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DESIGNING A MEDICAL TRAINING SIMULATION WITH A 6DOF FORCE FEEDBACK HAPTIC DEVICE IN VIRTUAL REALITY ENVIRONMENT

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Kırklareli Üniversitesi, Fen Bilimleri Enstitüsü'nün 1148203102 numaralı Yüksek Lisans Öğrencisi **HAKAN KISSABOYLU**, ilgili yönetmeliklerin belirlediği gerekli tüm şartları yerine getirdikten sonra hazırladığı **"DESIGNING A MEDICAL TRAINING SIMULATION WITH A 6DOF FORCE FEEDBACK HAPTIC DEVICE IN VIRTUAL REALITY ENVIRONMENT"** başlıklı tezini aşağıda imzaları olan jüri önünde başarı ile sunmuştur.

Tez Danışmanı :   **Yrd. Doç. Dr. Hakan ÜSTÜNEL**   ....
Kırklareli Üniversitesi

Jüri Üyeleri :   **Yrd. Doç. Dr. Evren İŞEN**   ....
Kırklareli Üniversitesi

Yrd. Doç. Dr. İlhan UMUT   ……………………
Trakya Üniversitesi

Teslim Tarihi :   **03.03.2017**
Savunma Tarihi :   **10.04.2017**

To my mother,father,sister,brother and darling,

Tez içindeki bütün bilgilerin etik davranış ve akademşk kurallar çerçevesinde bizzat elde edilerek sunulduğunu, ayrıca tez yazım kurallarına uygun olarak hazırlanan bu çalışmada özgün olmayan tüm kaynaklara eksiksiz atıf yapıldığını, aksinin ortaya çıkması durumunda her türlü yasal sonucu kabul ettiğimi beyan ediyorum.

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Hakan KISSABOYLU
02/03/2017

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PREFACE

First of all, I express my sincere appreciation and deepest gratitude to Asst. Prof. Dr. Hakan ÜSTÜNEL for his guidance and encouraging supports throughout the researching and writing of the thesis.

I would like to thank my family who was with me whole my life, supported me in any condition and made me feel I will never walk alone.

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Finally, I want to thank the woman, who changed everything in my life, made me the happiest man in the world,and give her love to me.

MARCH 2017   Hakan KISSABOYLU
                                                                              Elektrical-Electronics Engineer

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ABREVIATIONS

VR	**:** Virtual Reality	
VRE	**:** Virtual Reality Environments	
AR	**:** Augmented Reality	
HSVRE	**:** Haptic Supported Virtual Reality Environments	
OPENGL	**:** Open Graphic Library	
DOF	**:** Degree of Freedom	
GUI	**:** Graphical User Interface	

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DESIGNING A MEDICAL SURGERY SIMULATION WITH A 6 DOF FORCE FEEDBACK HAPTIC DEVICE IN VIRTUAL REALITY ENVIRONMENT

SUMMARY

In this study, it is aimed to determine the effects and contribution of anatomy and surgery simulation, which will be developed in virtual reality environments supported by force feedback haptic device on the learning skills and speed of health education students who are receiving surgery lessons.

A 6-DOF Phantom Geomagic® Touch ™ haptic robotic device is preferred because it responds to all the planned actions (scraping, haptic interaction, force feedback, etc.) in the application to be developed. VR 2000 Pro dual (HMD) which is a high-resolution virtual reality goggle was used as the external 3D imaging unit. Visual Studio was selected as the software development environment, and coding was done with C ++ based OpenGL libraries.

In application development process, real Computed Tomography (CT) images were used to create a 3D virtual leg including a tibia benign tumor and to design a surgical simulation. This simulation is aimed to allow surgeons to carry out the surgery for a limitless trial before the actual one.

During this research, 35 randomly selected medical students as participants used the developed application. Afterwards a questionnaire, which has 27 questions about haptic supported virtual reality applications, was asked those participants to learn their ideas and feelings about HSVRE application. The data obtained from the questionnaire was analyzed with machine learning by using WEKA software. Learning percentage values were analyzed by examining the results of the analysis to see if learning has come true. Decision trees were created to show the impacts of application for medical education.

It has been found from the results of analyses that HSVRE applications can be used as a lecturing material, enrich the success of learning and prevent ordinary negative consequences like boredom and monotony. Also, learning with HSVRE is more effective than Traditional learning methods.

Keywords: virtual reality environment, haptic devices, benign tumors, virtual surgery simulations, machine learning.

SANAL GERÇEKLİK ORTAMLARINDA 6DOF KUVVET GERİBESLEMELİ HAPTİK CİHAZ YARDIMIYLA TIPTA AMELİYAT SİMÜLASYONU TASARIMI

ÖZET

Bu çalışmada kuvvet geri beslemeli haptik cihaz destekli sanal gerçeklik ortamlarında geliştirilecek bir anatomi ve ameliyat simülasyonu uygulamasının cerrahi eğitimi almakta olan sağlık öğrencilerinin eğitimine katkısı, öğrenme hızı ve becerilerine etkilerinin tespiti amaçlanmıştır.

Çalışma kapsamında geliştirilecek uygulamada yapılması planlanan tüm işlemlere (kazıma, haptik etkileşim, kuvvet geribesleme vb.) cevap verdiği için 6-eksenli Phantom Geomagic® Touch ™ haptik robotik cihazı tercih edilmiştir. Harici 3D görüntüleme birimi olarak yüksek çözünürlüklü bir sanal gerçeklik gözlüğü olan(HMD) VR 2000 Pro dual kullanılmıştır. Yazılım geliştirme ortamı olarak Visual Studio seçilmiş, C++ tabanlı OpenGL kütüphaneleri ile kodlama işlemi yapılmıştır. .

Uygulama geliştirme işlemi için insan gerçek hasta ayak bilgisayarlı tomografi görüntüleri kullanılarak, iyi huylu kemik tümörüne sahip 3D ayak modellenmiş ve sanal ameliyat ortamı tasarlanmıştır. Bu ortamlar ameliyata, ameliyat öncesi hazırlıklar olanağı sağlayıp istenildiği kadar deneme fırsatı sunmaktadır.

