Chapter 13
Applications of Haptic Systems in Virtual Environments: A Brief Review

Alma G. Rodríguez Ramírez, Francesco J. García Luna, Osslan Osiris Vergara Villegas and Manuel Nandayapa

Abstract Haptic systems and virtual environments represent two innovative technologies that have been attractive for the development of applications where the immersion of the user is the main concern. This chapter presents a brief review about applications of haptic systems in virtual environments. Virtual environments will be considered either virtual reality (VR) or augmented reality (AR) by their virtual nature. Even if AR is usually considered an extension of VR, since most of the augmentations of reality are computer graphics, the nature of AR is also virtual and will be taken as a virtual environment. The applications are divided in two main categories, training and assistance. Each category has subsections for the use of haptic systems in virtual environments in education, medicine, and industry. Finally, an alternative category of entertainment is also discussed. Some representative research on each area of application is described to analyze and to discuss which are the trends and challenges related to the applications of haptic systems in virtual environments.

Keywords Haptic systems · Virtual environments · Augmented reality Virtual reality

13.1 Introduction

Humans are in constant interaction with different environments. The interaction is possible through the sense of sight, touch, taste, hearing, and smell. Basic knowledge is learned through the five senses. Particularly, sight, hearing, and touch are essential to acquire knowledge based on the fact that people learn best when they see, hear, and do (Volunteer Development 4H-CLUB-100 2016).

A. G. Rodríguez Ramírez (✉) · F. J. García Luna · O. O. Vergara Villegas · M. Nandayapa
Instituto de Ingeniería y Tecnología, Universidad Autónoma de Ciudad Juárez, Ciudad Juárez, Chihuahua, Mexico
e-mail: alma.rodriguez.ram@uacj.mx

O. O. Vergara Villegas et al. (eds.), *Advanced Topics on Computer Vision, Control and Robotics in Mechatronics*,
https://doi.org/10.1007/978-3-319-77770-2_13

Actually, 90% of what is learned by doing is kept by the person who is learning (Volunteer Development 4H-CLUB-100 2016). So, sigh, hearing, and touch are the main senses that allow us to recognize and perceive an environment. When it comes to virtual environments, such as virtual reality (VR) and augmented reality (AR), the user interacts fully or partially with virtual objects only through sight and sometimes also with hearing. The addition of the sense of touch as haptic feedback from a virtual environment could enhance the recognition and perception of the virtual environment. The computational requirements are essential to accomplish this integration.

The evolution of computers in terms of better processing, graphics, and peripherals has allowed the development of virtual environments. Nowadays, virtual environments have been studied and have been applied in different areas such as medicine, education, industry, military, entertainment, aeronautics, among others. All the areas of applications look forward representing a realistic environment, but interaction of users in virtual environments usually misses the feeling of touch which is essential for a realistic experience.

Part of the human experience of interaction with any environment is touching. A common reaction in users, immersed in a virtual environment, is trying to touch the objects in it. Given the importance of senses for interacting in an environment, some robotic systems represent or simulate senses through the integration of different devices and systems like sensors and actuators. For example, the use of vision, acoustic, and haptic systems are commonly used for simulating sight, hearing, and touch, respectively.

The systems, that represent senses in an artificial way, require either unilateral or bilateral transmission of information through an interface as it is shown in Fig. 13.1. The interface works as a means for the exchange of information. For example, a camera as a vision system may represent sight. A camera, just as sight,

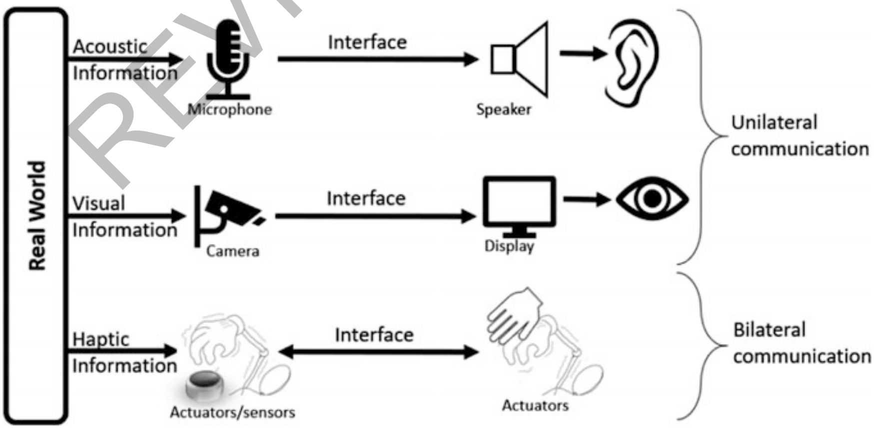


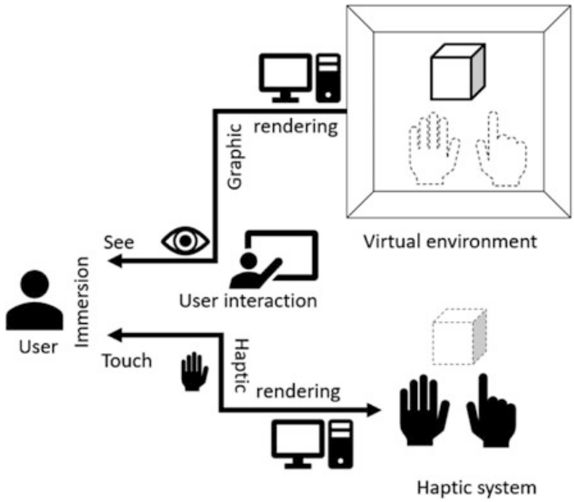
Fig. 13.1 Acoustic, visual, and haptic information acquisition and reproduction

requires a unilateral communication since it captures visual information and displays it on a screen; what was capture does not receive any feedback. When it comes to acoustic systems, the communication is also unilateral. The acoustic system may record an acoustic information and play it through a speaker without having a feedback from the recorder or speaker.

Unlike other senses and systems, touch and haptics require a bilateral communication between the entity and its physical environment. Bilateral communication entails an exchange of information; for example, the feeling a user has when dragging a pencil along a surface involves the exchange of information of the movement of the pencil and the roughness of the surface. Some examples of haptic systems are buttons, vibrators, or complex electromechanical devices that generate reaction forces to emulate the feeling of touch. When it comes to virtual environments such as VR and AR, haptic systems seek to contribute to the immersion of the user by adding information to the interactions with environment. Immersion is a deep mental involvement in something (Oxford University Press 2017). For a user to be involved in an activity, the interaction with the environment is essential.

This chapter is focused on two technologies with the objective of showing how haptic systems have been applied in virtual environments. The interaction of a user in a virtual environment with a haptic system is described in Fig. 13.2. The user will be able to see and touch objects in the virtual environment with a haptic system. So, the immersion is pursued through sight and touch as the user interacts with the environment. The graphic and haptic information is computer rendered so all the information has to be synchronized for the use to feel immersed. Figure 13.2 shows how the graphic rendering generates the virtual object while the haptic rendering generates the haptic information, but both are related; the virtual object generated in the virtual environment is needed to generate the haptic information.

