it touches. Typically, this technology is developed based on the thermoelectric effect, which is a change in temperature caused by an electric current and the change simulates the sensation of going from hot to cold. Thermal haptic feedback devices allow for precise temperature control to create more realistic environments in virtual reality (VR) and augmented reality (AR) experiences. In education and training, thermo-haptic feedback technology helps with the construction of a variety of temperature-related work environments. For example, firefighters can train in virtual environments and improve their skills by experiencing temperature changes at a real fire scene without having to physically face a real hazardous environment. Similarly, thermo-tactile feedback technology can be applied to help students with their medical simulation and enhancement

Third, the combination of electric and thermo-haptic technologies brings users with an all-encompassing multi-sensory experience. This integrated haptic feedback system can provide rich environmental information in complex virtual environments, such as simulating natural disasters or complex physical responses, making the sensation more realistic and comprehensive. For example, in virtual reality games, players can feel the heat of flames and the coldness of metal objects. In addition, after applying electric touch technology, players can even feel simulated raindrops falling on their skin or simulated wind in the virtual world. This sensation enables readers to obtain better immersion into virtual reality and makes the player feel like they were in a completely different world. In the healthcare field, the integration of electro- and thermo-haptic feedback technology with can be applied into pain management. This technology helps patients relieve pain by simulating topical or ice treatments, instead of relying on medication. Additionally, the technology is applied in psychotherapy, such as treating post-traumatic stress disorder (PTSD) by simulating and controlling specific sensory stimuli. These advanced haptic technologies can also be applied into art. Artists can create digital artworks that can be touched and felt, allowing viewers to understand and feel the meaning and emotion of the work through a multi-sensory experience.

3. Styling Haptic Devices in Virtual Reality

3.1. Medical simulation and surgical training

In virtual Reality (VR), applying haptic feedback technology brings great changes to medical simulation and surgical training. The application of this technology not only helps avoid risks in the learning process, but also improves the efficiency of training [6]. Medical students and specialized physicians can now be trained in a fully controlled environment to complete various surgical procedures, including both basic suturing to complex cardiac surgery. Due to the haptic equipment,

operators can feel subtle differences in surgical procedures, including tissue resistance, the contact of equipment with body structures, and the specific sensations of different tissue types.

Realization of realistic haptic techniques. Haptic feedback techniques are essential in surgical training. A simulator can provide accurate force and material feedback because it simulates a needle passing through the skin, cutting tissue, or moving a device through a body cavity. For example, when studying medicine and operating a simulated scalpel in a virtual reality environment, they can feel the change in resistance when cutting different tissues, allowing them to accurately control the depth and intensity of the cut. This feedback is important for distinguishing between diseased tissues, such as tumors, and surrounding normal tissue, as it allows doctors to perceive the difference between hardness and texture through the sense of touch [7].

This technology helps improve learning efficiency and shorten surgery time. According to the American Medical Simulation Association, applying the virtual reality training to apply haptics improves learning efficiency and shortens surgery time. Through repeated simulation training, medical students get familiar with a variety of surgical skills, without causing any risks of patients. In addition, these trainings enhance the doctor's "sensory" acuity during surgery, so that he or she can achieve the goals of the actual surgery faster and more accurately. The da Vinci Surgical System provides an advanced platform for simulators that enable physicians to receive critical haptic feedback. Besides, training the operation of the robotic surgical system improves accuracy of surgery and makes patients more comfortable.

It helps reduce error rates during surgery. Haptic feedback helps with the reduction of surgical error rates. Its application into surgery provides instant information about the position of the device and the force applied, and reduces guesswork during surgery. For example, during arthroscopic surgery training, physicians can learn how to accurately manipulate devices within a joint to avoid unnecessary damage of the surrounding soft tissues. For example, the VIST-C system is designed to simulate complex endovascular surgical procedures, allowing doctors to operate in a dynamic vascular environment. The haptic feedback provided by the system enables medical students to practice completing various procedures without harming the safety of patients.

3.2. Games and Entertainment

Haptic technology brings a sensory revolution in gaming and entertainment. In the past, players could only rely on their eyesight and hearing to interact with the game world. However, owing to the application of the haptic feedback technology, players can interact with the game through somatosensory. This multi-sensory interaction technology not only enhances the immersion of the player, but also increases the realness and attractiveness of the game [8].

Haptic feedback technology is applied by adding various devices, including haptic gloves, haptic undershirts, feedback chairs, and specialized controllers. These devices enable users to achieve haptic sensations by means of vibration, pressure, motion, and so on. For example, when a player picks up a stone in a virtual reality game, the haptic glove can simulate the weight and texture of the stone; when the player is attacked in the game, the haptic undershirt can generate a sense of impact in the corresponding position of the player, increasing the sense of crisis and realism. According to data analyzed by Google in the United States, customer satisfaction with the games has increased by 40% after applying haptic technology. Crucial reasons for the increase include the advancement of the technology and the game developers' skillfully integrating haptic elements into game design. Game developers keep exploring ways to integrate haptic feedback into game stories and mechanics to bring players with more coherent gameplay experience. Teslasuit is a full-body haptic feedback suit that provides detailed tactile feedback to simulate a variety of sensations, such as temperature changes and physical impacts. Players wearing the suit can feel various clothing in the game, including the light flick of a feather and the blowing of a strong wind.

A popular game to apply the advanced haptic feedback technology is Sony's Play Station 5 controller. It can provide accurate vibration feedback to simulate various in-game sensations, such as the tension of drawing a bow or the feeling of walking on different terrains. Manus VR Glove is an

advanced haptic glove that provides detailed hand tracking and tactile feedback sensations. When using this glove, players can sense the size, shape and texture of virtual objects, which in turn enhances the sense of control and satisfaction. The haptic feedback technology is applied to the DXRacer gaming chair to ensure players sit comfortably. This chair can be synchronized with the movements in the games to provide vibration feedback, allowing players to clearly feel the explosions in the game or to feel them shaking on the car track.