Çalışma kapsamında, rastgele seçilmiş 35 öğrenci ile uygulama gerçekleştirilmiştir. Uygulama sonrasında bu öğrencilere haptik destekli sanal gerçeklik uygulamaları hakkında 27 sorudan oluşan anket yapılmıştır. Ankette elde edilen veriler makine öğrenmesi yöntemi ile değerlendirilmek üzere WEKA uygulamasında analiz edilmiştir. Analiz sonucunda öğrenme yüzdesi değerleri incelenerek öğrenme sağlanıp sağlanmadığına bakılmıştır.

 Çıkarımlar sonucunda, haptik destekli sanal gerçeklik ortamları uygulamalarının ameliyat öncesi hazırlık ve eğitim materyali olarak kullanılabileceği, öğrenme başarısını arttıracağı, monotonluk, sıkıcılık gibi negatif etkileri azaltacağı görülmüştür. Son olarak bu uygulamalarla desteklenmiş bir eğitimin geleneksel eğitime göre daha etkili olacağı sonucuna varılmıştır.

Anahtar Kelimeler: sanal gerçeklik ortamları, haptik cihazlar, iyi huylu tümörler, sanal ameliyat simülasyonları, makine öğrenmesi.

1. INTRODUCTION

Root of the word "haptic" lies to Hellenistic Period. It represents the sense of touching. Haptic interaction can be defined in two ways, tactile and kinesthetic. Tactile perception is the perception of pressure applied to the skin by means of touch receptors. Kinesthetic perception is the feeling of the position and movement of the limbs.

Haptic devices are giving sense of touch to users from multimedia images and objects. These devices provide human-computer interaction between virtual objects and the user with touching in virtual reality environments (Figure 1.1). Haptic devices usually address only the user's tactile or only kinesthetic senses.
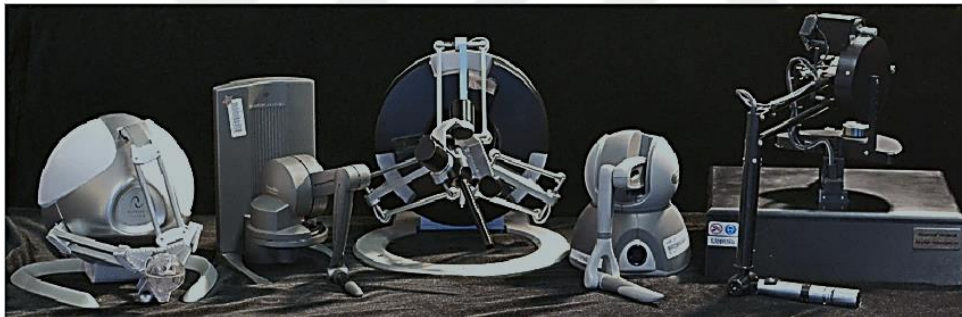
Figure 1.1 Haptic devices being used for human-computer interaction applications[1]

The virtual reality environment is a digital data space that interactively directs the users' senses to the environment in order to artificially reproduce physical reality or to create an alternative sense of reality.

Haptic device and virtual reality environment usage is rapidly growing during last decades, especially in the fields of medicine, entertainment, dentistry, education, military. Despite the fact that many studies have been carried out in these areas, the need for new studies, especially in the fields of military and medical education, is clearly seen.

Haptic supported virtual reality environments (HSVRE from now on) are widely used in health education especially in dentistry, medicine and nursing. Particularly

because of the demand of surgery practices, the hardness of cadaver finding and also deformation on cadavers while used for a few time, traditional education of medical students should be supported by HSVRE applications. Moreover, to extinguish the risks of hygiene and to provide security of patients these applications are thought to be more estimable in medical education [2].There have been too many researches about surgeries prepared on HSVRE. Virtual reality surgical application development[3] and cataract surgeries[4], haptic interaction simulations of fracture surgeries of are some good examples of these researches.

The main purpose of this thesis is to make learning easier, faster and more efficient in subjects which medical students may have difficulty while learning just by anatomy books with the use of haptic technologies and virtual reality environments.

Prior to designing a virtual reality simulation with haptic support for use in the education of medical students, the studies in the field of medicine were examined and the topics that could contribute to the literature were determined by consulting with the health sciences staff.

Subjects such as creation of three-dimensional (3D) virtual organs by coloring a computerized tomography image of a real patient, examination of the internal structure and detection of tumorous areas of these organs are intended to constitute the main structure of the work (Figure 1.2). A haptic supported virtual reality simulation has been designed including these subjects. The virtual organs that medical students will examine in a three-dimensional environment instead of two-dimensional pictures and shapes in books will increase their speed and desire for learning.
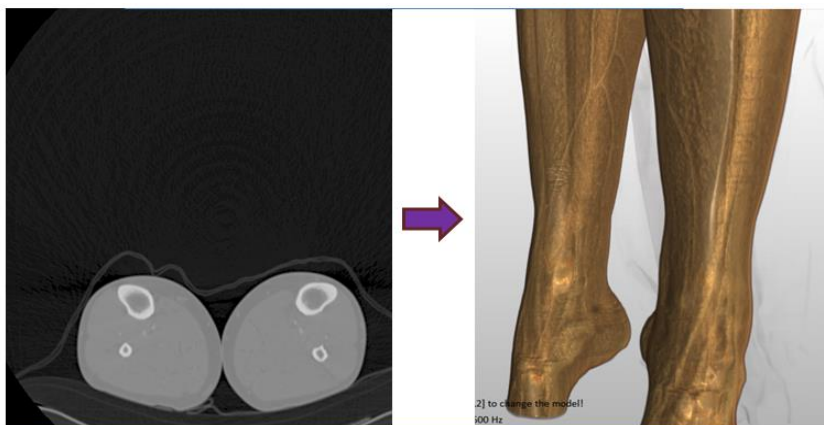
Figure 1.2 Conversion of CT images of lower limbs to 3D haptically visible organs

Haptic supported virtual reality environment simulation of benign tumor resection surgery was coded on Visual Studio environment with C++ codes and OpenGL libraries. The RhinoCeros 3D design program was used during the scaling and shaping of virtual objects. Phantom Omni Geomagic Touch device was used as the haptic device during the study. As display units; Head Mounted Display (HMD) virtual reality glasses, laptop computer and projector are used.