Fig. 13.2 Haptic systems in virtual environments



The virtual environments discussed in this chapter are visual systems based on VR and AR. Haptic systems will be represented as haptic feedback either kinesthetics or cutaneous (discussed in Sect. 13.1.1). Many systems developed by the scientific community, that integrate the feeling of touch, use haptic interfaces. The haptic interface captures information from the environment and sends it to the user to make him/her have the feeling of touch through a device while the device senses the position and force of the user (Lin and Otaduy 2008).

In a virtual environment, users can see and touch rendered objects. Artificial vision systems are carried out by digital image processing techniques, and the generation of images in computer graphics is called graphic rendering. In the case of haptics, haptic rendering is the calculus and simulation of force and/or torque that the user feels when manipulates an object in a virtual environment through a haptic device in real time (Luo and Xiao 2004).

In general, a mathematical model is required to represent the behavior of an object or a system from the real world. A mathematical model of a dynamic system is defined as a set of equations that represent the dynamics of the system (Ogata 1998). When the behavior of an object is mathematically modeled, it is possible to simulate it in a virtual environment. Mathematical models allow to obtain an answer from the interaction between virtual objects and send it to the user through an interface, giving the sensation of touching a virtual object.

There is another way to perceive haptic feedback in a virtual environment; some authors call it pseudo-haptics (Lecuyer et al. 2008; Punpongsanon et al. 2015; Li et al. 2016; Neupert et al. 2016). Pseudo-haptics is the simulation of the haptic sensation when the user interacts in a virtual environment usually through sight. This technique has been proven to enhance the interaction with different materials, helping the user to distinguish them.

The use of haptic systems in virtual environments has increased in the last decades. In Sects. 13.1.1 and 13.1.2, haptic systems and virtual environments are described, respectively.

13.1.1 Haptic Systems

The word haptic refers to the capability to sense a natural or synthetic mechanical environment through touch (Hayward et al. 2004). A haptic system works as a teleoperated system by its bilateral communication nature. Just like teleoperated systems, haptic systems have a master and a slave robot. The master controls the slave's moves; the slave sends feedback to the master in response to the interaction with the remote environment. The objective is that the user, through the master, feels an object even if is not in direct contact with it, the one in contact would be the slave. When it comes to haptic systems in virtual environment, the slave and remote environment are computed, meaning they are virtual (Hayward et al. 2004).

Most of the commercial haptic devices developed are force-feedback based. The lack of realistic touch sensations in the applications is largely due to limitations in traditional force-feedback haptic devices and rendering methods (Aleotti et al. 2016). These are mainly limited in space and transparency.

The fidelity of a system relies on how the feedback is reality like. In haptic systems, the fidelity is called transparency. Some applications require more transparency than others depending on the kind of task carried on. For example, medical assistance applications require more fidelity than entertainment since the user in a medical application interacts with a living patient. In teleoperation applications, if the user is immersed in the remote environment and has the actual feeling of being there, the term of telepresence takes place (Pacchierotti et al. 2014). Telepresence is possible through the feedback that the user receives from the remote environment. The most common feedback in teleoperation is visual and acoustic. To represent completely the human interaction in an environment, all senses should be included. The sense of touch has been taken in count in the last decades though haptic feedback systems.

Haptic feedback may be kinesthetic (position/force feedback) or cutaneous (pressure/temperature feedback). Kinesthetics haptic systems represent the sense of touch through the calculus of contact forces following the physics laws that govern their behavior. Cutaneous feedback is related to the stimuli detected by the skin and relies on measures of the location, intensity, direction, and timing of the contact forces on the fingertips (Pacchierotti et al. 2016).

Ideally, the combination of the two kinds of haptic feedback would represent completely the sense of touch with the constraints of the haptic devices used. For example, Paccierotti et al. (2014) integrated kinesthetic feedback using an Omega 3 (Force Dimension 2017) haptic device and the cutaneous feedback with a non-commercial device developed by the authors. The cutaneous haptic interface consisted of two platforms; one is fixed to the back of the finger and another in the fingertip integrating a force sensor and three 0615S DC micromotors (Faulhaber Group 2017). The system was tested in a virtual environment displaying an object in a computer screen for manipulation. The main objective of this study was to analyze the role of each haptic feedback. Since the stability of a teleoperation system is crucial, it was determined through several experiments that the kinesthetic feedback may bring instability to the system, but it creates more realistic illusion of touch. The cutaneous feedback does not affect the stability of the overall system, but it provides less realism than kinesthetic. The compensation for the feedbacks was not validated for their use in teleoperation tasks because of the performance of cutaneous channel, besides they only considered one degree of freedom (DOF) teleoperation task so it was not realistic for common operations.

13.1.2 Virtual Environments

In this chapter, virtual environments refer to either VR or AR. AR is a mean used to add information to the physical world (Craig 2013) while VR involves only the visual environment without the physical world. Both technologies have in common the generation of virtual information fully or partially in the environment. Typically, virtual objects are computer-generated graphics, so they only represent real objects visually. If the virtual object is programmed to simulate the behavior of its real counterpart, the user will be able to feel it through a haptic interface. We can see virtual objects that are just visual as virtual inert object and the ones programmed with a mathematical model of its behavior as virtual dynamic objects.

On the other hand, motion tracking is an important requirement since its precision, accuracy, speed, and latency affect directly the immersion of the user on its interaction with a virtual environment. AR and VR on their need to place virtual information, either in the real world for AR or keep track of the user in VR, uses image recognition to identify where to place the virtual information and know where the user is. The main techniques are marker and markerless based. Either of these techniques track a mark, and the difference is that marker based uses a digital image processing to identify a physical mark such as an optical square marker, a coated marker with a reflective material (usually a small round object) an array of blinking LEDs, among others. Optical square markers are very popular for their low cost and easy implementation; they consist in a back-square box, of known dimensions, within a white square with an ID mark inside (specific draw, QR code, barcode). Markerless-based technique uses pattern recognition for identify body parts and specific objects to superimpose the virtual information, and also, it could use an external signal such as global positioning system (GPS) to identify where to place the virtual information.

The interaction of a user in a virtual environment requires technology that can accurately measure position and orientation of users and objects of interest as they move in the virtual environment (Rolland et al. 2001). For further information on user tracking technologies and techniques for virtual environments, Rolland et al. (2001) proposed a classification based on the principles of the techniques. The characteristics, limitations, and advantages of each user tracking technique are also described. In Table 13.1, a summary of the classification is shown.

The rest of the chapter is organized as follows. In Sect. 13.2, the objective of the research is presented and so as the databases and selection criteria for the articles described. In Sect. 13.3, the categories of training, assistance, and entertainment for the applications of haptic systems in virtual environments are presented with the description of particular cases. In Sect. 13.4, the discussion about trends and challenges in the integration of haptic systems and virtual environments is presented. Finally, in Sect. 13.5, the conclusions about the issues discussed in the chapter are presented.