While haptic devices brings more possible designs of the games, but they have to face some challenges. On the one hand, the technology applied to this device should be advanced enough to ensure the accuracy and timeliness of haptic feedback. On the other hand, designers should consider how to balance the game's challenge and the haptic feedback's timeliness to prevent over-reliance on haptic alerts. In addition, the designers must ensure the comfortableness and convenience of haptic devices so that players do not feel uncomfortable after playing gaming for a long time. Owing to the continuous development of the technology, haptic devices will definitely be continuously improved and become more and more lightweight and wearable. The haptic feedback in the future may include simulated sensations of taste, temperature and even wind, which will bring players with a fully interactive experience. These improvements will further blur the lines between the real and the virtual world, providing even more opportunities of innovation in the gaming and entertainment industries.

3.3. Training and education in various fields

The application of haptics to virtual reality (VR) has become one of the most compelling technologies of the 21st century. By simulating haptic feedback, it provides users with an unprecedented interactive experience. This technology brings a broader scope of learning and enables learners to learn and practice complex skills in a safe virtual environment. It has been proved that interactive learning methods with haptic devices enable learners to make more progress in learning and to have more sense of engagement than their progress in the traditional teaching and learning. According to one of the relevant studies about haptic technology applied into VR, students who used haptic devices in their self-learning had better memory and comprehended more knowledge than when using only images and text.

(1) In aerospace, haptic devices provide pilots with almost the same sensation as they do in the real navigation through advanced flight simulators. For example, companies like Boeing and Airbus have developed simulators that can reproduce a variety of true navigational situations, including changes in airflow, landing gear expansion and contraction, and even equipment failure in emergency situations. These simulators can simulate an aircraft's flight response in different climatic conditions, such as turbulence and hurricanes, allowing pilots to rehearse and to become familiar with the skills to cope with various complex situations on the ground.

(2) Haptic feedback technology is increasingly important in industrial training. For example, the oil and gas industry uses virtual reality and haptic devices to simulate drilling and maintenance operations. In this way, engineers and technicians can practice applying the high-pressure equipment without actual physical risk and effectively respond to potential hazards. Such simulation training not only reduces the risks of accidents, but also reduces the cost of training.

(3) Haptic equipment is also applied into military training. A variety of virtual reality training system has been developed and applied into the U.S. military. The system covers both simple firearms operations and complex strategic operations. Haptic undershirts, gloves, and other devices provide feedback when a soldier is "hit", which not only brings soldiers with more sense of realism in the training, but also improves the soldier's ability to survive in real combat. In addition, haptic devices also play an important role in battlefield medical rescue training. They allow medical personnel to learn first aid skills in a simulated environment in order to deal with casualties more effectively.

(4) The use of haptic technology in educational institutions has caused the change of the traditional way of learning. In the field of medical education, students can learn surgical skills through virtual surgical simulators. These simulators provide realistic sense of surgical operations, especially the haptic feedback between equipment and tissue. Similarly, in physics and chemistry, students can use

virtual experiments in which haptic devices are applied. These experiments are not only safe, but also help students easily understand abstract scientific concepts.

Overall, haptic devices brought great changes of the traditional methods of training and education in the field of virtual reality. Such devices bring a safe, affordable and efficient learning platform for teachers and students from all walks of life. Owing to technology development, it can be predicted that haptic devices will play an even more critical role in the training and education industry in the future.

4. Conclusion

This paper gives an in-depth overview of the application of tactile equipment in various fields, and summarizes the advantages and disadvantages of their application, and put forward their own opinions. With the rapid development of virtual reality (VR) technology, haptic devices are becoming increasingly important in enhancing user perception and immersion. Advancements in haptic technology have made virtual worlds more realistic, owing to various feedbacks including both simple vibration feedback to advanced force feedback and electro-haptic simulation. In virtual reality, haptic feedback is very important for user perception and behavior. It enhances the user's perception and improves the utility and educational value of virtual reality by simulating real-world haptic signals. However, the application of efficient and accurate haptic devices brings great challenges. For example, no answers have been found about how to provide accurate and diverse haptic sensations without compromising user comfort and system reliability; it is necessary to find out how to achieve complex haptic simulations with limited space and resources. Despite of these challenges, the technical staffs have made significant progress in medical simulation haptic devices, gaming and entertainment, professional training, and educational applications. When applying the haptic devices in the medical field, the doctors and medical students not only improve the surgical skills, but also greatly reduce the risk of actual surgery by simulating the real surgery. In the gaming and entertainment industry, haptic device application enhances player immersion and interactive fun. It is highly possible that the haptic devices will provide risk-free hands-on environments and improve learning efficiency for professional training and education.

In summary, applying haptic devices in virtual reality has proved effective and revolutionary in many fields. Although it is still a complicated task to design highly realistic haptic feedback mechanisms, it's still worthwhile because of its deep impact. Its development in the future is expected to help humans reduce the challenges and further expand the scope of haptic technology application, so users will obtain with richer and more realistic virtual experiences. Despite of the great potential of the application of haptic devices in virtual reality, there are still various obstacles and challenges in the design and implementation of haptic devices, which are analyzed as follows. First, haptic perception is a complex physiological and psychological process, and it is difficult to accurately replicate human haptic perception. In addition, haptic devices should provide feedback in real time, which means that they must be highly responsive and accurate. At the same time, to meet the needs of different users, devices must be designed based on ergonomics and adaptability to ensure users' comfortableness and convenience. Finally, cost control is another huge challenge, as advanced haptic technologies often come with higher application costs.

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