1.1 Thesis Outline

The following sections of the thesis are as follows;

Chapter 2: Virtual reality environments

Chapter 3: Force Feedback Haptic Technologies

Chapter 4: Benign tumors and treatment in Tibia

Chapter 5: Field Study: Resection of Benign Tumor in Tibia with a High Speed Burr by Haptic Devices in Virtual Reality Environments

Chapter 6: Evaluation of the Outcomes of the Implemented Application.

Chapter 7: Discussion and Future Works

In second chapter, literature review about the working principles and usage areas of virtual reality environments was made, and application examples and applications in medicine were given. In third section, the literature about the types, working principles and usage areas of haptic devices with force feedback is searched and information about virtual reality and applications in medicine is given. In fourth chapter, General information about the role of benign bone tumors in medical literature and treatment methods is given. In fifth chapter, selected devices and their technical properties, software development environment, devices used in application and application of software in the field of medicine are given. In sixth chapter, sample of the study, data collection procedure and analysis, analysis of data using machine learning algorithms and findings are discussed. In seventh chapter, interpretations were made on the results of the study, emphasizing the importance of studying for medical education. Studies that could be done in the future were discussed. A block diagram of thesis which is given below in Figure 1.3 shows the block diagram of thesis work outlines.
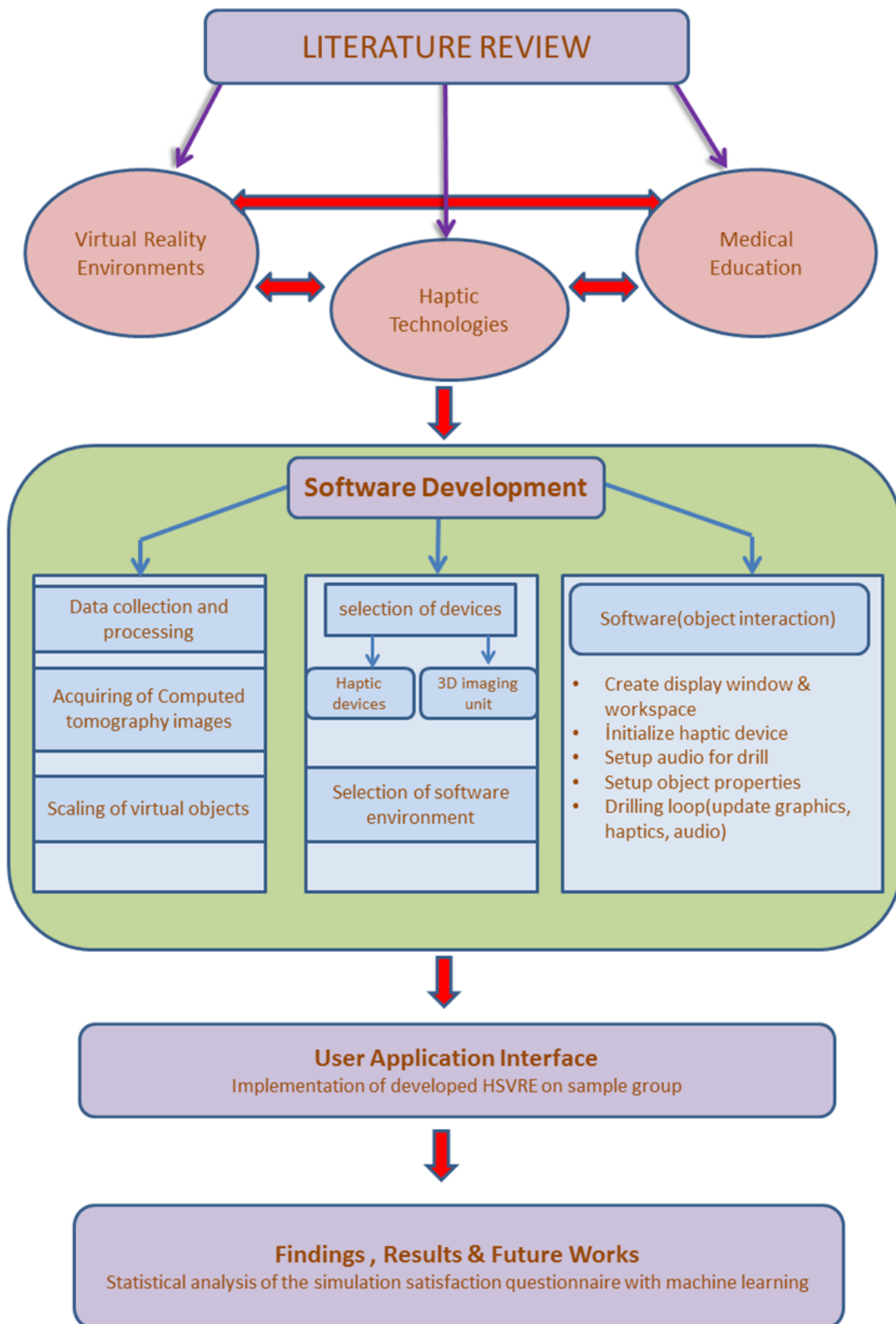
Figure 1.3 Expression of block diagram of thesis work outlines

Literature review has been done on topics of virtual reality environments, haptic device technologies and medical education and interdisciplinary studies of them. Studies about medical education with haptic devices and VRE are increasing but not enough to respond the demands. Creating virtual organs having the same properties as much as similar to real life organism is a crucial issue for medical education with HSVRE. Also, it has been seen that the detection of the tumor zone will greatly facilitate the surgeons' convenience during the surgery. Taking these shortcomings into consideration, firstly the tumor regions to be transferred to the virtual center were determined and tomographic images were obtained. The objects to be used in the virtual environment were created and scaled. Appropriate software environment has been identified. Then, in the virtual reality environment, an application interface for tumor detection and resection was developed. Then the application for tumor detection and resection was developed and the user interface was created in VRE. Samples from health students who were getting surgery and anatomy (including orthoepy lecture) course performed the developed application and answered a questionnaire about the effects of the application. Statistical analyses of the questionnaire have been done and results and future plans were discussed in the end.

2. VIRTUAL REALITY ENVIRONMENTS

Every day, computers and intelligent systems become indispensable parts of our lives. As the computer enters our lives, the usage areas also increase. The usage of computers has gained a different dimension especially when the internet has been actively used. The increase in computer usage inevitably accelerated both software and hardware development. While computers are shrinking, processor speeds, storage capacities, and image quality are increasing day by day. Computers seem to be used as the most basic auxiliary elements in many fields such as health, engineering, education, cinematography, marketing & finance, military.