13.2 Research Method

The objective of the search presented in this chapter is to show how haptic systems have been applied in virtual environments. When these two technologies are combined, a whole world of application emerges, all seeking for the immersion of

Table 13.1 Classification of user tracking in virtual environments based on (Rolland et al. 2001)

Principle	Classification	Sub-classification
Time of flight (TOF)	Ultrasonic measurements	
	Pulse infrared laser diode	
	GPS	
	Optical gyroscope	
Spatial scan	Outside-in	
	Inside-out	Videometric
		Beam scanning
Inertial sensing	Mechanical gyroscope	
	Accelerometer	
Mechanical linkages		
Phase difference		
Direct field sensing	Magnetic field sensing	Sinusoidal alternating current
		Pulse direct current
		Magnetometer/compass
	Gravitational field sensing	
		Hybrid inertial platforms
		Inside-out inertial
		Magnetic/videometric
	Hybrid systems	TOF/mechanical linkages/videometric position tracker
		TOF/mechanical linkages/videometric 5-DOF tracker

the user in the activity performed. For this research, a virtual environment can be either VR or AR. Four main areas were identified for the application of haptics in virtual environments. Certainly, there are many other areas of applications, but the one described in this chapter circles most of them in a global way.

The databases used for the search were IEEE Xplore (IEEE 2017), ScienceDirect (Elsevier B.V. 2017), ACM Digital Library (ACM Inc. 2017) EMERALD (Emerald Publishing 2017), and Springer (Springer International Publishing AG 2017). These databases are related in general to the areas of computation, technology, engineering, electronics, having also the advantage of having them in the repertory of the UACJ Data Base BIVIR (Biblioteca virtual, virtual library). From the start of the search, the main key words used in the databases were haptics and virtual since this is the technologies of interest. Throughout the investigation, other key words like augmented reality, visuo-haptic, pseudo-haptics, mixed reality, virtual education, virtual training, haptics augmented surgery, and virtual haptics entertainment was used.

The selection criteria for the articles were first based on four areas of application: education, medicine, industry, and entertainment. The researches were not older than 2007 and were taken from journals and conferences related to the two technologies (haptic systems and virtual environments). Finally, other sources used were books, for the fundamental theory and online links, for commercial trends and identification of haptic devices and interfaces.

13.3 Applications of Haptic Systems in Virtual Environments

In this chapter, some works related to haptic systems in virtual environments are described. Three categories are presented: training, assistance, and entertainment. In the first two categories, applications related to education, medicine, and industry will be mentioned. The category of training is based on the application of haptic systems in virtual environments as tools or strategies for acquiring knowledge about a specific task/topic. In contrast, the category of assistance focuses on the application oriented to help during an activity having in count that the user already has the knowledge and experience to do it, but the system is expected to enhance the performance. The final category presented is entertainment. Entertainment industry has played an important role in the development of haptic systems and virtual environments since they have the same objective, the immersion of the final user.

13.3.1 Training

Along their lives, humans are in constant learning. Since humans are born, the process of learning is important, and it starts with the interaction with other human beings and the environment in general. Later, when humans want to acquire an explicit knowledge, they proceed to training activities where the user interacts with a given environment. Haptic systems in virtual environments can be applied in training applications where the user obtains knowledge through interaction and immersion, Fig. 13.3. The user carries on a certain interactive activity; trough sigh and touch, the user is immersed in the activity; the immersion enhances the process of learning; finally, the objective is to acquire certain knowledge. Training is the action of teaching a person or animal a specific skill or type of behavior (Oxford University Press 2017). To enhance the process of training, the integration of different technologies has taken place in the last decades. That is the case of haptic systems and virtual environments.

In general, virtual trainings reproduce an activity and give feedback to the user to get the feeling of doing it on real life. The purpose of training applications is transferring user's knowledge from the virtual experience to real-life operations.

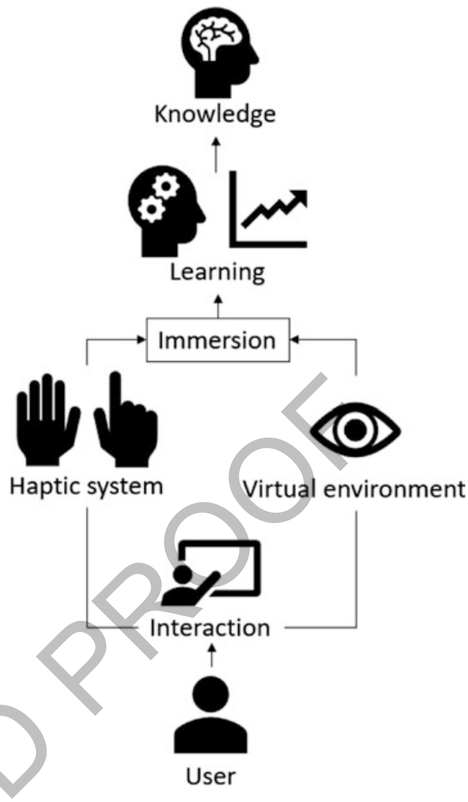


Fig. 13.3 Training applications of haptic systems in virtual environments

This purpose can be achieved through immersion and interaction. If the user has the feeling of reality, he/she will gain certain degree of experience and the ability even if the environment is controlled and safe.

Haptic systems as the feeling of touch in artificial systems work through a haptic interface, while virtual environments simulate the physical surroundings humans interact with trough computer graphics. In combination, these two technologies have tried to enhance different experiences of the user such as the process of training. In the following subsections, some cases of training application are described particularly in the areas of education, medicine, and industry.

13.3.1.1 Education

In general, human machine interfaces (HMIs) are the link between the user and an artificial system, allowing the interaction with computers and machines. Currently, tangible interfaces offer new ways of interaction with virtual objects. Nevertheless, the design of this interface has not been much studied with an educational approach in a spatial learning context (Skulmowski et al. 2016). Lindgren et al. (2016) considered that simulations that use more than one digital technology (mixed reality) help to improve the learning process since they bring with them cognitive and motivational benefits related to immersion and interaction capacity.

Han and Black (2011) incorporated haptic feedback in a physics learning simulator. The study proposed an instructional model for embodied understanding, a theory that suggested that people with perceptual experiences construct multimodal representations to later be able to mentally simulate what is being presented. The instructional model is based on the fact that the first approach to knowledge should be multimodal (visual, auditory, and haptic) and the following instructions had less sensory modalities. The simulator was for experimenting with force transmission through gears. The system included Sidewinder Force-Feedback Joystick II by Microsoft as a haptic interface to generate the feeling of force magnitude needed to spin a gear given an input force. Students could change the configuration of the transmission, composed by four gears, to see how the gears move and the in and out force level (high, medium, and low). The results of recalls, inferences, and transfer tests applied indicated that the addition of haptic feedback had a positive effect in student's comprehension of later instructions with less sensory modalities so as in transfer knowledge to new learning situations.