While computers have taken up so much space in every aspect of life, various researches have been made to reveal different concepts for processing and presentation of information by computers. One of these concepts is "virtual reality". Virtual reality technologies, as the name implies, are technologies that aim to create a sense of reality in the virtual environment.

2.1 Virtual Reality

The use of three-dimensional (3D) objects and environments that provide a more realistic picture is becoming widespread nowadays. The most basic idea of 3D imaging and modeling is the feeling of reality given to the person. The environments that provide this reality are called virtual reality environments.

We can define the concept of virtual reality briefly as "rebuilding of reality". Virtual reality is the environment simulated by computers. Most virtual reality environments are visual experiences acquired through a computer screen. In addition to this, some environments also benefit from other senses such as hearing and movement (Figure 2.1). Virtual environments composed of 3D objects and animations created in computer environment are simulated using 3D image units. The user interacting with the created virtual environment perceives the physical properties of the virtual objects.
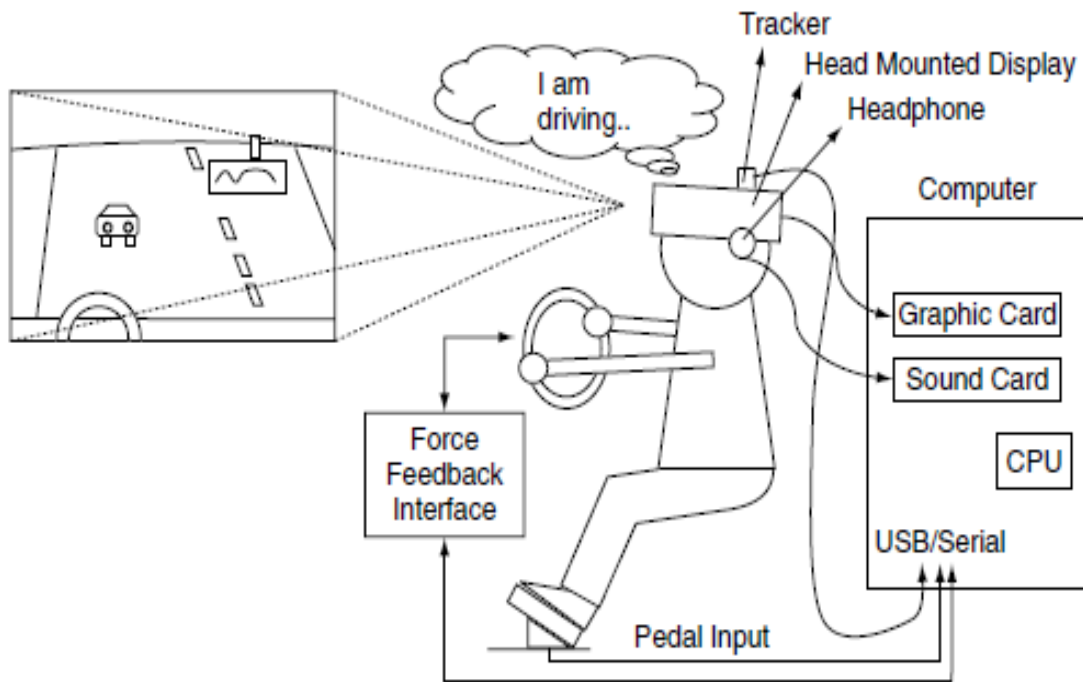
Figure 2.1 A virtual reality simulation system that provides driving training [5]

2.2 Advantages of Virtual Reality Environments

This thesis aims to support traditional education with virtual reality environments. The advantages of virtual reality environments for education are listed and explained below.

- *Transformation of theoretical knowledge into practice:* Virtual Environments allow the theoretical knowledge to be put into practice and become more permanent in the mind.

- *Real life experiences:* Virtual learning environments allow many things to be simulated, such as objects, human movements, logic of workings of machines in real life.

- *Making the course fun and interesting:* In traditional education, especially as the length of lessons increases, it is seen that there is a problem of lack of motivation and focus in the students. A lot of training simulations for virtual reality environments show that these environments are fun and interesting. This allows students to perceive concepts better and not to be bored and to love lessons.

- *Reduction of material and budget needs:* Although using the virtual reality environment has many advantages, one of the most important is reducing

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costs and the need for materials. Sometimes it is difficult to find the necessary materials, sometimes it can be dangerous to use them, and sometimes these materials are quite expensive. Virtual reality environments offer very practical solutions in such situations. For example, in medical education, surgical simulations eliminate the need for cadavers and provide unlimited practicality for novice surgeons.

- *Making complex structures easy to understand:* Virtual environments enable users to learn about physically challenging mechanisms and processes and put them into practice.

- *Useful environments for safety:* Occupational accidents and injuries occasionally occur in learning environments. Practicing in a virtual environment to learn high-risk applications that students may suffer can be a huge security benefit. In medicine, it is also beneficial for the safety of the patient to perform the surgical experiments at the beginning in the virtual reality environment.

2.3 VR Devices

VR2000 Pro Dual^{TM} (Figure 2.2) is a new high-resolution XGA (1024x768) Head Mounted Display which is designed to show 3D applications. The VR2000 Pro Dual^{TM} is used for University, Space, Military, and Medical Researches. Benefits of VR2000 Pro dual^{TM}:

- It gives a Wide 45 degree field of view.
- It allows Stereo 3D with Any Video Card.
- It works almost as compatible with all computers.
- It is compatible for 3D DVD.
- IPD adjustable to accommodate.
- It has a light weight and is small.
- Brilliant, high contrast 800:1.[6]

Figure 2.2 VR 2000 HMD**™**

Ahn and his colleagues developed a software to raise awareness about the destruction of forests in three-dimensional virtual reality environments. Using the VR2000 HMD^{TM}, the developed environment enables the user to realize the tree cutting (Figure 2.3) application in the virtual environment by abstracting from the real world. It is aimed to make the users aware of the trimming of the tree and reduce the waste of paper[7].
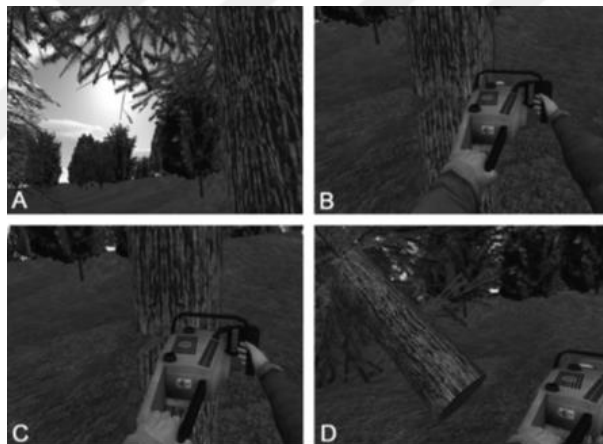
Figure 2.3 Tree cutting in VR

Oculus Rift®(Figure 2.3-b) is a virtual reality eyewear model. (Site) It is a model produced by Oculus® VR Company. The Oculus firm is one of the first companies to adhere to the virtual reality eyewear. DK2 is ultimate development kit of Rift for the programmers to design 3D games and applications [8].

In a study, Xu and his colleagues conducted a study on the examination of the accuracy of Oculus Rift® at the time of the measurement of cervical spine motions[9].

Figure 2.4 a-) HTC Vive^{TM} **b-)** Oculus^{TM} Rift DK2

HTC Vive^{TM} (Figure 2.3-a) is a virtual reality eyewear that HTC has partnered in development with SteamVR. The biggest advantage of the eyewear is the integration of body movements into the virtual world. HTC Vive offers a total resolution of 2160 x 1200 pixels. This means 1080 x 1200 pixel resolutions per eye. The HTC glasses also offer a refresh rate of 90Hz. There is a need for a computer with the following minimum features for the use of Htc Vive [10].

HTC vive was used to develop virtual reality environments for pediatric emergency medicine[11] and for augmented reality applications in neurosurgical training[12].

2.4 Software Environments

Software development environments and programming languages are needed to design virtual reality environments. In the design of virtual environments, mostly MATLAB Simulink, Visual Studio and Python programs are preferred.
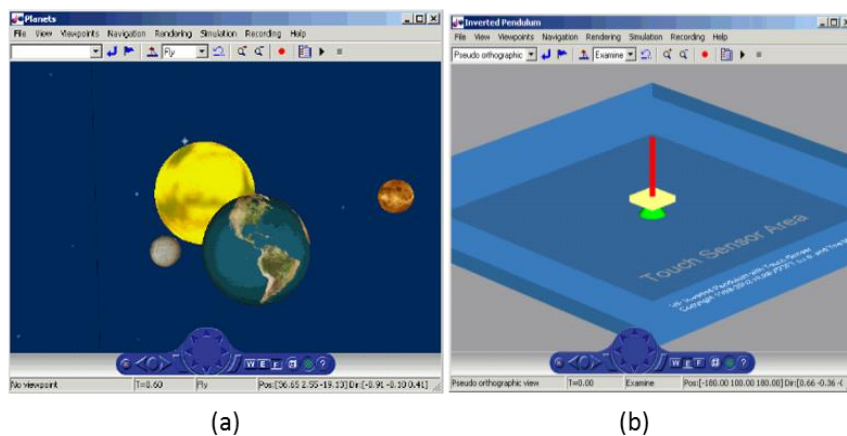
Figure 2.5 An overview to MATLAB Simulink VR Simulation

MATLAB Simulink: With virtual reality toolbox and MATLAB Simulink, 3D animations can be designed in virtual reality environments. The virtual reality modelling language (VRML) should be used to design a virtual reality simulation to run in MATLAB Simulink(Figure 2.4).[13]

Matlab-Simulink and Virtual toolbox was used to design a virtual robot manipulation system animation[14], to design an embedded system simulation[15], and to develope a learning assitant simulation for the students help them in learning of control theory basics[16].
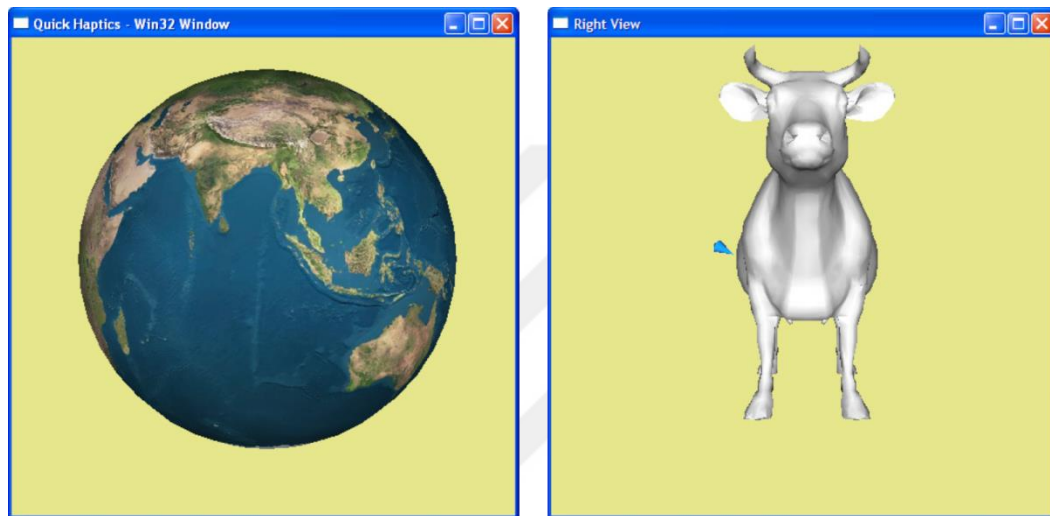
Figure 2.6 VR applications programmed in Visual Studio by Open Haptic API[17]