Potkonjak et al. (2016) discussed about twenty virtual laboratories software based, highlighting the advantages and problems. Some of the advantages detected were the economic saving, the flexibility, the multiple access, the easy adjust of parameters, the resistance to damage, and the capacity to show black boxes. Likewise, some of the problems identified were the computer capacity required, the lack of seriousness from the students caused by the virtual nature of the system, and the fact that the abilities acquired by real experience are different to a simulated experience.

Skulmowski et al. (2016) developed an educational software of 3D (three dimensions) learning that shows a 3D model of a heart with interactive labels of the names of each part. The system consisted in a camera tracking of a plastic heart, and the user held it in one hand while a stylus pen or computer mouse in the other to select a specific part of the heart. The system had two modalities: display and selective. The display mode sets permanent labels in the heart's parts; the user could see all the labels all the time while manipulating the heart's position. In the selective position, the user pointed and clicked the label that wanted to see. The overall system included a Polhemus FASTRAK (Polhemus 2017) motion tracking system and a stylus pen. The comprehension aid of the additional haptic input (plastic heart) is argued to be considerable since it represents a complex structure. In comparison to the subjects who just saw, clicked, and manipulated the heart on a screen, the subjects who had the haptic input required less mental effort according to the tests' results. Also, the selective mode resulted in higher learning performance than permanent display, under certain circumstances.

13.3.1.2 Medicine

Medical applications for training have become popular in the last decades. The benefits that haptic systems and virtual environments bring to the students are mainly based on the possibility of experience a medical procedure without the dangers of treating a living patient. It is certainly difficult to gain the same knowledge through a real experience than through a simulation due to the limitations of the systems in terms of perception of the world and the lack of realistic experiences. With the integration of haptic systems in virtual environments, the user could have a more realistic experience having visual and haptic feedback for medical training.

Rhienmora et al. (2010) developed a dental surgery training simulator. The simulator was developed in two virtual environments using two haptic devices. The system had two modalities, one with VR and the other with AR. In the VR mode, the environment was displayed in a computer screen; the user was able to interact with dental pieces for extraction training. The AR mode used a head-mounted display (HMD); the user manipulated the dental pieces shown also for extraction training. In the second mode, the virtual objects were set using markers. Both modalities required two haptic interfaces Phantom Omni (Sensable Technologies 2016c). It was reported that an experienced dentist confirmed that AR environment had many advantages over VR for dental surgical simulations like the realistic clinical setting.

Lin et al. (2014) developed and validated a surgical training simulator with haptic feedback for safe, repeatable, and cost-effective alternative in learning bone-sawing skill. The system had an Omega.6 as haptic interface and a Display300 as the 3D stereo display. For the haptic rendering, spindle speed, feed velocity, and bone density were considered as variables and multi-point collision detection is method applied. The position and orientation of the virtual tool were continuously updated, according to the position of the end effector of the haptic device. A multi-threading computation environment was applied to maintain, 1000 Hz for haptic rendering and 30 Hz for graphic rendering, update rates. Acoustic feedback was also added. Finally, the validation was based on three experiments: the first proved that the systems were able to differentiate between experimented and novice participants and also improved the performance with repeated practice by decreasing the operative time; the second to prove if the simulator acted as expected; and the third validated the knowledge transfer from training to real procedure in terms of maximal acceleration, and the trained group with lower maximal acceleration suggested that the simulator had positive effects on real sawing.

Chowriappa et al. (2015) developed and tested a training system AR and haptic based for robot-assisted urethrovesical anastomosis (needle driving, needle positioning, and suture placement). The environment called hands-on surgical training (HoST) consisted on a simulator that helps the trainees step by step on the procedures with simultaneous proctoring throughout the training. The experience of the user is visual, auditive, and haptic enable for didactic explanations, annotations, and illustrations in critical steps of the procedure. To evaluate the performance of the training, three tools were used: the Global Evaluative Assessment of Robotic Skills (GEARS) assessment score, the urethrovesical anastomosis evaluation score, and the National Aeronautics and Space Administration (NASA) Task Load Index assessment. Three groups were used for the analysis, the HoST group (received HoST-based training), the control group (video training, not HoST-based), and the cross over group (participants of the control group complete HoST-based training). The urethrovesical anastomosis (UVA) performed in HoST environment was resembled to da Vinci Surgical System. Among all results, according to 70% of all the participants, HoST AR-based environment was as realistic as the actual surgical procedure and 76% felt it was appropriate for learning. In general, HoST and crossover groups had better results in all tests which lead to the conclusion of the improvement in skill acquisition with minimal cognitive demand.

13.3.1.3 Industry

Industry has encounter solutions to train personnel in simulators with haptic feedback. Training personnel is a time- and resource-consuming activity that requires user immersion for it to have an impact on the user's knowledge.

Han et al. (2010) presented the construction of a visuo-haptic training system to satisfy the necessity of training personnel for a production line in manufacturing plants before the actual production begins. The effect of the haptic information for memorize the order of certain positions selected in a plane was studied. The work area covered the reach of an adult person's arm. The haptic interface was a robotic arm, WAM™ Arm. The system was tested in three training modes: visual, visual with haptic feedback, and visual with haptic guide. The visual with haptic feedback had the best results. An observation made was that the haptic guidance annulled the learning performance enhancement under the conditions taken. Passive haptic guidance and alternative guidance algorithms were recommended for better results.

On the other hand, there are industrial training applications for assembly operations. Xia et al. (2012) developed a training system for assembly operations of complex products. The system integrated Phantom and CyberGlove for the haptic feedback in a virtual reality environment. The configuration allowed the user to move freely in a relatively large area. All the data was automatically transferred through a graphic user interface (GUI) from a computer-aided design (CAD) to the virtual environment. The model for the simulation was physics-based taking in count the hierarchical constraints allowing a realistic simulation of the assembly operations. It was proved that the haptic feedback was valuable for the virtual training in the assembly process, using separately Phantom and CyberGlove interfaces. The combination of the two haptic interfaces was not viable for the application since it affected the virtual interaction.

Abidi et al. (2015) identified the assembly operations as the vital process of manufacturing. They developed an assembly training system for the chassis of a blower motor. The development was modular, including the graphic motor module, the physical motor module, and the haptic motor module. In the first module, the virtual environment and objects were developed. In the second module, the physical behavior of the objects was programmed. Finally, the third module was related to the haptic device Phantom Desktop (Sensable Technologies 2016b), now called Geomagic Touch X. In a screen, the user saw the correct order for assembly and then had to do the assembly having the haptic feedback for improving the experience of the virtual assembly task. The case study presented resulted in the identification of the haptic feedback as a beneficial technology for virtual assembly tasks. The importance of the physical features was also identified for the realistic simulation of the assembly task, features like restitution coefficient, control spring stiffness, and other should have been included; so, as a stereoscopic visualization for enhancing the user's immersion.