Visual Studio C++: C ++ is one of the most widely used programming languages. Microsoft Visual Studio Visual C ++ development environment is needed to design virtual reality environment using Open Haptics libraries and OpenGL code with C ++ code. OpenHaptics libraries and OpenGL are used in 3D application development phases. Figure2.5 shows examples of applications developed in visual studio environment using Open Haptics libraries and OpenGL codes.
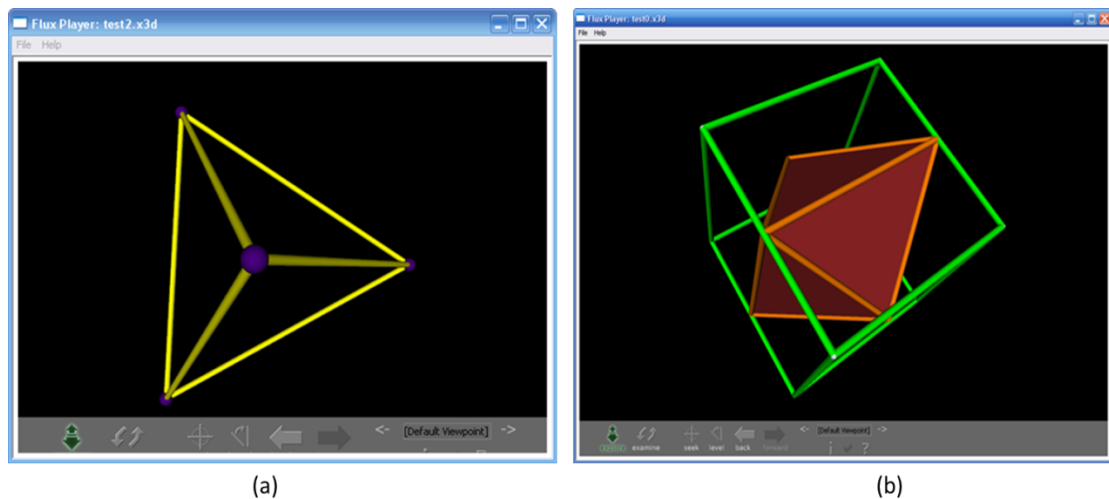
Figure 2.7 VR applications programmed in Python x3D

Python X3D: Python is a high-level object-oriented programming language. Easy-to-use software makes it an ideal programming language for beginners to learn. Python and X3D code are used together to create 3D animations and simulations for virtual reality environment design (Figure 2.6).

2.5 Augmented Reality

Augmented reality (AR) is an enriched view of computer-generated sensory inputs such as sound, video, graphics combined with physical, real-world environments. The arguments that will appeal to the human senses with the increased reality are modified and enriched by the computer and the new reality is presented to the perception of the user. Enrichment occurs in real-time and instantaneously and interacts with the surrounding objects. Augmented reality simply links graphics, sound and other sensory developments to the real life environment. Augmented reality is a technology that can be used in every field and make life easier. Today, the augmented reality technology has begun to be used in archeology, architecture, education, art, health, and military.

In a study an augmented reality application developed in a mobilephone interface to localize Basal Ganglia[18] (Figure 2.7-a). In another study Andersen [19] and her colleagues aimed to develop a medical telementoring by means of AR transparent visualization (Figure 2.7-b). Also, Wang and colleagues has developed an AR based[20] installation system (Figure 2.7-c).
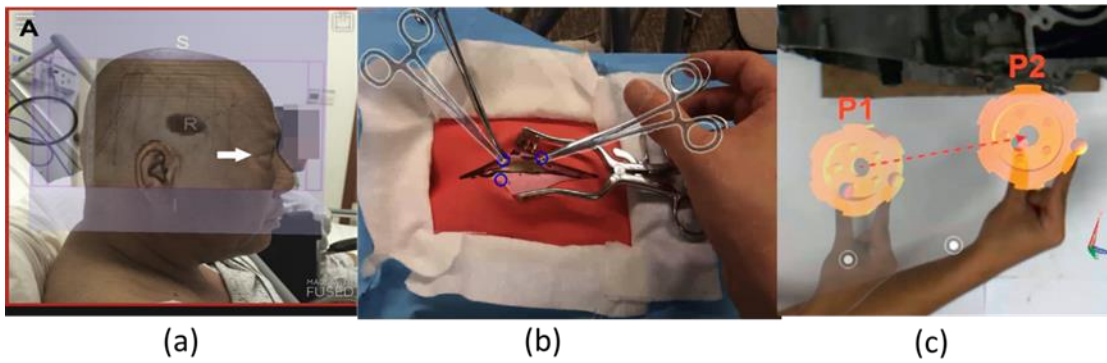
Figure 2.8 a-) A mobilephone based localization **b-)** Medical Telementoring **c-)** AR Installation

2.6 Workspaces of Virtual Reality Environments

As features of virtual reality devices and of computers' video cards and processor speeds evolve, works and their qualities in virtual reality environments are rapidly increasing. A comprehensive review of literature on virtual reality has been conducted. It has been observed that virtual reality environments spread to almost all areas where computer and technology exists. These areas can be listed as medicine, dentistry, nursing, engineering, education, cinematography, entertainment and military (Figure 2.8). Medicine, dentistry and nursing can be evaluated under the health field. Virtual reality environments are often used to develop training simulations in these areas.
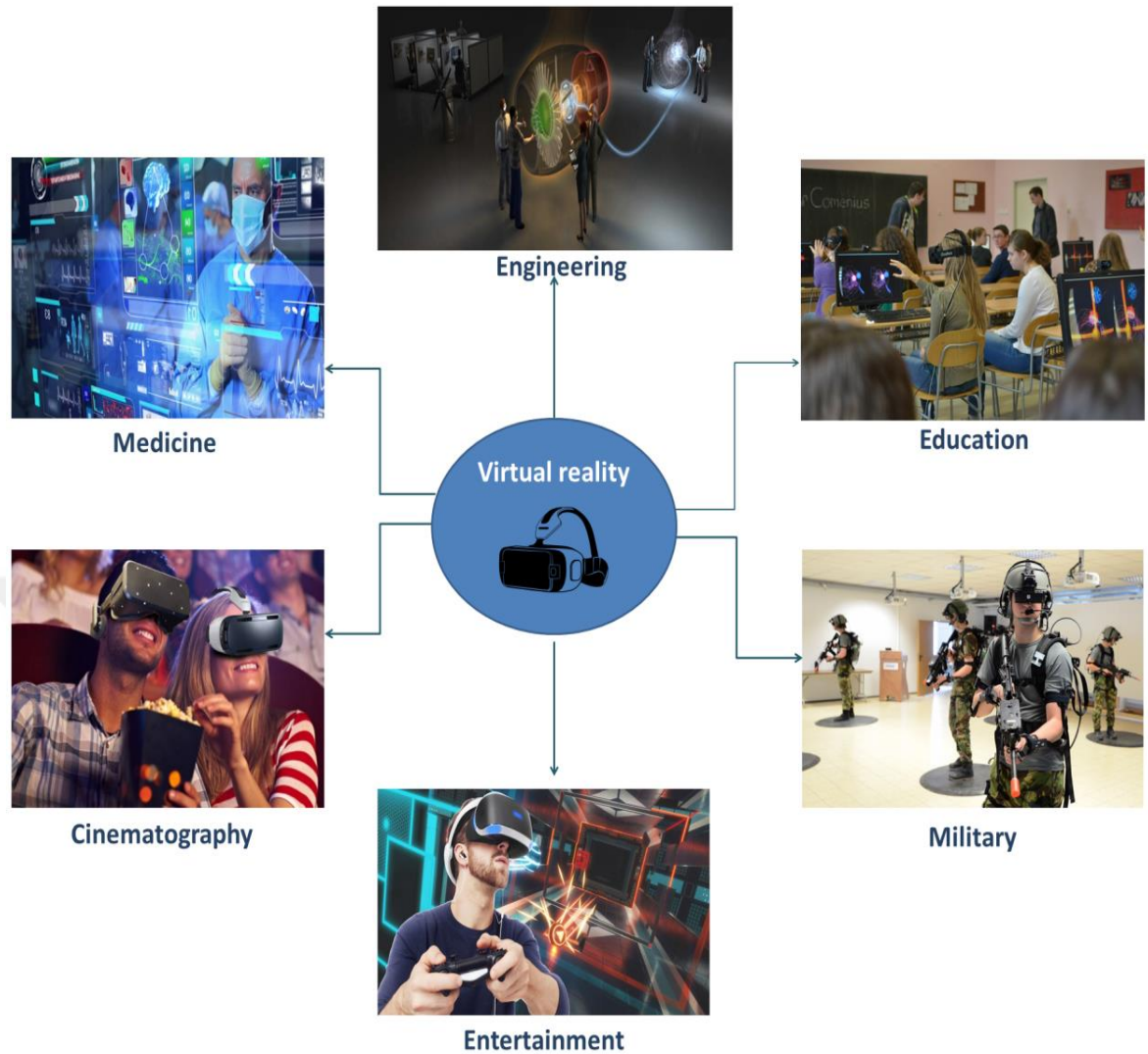
Figure 2.9 Usage of VR has an important place in any field

Education: Virtual reality environments are used perhaps the most for educational purposes. A lot of studies have shown that these environments contribute positively to education. Solak and Erdem have analyzed the studies conducted in the field of foreign language teaching related to virtual reality applications which are becoming increasingly used in educational field. In this study, Solak and Erdem, who use document analysis method, presented suggestions for future studies in the light of analysis of past studies on foreign language teaching. [21]

Training simulations are generally focused on health and military areas. The virtual reality environments frequently used in the rehabilitation of patients and have been used as the training method of soldiers in recent years.

Medicine: Studies in the medical field usually aim to encourage students or interns to virtually see materials that cannot be brought into the learning environment and to support their training. The contribution of virtual reality environments to medical education continues to increase day by day. Simulations such as surgery, rehabilitation, injection are being developed in the virtual environment.

(a)   (b)
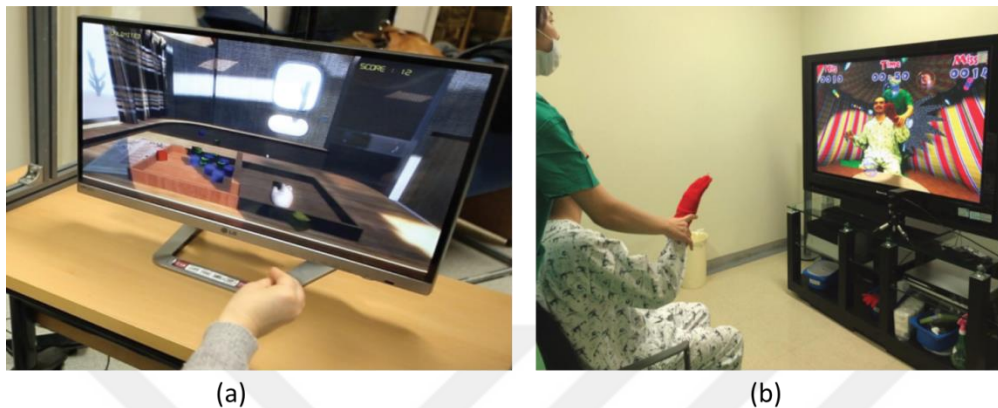
Figure 2.10 virtual reality environment simulation for a-) rehabilitation on the upper limbs of patients with brain tumors b-) stroke patients to grasp objects

Virtual reality environments are being used in development of many rehabilitation simulations with the aim of treatment of the disabled patients. Yoon J and colleagues conducted a study to investigate the effects of virtual reality environments and rehabilitation on the upper limbs of patients with brain tumors (Figure 2.9-a). Within the scope of the study, two patient groups were formed according to age and tumor type. Results revealed that virtual reality-based rehabilitation combined with traditional therapy can give more favorable outcomes than conventional occupational therapies for proximal upper limb function in patients with brain tumors[22]. Another study was conducted about the examination of past motor rehabilitation studies[23]. Sveistrup examined past motor rehabilitation studies of virtual reality environments and aimed to compare the results of these studies with those of rehabilitation in real world applications. Sveistrup noted that, as a result of the applications examined, certain groups had improved motor functions. She also emphasized the importance of applications developed in virtual reality environments that would contribute to certain types of rehabilitation. Cho and his colleagues have developed an application that will increase the ability of stroke patients to grasp objects in a virtual reality environment (Figure2.9-b). They emphasized that stroke is the most important concept that causes disability[24].