Carlson et al. (2016) evaluated a virtual assembly task using different combinations of interfaces used by the user. The task consisted in manipulating two different pieces at the same time with two haptic interfaces for insert one in the other. The haptic interfaces used for the first experiment were a Phantom Omni (Sensable Technologies 2016c) and a 5DT Data Glove (Virtual Realities, LLC 2017) and for the second one two Phantom Omni. Several combinations related to the device used by the dominant hand were also made, but it was not proved that there was any significant difference in this combination. The insertion in assembly tasks is a difficult operation for training simulation for the complexity in synchronizing the instruments. In general, it was reported that participants performed equally well in all treatment conditions. The tests did not include gravity force in the objects; the haptic feedback was limited to object's collisions. Either way, the participants showed interest in the experiments.

13.3.2 Assistance

The combination of haptic systems and virtual environments, such as VR and AR, has attracted the attention of assistance applications, mainly in the areas of education, medicine, and industry. Assistance is the action of helping someone by sharing work (Oxford University Press 2017). In this subsection, the cases presented are related to systems developed with the purpose of assisting in different tasks for enhancing the performance, productivity, and/or precision of the user.

Figure 13.4 described how the user interacts with a system through sight and touch with the integration of haptic systems and virtual environments, respectively. The integration of these two technologies contributes to the user's immersion in the task carried on. The overall system has the purpose of aiding the user in a specific task, taking in count that the user already has the knowledge and skills to do it. For example, if the task involves a dangerous procedure, the system could help by warning the user, visually and tangibly, if danger is close. The final objective of this application, and mentioned before, is to enhance the performance, productivity,

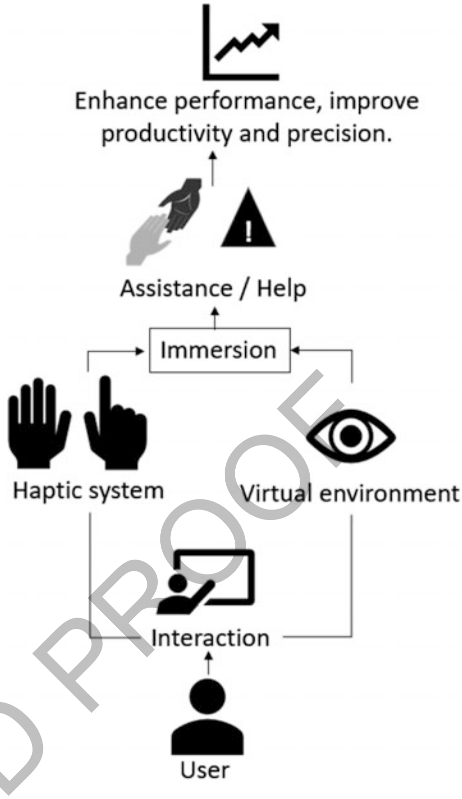


Fig. 13.4 Assistance applications of haptic systems in virtual environments

and/or precision of the user. Unlike training applications, assistance applications assume the user already have the ability or skill to carry on the task and the systems are developed to help the user have a better result.

13.3.2.1 Education

In education, the teachers usually use different tools and strategies to improve the process of teaching. Unlike training applications for education, assistance applications are focused on facilitating the teaching–learning process more than teaching a specific topic. For example, Csongei et al. (2012) developed a system called ClonAR that allowed the user to clone and to edit objects from real world. First, the real object was scanned by a Kinect Fusion (Microsoft 2017). Then, the object was rendered and could be edited in a visuo-haptic AR environment. The information for the rendering was not managed in meshes, instead signed distance fields (SDF) were used because of the Kinect Fusion. They assured the information flow was faster than meshes. The system was tested as a didactic tool, but other possible applications were identified such as medical training a medical education.

Eck and Sandor (2013) defined the term visuo-haptic augmented reality (VHAR) as a technology that allows the user to see and to touch virtual objects. The authors presented a software development platform called HARP that allowed to program VHAR applications. The platform worked either as an educational tool or just for application development. The authors used H3DAPI (SenseGraphics AB 2012), a haptic software development platform that is open source and they complemented it with the Phantom Omni haptic device (Sensable Technologies 2016c). The platform developed was tested and validated by undergraduate students who used it for making different projects. The applications developed in HARP were limited to 30 FPS (frames per second) so the image was reported as looking shaky. Another limitation was that it did not allow the use of more efficient rendering techniques.

Murphy and Darrah (2015) created a set of twenty applications for teaching math and science to students with visual impairments. Certainly, the objective is to teach the students, but the haptic feedback was taken as tool/strategy to improve the teaching–learning process in students with visual difficulties. The haptic device used was the Novint Falcon (Novint 2017). The applications were developed with the haptics software developers kit (HSDK) and the game engine GameStudio. The students were able to select the application of interest and interact with the virtual objects on the simulator through the haptic device having the feeling of touching the objects, and also, acoustic and visual feedback was included. Some of the applications were a plant cell nucleus, volume of shapes, gravity of planets, and exploration of atoms. Six applications were tested in classroom with pre- and post-tests for each application. The results showed, in general, a significant learning gain for all the applications tested, and most of the teachers agreed in the easy to use characteristic of the whole system.

13.3.2.2 Medicine

The rehabilitation of patients is a motivation for the development of systems with haptic feedback in virtual environments. Other important motivation for integrating robotic systems in medical assistance, particularly in surgery application, is having the capacity to perform minimally invasive procedures. The precision of a machine combined with the intuition and ability of a medical doctor is a powerful combination when it comes to surgery. The following researches described are examples of assistance application in medicine.

Atif and Saddik (2010) developed a rehabilitation system based on AR technology and adopted the concept of tangible objects. When a person has a partial paralysis in the body, usually they require rehabilitation assistance. In the system proposed, the user had to manipulate objects in such way that gradually could increase the complexity of the movements based on daily life activities such as handling and moving a cup. The user obtained the haptic feedback through the haptic interfaces Phantom (Sensable Technologies 2016b) and CyberGrasp (CyberGlove Systems Inc. 2017); the visual feedback was obtained from a head-mounted display (HMD) iWear VR920 (Vuzix 2017). The results of the tests coincide with the motivation of the subjects to do the exercises besides the difficulty in depth perception (overcame with practice of the participants). Some of the participants felt arm fatigue because of the weight of the tangible object, but this could be changed in customized exercises depending on the subject's capabilities. In general, the study showed efficiently motivation in patients and the capability of the system to measure important performance factors for the assess of the patient's treatment progress such as task completion time.

Unilateral spatial neglect (USN) is a post-stroke neurological disorder that causes a failure in stimuli response of the brain hemisphere damaged. The patients who have USN present spatial deficits such as stepping into objects when walking and only can dress on side of their body. Tsirlin et al. (2010) studied a therapy application based on a string haptic workbench. The technique for rehabilitation included a space interface device for artificial reality (SPIDAR) and a Fastrack stylus attached. SPIDAR is a device that has a ring suspended by wires, a pair of red and green glasses, and a large screen. An object was displayed on the screen and perceived as a 3D object by the user. Then, the user moved the ring with the finger and had the feeling of touching the object. This occurred when the position of the ring and the object was the same. This illusion was possible because the motion of the string was restricted when the collision occurred. The study revealed that spatial biases could be induced when the user was in a scenario where he/she should avoid a perturbed sensorimotor experience in one side of space. The tests were made with subjects who had to draw a trajectory with the Fastrak stylus and felt a disturbance on one side of the space. For example, when the user traced a line from left to right and the right hemispace as disturbed, they induced a significant bias to the left.

Yamamoto et al. (2012) presented a system for surgical robotic assistance tested in artificial tissue. The system had a pair of haptic devices Phantom Premium (Sensable Technologies 2016a) communicated with a master–slave control and a Bumblebee2 IEEE-1394 stereo-vision camera (FLIR Integrated Imaging Solutions, Inc. 2017). The authors made a prohibited-region user-defined to make sure the procedure was minimally invasive, and the healthy tissues stayed safe. The region of interest was augmented so the user could carry out the task easily and reliability. For the tests, the artificial prostate tissue was reconstructed as the user interacted with it. The task consisted in a teleoperated palpation of tissue to differentiate soft and hardener surfaces, in real time. The forbidden region virtual fixture was found to be useful in the procedure and so as the haptic feedback during the experiments. The force feedback resulted in discontinuities; this could be fixed with modification of impedance and edge geometry of the virtual fixtures according to the authors.

Haptic devices allow users to interact with a remote or virtual environment through the sense of touch (Díaz et al. 2014). Since some surgery devices are manipulated by pedal, Díaz et al. (2014) proposed the use of a pedal with a double haptic channel. The double haptic channel was referred to the hand and foot haptic feedback received during a procedure. The haptic feedback would help the surgeon perform the necessary task not only visual based but also tactile since the surgeon cannot feel what the instrument is touching. The one DOF pedal system proposed consisted in a Maxon RE40 DC motor and a transmission cable (26.66:1), with a

Quantum Devices QD145 encoder. The pedal had a peak torque of 10.72 Nm, a continuous torque of 5.36 Nm, and 15° of workspace. The performance of the haptic pedal was validated on a user-study, with warning signals and resistance to tool's penetration, during a drilling procedure with a double haptic channel. The hand haptic feedback was acquired through a PHANToM 1.0 device with a micro-vibrating electric motor attached at the tip of the PHANToM's stylus. The haptic pedal controlled the speed of the drill, and the resistance torque of the tool's penetration was emulated back to the pedal, so the user could feel that resistance. In general, during the experiments, the users with haptic feedback had a faster reaction to warning signals. The results indicated that the haptic information is helpful during a drilling procedure, and it improves the surgeon accuracy.

Also, haptic systems in combination with VR have helped in diagnosis task and medical analysis. This is the case of the cephalometric diagnosis and analysis, and the current 2D and 3D tools are often complicated, impractical, and not intuitive (Medellín-Castillo et al. 2016). Medellín-Castillo et al. (2016) presented a solution to the disadvantages of the cephalography analysis based on a haptic approach. The proposed system required a haptic device, either a Phantom Omni (Sensable Technologies 2016c) or a Falcon (Novint 2017). Since they used the platform H3DAPI (SenseGraphics AB 2012) (open source haptics software development platform that uses the open standards OpenGL and X3D), the system could interact with any of the two haptic devices. The 2D and 3D crane models were imported in the interface where the haptic interaction was integrated. The user manipulated the crane and had the feeling of touch through a pencil/pen easing the processes of diagnose and surgery planning.

13.3.2.3 Industry

The assistance in industrial applications, by virtual environments and haptic systems, is presented in the cases of assistance for path planning in maintenance assembly/disassembly, motion-impaired operators, and welding. Certainly, the combination of virtual environments and haptic systems could be used in other assistance cases, for example design, manufacturing, and data analysis.

Hassan and Yoon (2010) presented a haptic-based approach for path planning in virtual maintenance assembly/disassembly (MAD). This approach consisted on an automatic system that processed MAD starting by loading the CAD models and then assemble them to their final position to get a sequence table and afterward apply a path planning algorithm; finally, the haptic control mode is applied in the virtual environment. The haptic mode guides the user throughout the maintenance for revision. The 3D algorithm for MAD optimization was based on 3D potential field and genetic algorithm. Computational time was considerable but, the expected results were optimal for the MAD. The haptic feedback was reported as very useful for assisting the user in the simulation process.

Asque et al. (2014), looking to reduce of error rates and targeting times in GUIs for motion-impaired operators in human-computer interaction, presented two haptic assistive techniques using the Phantom Omni. The reduction of this error rates and time targeting in industrial applications could improve productivity and efficiency in human–computer interaction operations. The techniques are based on a virtual plane designed with deformable cones and deformable switches to develop a haptic virtual switch for implementation on existing GUIs. For the experimentation of the techniques, six measurements were defined in terms of characteristics of the clicking operation. Gravity wells and haptic cones were implemented: the first, based on a bounding volume with a spring force toward the center of that volume (Asque et al. 2014); the second, based on the cursor clamping to the apex at the target center by extracting the button position to embed the cones correctly into the mesh of a virtual plane. Finally, deformable virtual switches were developed to help people with physical disabilities target and operate accurately different devices and interfaces. The first experiment of cursor analysis of the haptic assistance proved significant improvements in the measures. The second experiment of the effect of target size (small, medium, and large) and shape showed that only in small and medium, the haptic condition has a significant effect and that target shape has less significant effect on the participant's performance than the haptic condition and the target size.

Ni et al. (2017) noticed that programming remote robots for welding manipulation becomes difficult when the only feedback, from the remote site, is visual information. They proposed an AR application with a haptic device integrated. They used a display for showing the real robot and augment a virtual arm and the end effector. The robot was manipulated by moving the haptic device (PHANToM) remotely. The user got the feedback from the remote robot to the haptic device before the end effector reached the welding surface. This helped keeping a constant distance while the user defined the welding path. The workpiece was captured by a Kinect camera for a 3D point cloud data acquisition. The virtual robotic arm was placed in scene using a marker in the physical workspace of the real robot. The system was tested by ten users with no background in welding or robot programming. The test consisted in recording the path followed to weld two workpieces. The user could choose the welding points as they moved the remote virtual arm as they saw the real scene with the augmented robot on a display. The user-defined paths from the actual welding path were within ±15 mm of the actual path.

13.3.3 Entertainment

Entertainment has become such an important part of our lives that new studies have pursuit the understanding of the "Psychology of Entertainment" (Invitto et al. 2016). Entertainment has been studied with a multidisciplinary approach having in mind that is related to learning, perception, emotions, communication, marketing, science, therapy, and others (Ricciardi and Paolis 2014). That might be the reason why entertainment is an attractive area of application for the developers of haptic systems in virtual environments. In general, the applications of entertainment seek

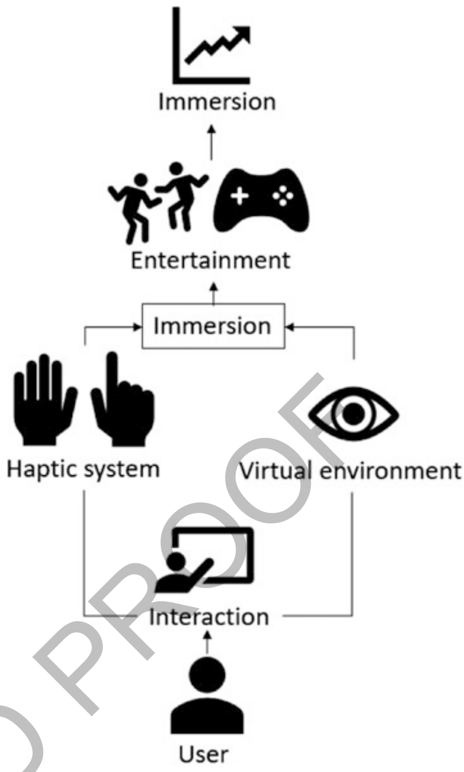


Fig. 13.5 Entertainment applications of haptic systems in virtual environments

for the user to feel comfortable and immerse in the environment given as described in Fig. 13.5. In the case of video games, immersion is usually accomplished through audio, graphics, and simple haptic feedback like vibration.

Other application of entertainment includes haptic systems like the one developed by Magnenat-Thalmann et al. (2007). The system consisted in an interactive virtual environment where the user could fix the hair of a virtual character. The user had the feeling of manipulating the hair by using different virtual tools to comb, wet, dry, and cut. A SpaceBall 5000 (Spacemice 2017) and a Phantom Desktop (Sensable Technologies 2016b) were used, so as an algorithm called virtual coupling based on physics modeling for the haptic representation. The algorithm was also used to link the haptic device with the virtual tools in a stable way.

From Disney Research Laboratories, Bau and Poupyrev (2012) developed a system they called REVEL. The system was based on AR combining visual and haptic feedback to virtual and real objects inserted in the reality. The visual feedback was delivered through a display that allowed the user to see the reality with virtual objects inserted. The haptic feedback allowed the user feeling the virtual object through reverse electrovibration (induce AC signal in the user instead of in the object). The system maintained a constant tactile sensation by adjusting the signal amplitude dynamically to compensate all the varied impedances. The signals generated and applied to the user were safe since the current applied to the user was in the microampere range (max. 150 μA). When the user touched a real object, a capacitive sensing of the touch occurred, and the haptic augmented feedback was delivered from a database. The touch sensing of virtual objects was optical, a user finger tracking through a Kinect. The virtual objects were inserted with markers. The system required an infrastructure previously prepared for the tactile augmentation when touching an object.

Sodhi et al. (2013), also from Disney Research Laboratories, developed the project AIREAL. AIREAL was a device that gave the user the feeling of free air textures. The device consisted of a servo actuated flexible nozzle that generated an air vortex and a camera to measure the target's distance, and the camera was mounted over a gimbal structure. The vortex control was based on four dimensions mainly: pulse frequency, intensity, location, and multiplicity. The experiences of the users consisted on having a projection, for example, over the hand, of an object and the air haptic feedback should coincide with it in space and time. The system could synchronize with others of the same type to create a whole atmosphere. The authors tested the systems simulating an environment where the user felt seagulls flying around while seeing it on a computer game. The system presented by Sodhi et al. (2013) made considerable sound considered as noisy and could make the user feel uncomfortable because of the position of the devices.

On the other hand, Ouarti et al. (2014) developed a test platform to differentiate between a visual, haptic, and visuo-haptic experience of a user in a virtual world. The experiment of interest was the visuo-haptic one where the system had the capacity to make the user feel like being inside of an accelerating car. The user could see on a screen a video generated in a graphic engine for simulating the movement. The system had a Virtuose (Haption 2017) haptic device connected to a mechanism to simulate the movement when the car accelerated. The authors concluded about the importance of the haptic feedback synchronized with the video for the user to be immersed in the game.

Israr et al. (2014) presented a story-telling application. Just like any other entertainment application, immersion was important for the user to have a satisfying experience. The application was kids oriented. The system was capable of making the user felt like it was raining, something walked around, started a motor, and others. Each feeling was classified within a haptic vocabulary list, and it could be intensified as wanted. The effects were also visual and auditory. The system had two modules. The first module was an arrangement of tactile vibrators called tactors C-2 (Engineering Acoustics Inc. 2017) aligned in the back and waist (arranged in a vest). The second module was a graphic interface for the manipulation of parameters of vibrators (mainly time and intensity), this could be shown in a computer or a mobile device. When someone said a phrase of the haptic vocabulary, a vibration corresponding to it was produced.

Punpongsanon et al. (2015) developed a system called SoftAR which was an application of AR where the user could feel the softness of an object. The user could see a projection of a surface over a real object and when the user touched it, he/she saw the deformation of the material projected. The projection created the haptic illusion. The author also identified marketing and design applications of the system, to show clients or designers different options of materials to select based on the softness simulated.

13.4 Trends and Challenges

In Tables 13.2, 13.3, 13.4 and 13.5, a summary of the researches, described in representation of each area of application, is shown. From Tables 13.2, 13.3, 13.4 and 13.5 it should be noted that most of the applications use commercial haptic interfaces, so there are opportunities in the development of customized haptic devices. The design of customized devices could help in the development of more complex, cheapest, specialized, and/or precise applications to enhance the immersion of the user given a specific application. In a future, people will be able to touch virtual information and do it in a natural way just like interacting with the natural environment.

Nowadays, the educational applications, of haptic systems in virtual environments, have impact in society since currently digital technologies are been more incorporated as strategies for teaching. Nevertheless, the access to some technologies may not be at hand for everyone yet one day the use of haptic systems and virtual environments will be used as didactic materials like today we use books and computers. Certainly, with the advantage of access to intelligent mobile devices, it seems feasible to scale different applications in the classroom or for the common use. When it comes to apply haptic systems in virtual environment in training for education, it seemed to be difficult. The difficulty resided in the fact that a virtual experience might not be as good as gaining real experience. Multisensorial feedback has recently been taken as a solution to this problem, integrating different technologies such as computer vision, haptic feedback, and audio effects; it is possible to have a close approach to real tasks. On the other hand, assistance applications for education have big potential for simplifying the teaching–learning process. Teachers will be benefited with the flexibility of educational tool based on haptic systems in virtual environments. The use of multisensorial experiences trough haptic systems and virtual environments has also taken place in medical applications.

On one hand, training medical applications have become very popular in the last decades. The main limitation is the use of commercial haptic devices. The next step in haptic systems development for medical applications is to develop customized devices. The transparency is the main factor of a haptic device; it could be improved by implementing low friction actuators. The development of realistic simulators in virtual environments with haptic feedback has become an important trend given the fact that user in this field requires the feeling of touch to gain the experience needed. On the other hand, medical assistance applications focus on enhancing the performance of the user with multiple feedback of sensory information such as visual and haptic.

Table 13.2 Researches of applications for haptic systems in virtual environments

References	Category	Area of application	Haptic feedback	Haptic interface	VE	Latency/ real time/ frequency	Graphic/haptic Rendering	Subjects	Tracking	Display device
Magnenat-Thalmann et al. (2007)	Entertainment	Entertainment	Kinesthetic	Phantom Desktop and SpaceBall 5000	VR	Real time	Haptic and visual sensory channels are processed in separate threads	–	Simulation	Computer screen
Rhienmora et al. (2010)	Training	Medicine	Kinesthetic	Phantom Omni	VR/ AR	Real time	PolyVox library	Students and two instructors	Marker-based	HMD
Han et al. (2010)	Training	Industry	Kinesthetic	7-DOFWAM Arm	VR	–	Physics-based modeling UDP comms	36	Teleoperation UDP comms	42-inch LCD TV (1920 1080 pixels; LG Electronics Inc., Korea)
Atif and Saddik (2010)	Assistance	Medicine	Kinesthetic and cutaneous	Phantom; CyberGrasp	AR	Real time	ARToolKit; CHAI3D; Open Dynamics Engine; VirtualHand SDK	15	Marker-based	Display or HMD
Tsirlin et al. (2010)	Assistance	Medicine	Kinesthetic	SPIDAR	VR	–	–	15	Fastrack stylus	Stereo google

Table 13.3 Cont. Researches of applications for haptic systems in virtual environments

References	Category	Area of application	Haptic feedback	Haptic interface	VE	Latency/real time/ frequency	Graphic/ haptic rendering	Subjects	Tracking	Display device
Bau and Poupyrev (2012)	Entertainment	Entertainment	Cutaneous	Reverse electrovibration system	AR	Real time; ~150 ms latency	ARToolkit library	2 applications	Kinect Fusion	Proyector; mobile device
Eck and Sandor (2013)	Assistance	Education	Kinesthetic	Phantom Omni	AR	1000 FPS in the haptic loop and 30 FPS for graphical rendering	Parallel graphic render rate	9 projects	Marker-based	Canon VH-2007 HWD
Sodhi et al. (2013)	Entertainment	Entertainment	Cutaneous	AIREAL	VR	~139 ms latency of a vortex	–	5 applications	Depth sensor PMD Camboard Nano; Kinect Fusion	Computer screen/ tablet/ proyector
Díaz et al. (2014)	Assistance	Medicine	Kinesthetic and cutaneous	Phantom Premium and pedal	VR	Real time; 1 kHz sampling rate	dSPACE 1104; OpenGL; virtual springs model	12	Simulation	Computer screen
Ouarti et al. (2014)	Entertainment	Entertainment	Kinesthetic	Virtuose	VR	–	OpenGL	17	Simulation	Computer screen
Israr et al. (2014)	Entertainment	Entertainment	Cutaneous	Tractors tipo C-2	VR	–	–	85	Button to enable the feeling described	iPad

Table 13.4 Cont. Researches of applications for haptic systems in virtual environments

References	Category	Area of application	Haptic feedback	Haptic interface	VE	Latency/real time/ frequency	Graphic/haptic rendering	Subjects	Tracking	Display device
Lin (2014)	Training	Medicine	Kinesthetic	Omega.6	VR	Real time; update rates of 1000 Hz for haptic rendering and 30 Hz for graphic rendering	CHAI3D; OpenGL; multi-threading computation environment	25 × 6	Polaris, NDI Canada; simulation; markerless	Display300
C.T.Asque et al. (2014)	Assistance	Industry	Kinesthetic	Phantom Omni	VR	Real time	CHAI3D API	6	–	Computer screen
Abidi et al. (2015)	Training	Industry	Kinesthetic	Phantom Desktop	VR	RT comms ph-hap eng	OpenGL; GLUT libraries; PhysX; OpenHaptics	Case study: a blower house assembly	Simulation	Computer screen
Parinya and Kosuke (2015)	Entertainment	Entertainment	Visual	Pseudo-haptic	AR	Real time	NVIDIA GeForce GT520 2 GB	17 3 Elastic objects simulated	Marker-based	NEC NP-L51 WD 1280 × 800 70 Hz ANSI lumen
Chowriappa et al. (2015)	Training	Medicine	Kinesthetic	Do not say	AR	Real time	–	52	–	–
Murphy and Darrah (2015)	Assistance	Education	Kinesthetic	Novint Falcon	VR	–	HSDK; GameStudio	32	Simulation	Computer screen

Table 13.5 Cont. Researches of applications for haptic systems in virtual environments

References	Category	Area of application	Haptic feedback	Haptic interface	VE	Latency/ real time/ frequency	Graphic/haptic rendering	Subjects	Tracking	Display device
Skulmowski et al. (2016)	Training	Education	Cutaneous	Stylus	VR	~4 ms latency	The tracked position and rotation was smoothed over 5 frames (approx. 83 ms)	96	Polhemus FASTRAK motion tracking system (six degrees-of-freedom, 60 Hz, 4 ms latency)	24" iiyama ProLite E2473HS screen (1920 1080 pixels)
Carlson et al. (2016)	Training	Industry	Kinesthetic and cutaneous	Phantom Omni/ 5DT data glove	VR	IS-900 at around 4 ms and the patriot at around 17 ms	OpenSceneGraph; VR JuggLua	52	Polhemus patriot magnetic tracker InterSense IS-900 hybrid inertial and ultrasonic tracking system.	Computer screen
Medellín-Castillo et al. (2016)	Assistance	Medicine	Kinesthetic	Phantom omni/ falcon	VR	Haptic device latency	Microsoft foundation classes; visualization toolkit library; H3DAPI	5 2D and 1 3D cephalometric radiographs, 21 dental surgeons	Simulation	Computer screen
Ni et al. (2017)	Assistance	Industry	Kinesthetic	Phantom device	AR	Real time	Point cloud data; Implicit surface of workpieces	10	Marker-based	Computer screen

Finally, the entertainment industry has a considerable contribution in the development of haptic systems in virtual environment. These applications have worked as development platform since their customers demand more immersive experiences in every way, every day. The game developers have proposed themselves to make systems with more quality in graphics, sound, haptic feedback, and more.

If researchers keep looking for new ways to make more realistic environments, more transparent haptic systems and find a way to combine these two technologies in a natural way, the possibilities to have all these applications in our common life grow.

13.5 Conclusions

The technologies of VR, AR, and haptics are in fast growing and have been of great interest of technology innovators. There are infinite possibilities of application in the use of this technology. The researches described were classified in training, assistance, and entertainment with a sub-classification for the first and second one, according to their area of application in educational, medical, and industrial. Nevertheless, some of the authors coincide with the fact that the development of a haptic system in a virtual environment may have a multidisciplinary impact.

Users in all areas demand immersive experiences. The lack of the feeling of touch in virtual environment limits the user immersion and could lead to a low-interest response from the user. Besides the enhancement of immersive experiences, haptic virtual environment-based trainings can improve safe acquisition of technical and basic skills. On the other hand, assistance application meets the benefits of haptic systems in virtual environments by the enhancements of operations in all areas of application.

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