Surgical operations have many risks such as infection or even death. For this reason, surgical education is a very serious issue that needs many practices. Because of this, it is very common to work on surgical surgery simulations in haptic supported virtual reality environments. The greatest advantage of surgical education supported by virtual reality environments is risk-free. Since the patient is virtual, there is no risk to damage patient. Also, the limitless training opportunity helps the novice surgeons to enhance their abilities.
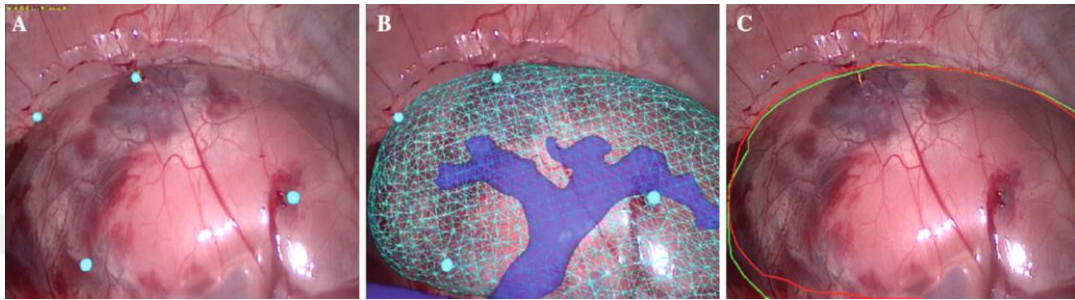
Figure 2.11 Supporting the tumor surgery by VR and AR

Kong and colleagues conducted a study to use 3D organ models created using CT images (DICOM) in virtual reality environment as a navigation tool to find tumors in the surgery (Figure 2.10)[25] .This method is known as augmented reality (AR) which helps the user with virtual images on real-time images. In summary, the study aimed to scan by interlacing virtual models obtained by using CT scan on the deformed kidney.

In another study, a virtual thoracic surgery simulation has been developed for the enhancement of motor skills of the surgeon (Figure 2.11-a). The features of this simulation are a low budget need, simple installation, usability, reducing training process, improving motor skills and provide visual coordination[26] . Another study carried out by Wu et al. in which vessels are colored by digital image processing method (Figure2.11-b)[27].
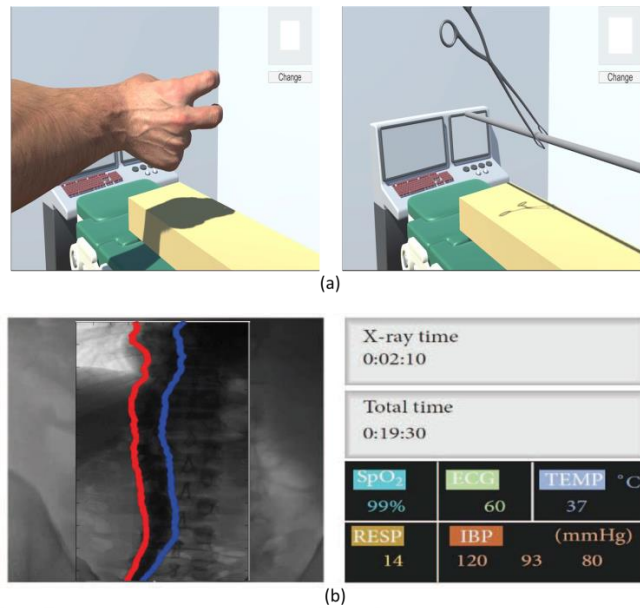
Figure 2.12 a-) Interface of the developed simulation for X-ray images **b-)** enhancement of motor skills of the surgeon

Military: Even the most experienced soldiers experience stress when they enter the armed conflict zone. They go through many exercises and training to overcome this stress. No matter how many exercises they make without the real target in front of them, something is missing. With the developing technology, it is aimed to eliminate these deficiencies with the enemies and targets in virtual reality environments. Virtual reality environments and augmented reality environments are ideal environments for the soldiers to feel in a conflict environment and to prepare themselves for hot clash environments by enabling them to fight against virtual targets. Work on this area was developed to support military exercises.

In a study, Kozlak has searched the development of military skills with the help of virtual reality environments and the use of these environments as educational environments[28]. In another study Rozzi's research describes the design of virtual reality simulation, which is designed to prevent and treat post-traumatic stress disorder caused by conflict in Iraq and Afghanistan[29] In another study, Lele A. emphasized that the use of virtual reality has increased rapidly in many areas, and has addressed the assessment of the suitability of these environments for military application[30] . In addition to these, studies were carried out such as examining the brain damage in the military staff[31] and application development in the virtual reality environments in order to cope with the violent stress of the military staff[32].

In a different study, Cavas and allies aimed to give brief information about the virtual reality environments, and tried to explain the methods and reasons of usage of these environments on education. They enumerated the features of virtual reality environments on education mainly as interaction, accurate collection of the attention of the student, narrative, experiential, importance to senses[33].
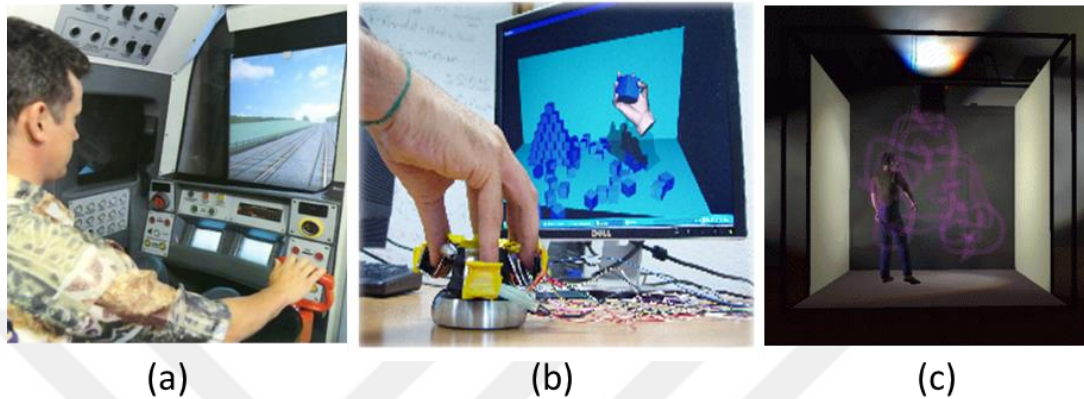
Figure 2.13 a-) Cabin Simulators, **b-)** Destop VR **c-)** Specialized Chambers

Virtual reality environments are divided into 3 parts; Stages, Desktop and Mirror World. The stage virtual reality environment makes the user feel completely in a virtual environment. Head Mounted Displays, Cabin simulators and customized chambers are main examples for the stages. In desktop virtual reality environment, besides the computer monitor, a mouse, a data hand glove or a space ball input system is required(Figure 2.12). In mirror world virtual reality environment, users participate in virtual reality by watching their images spread around.

3. FORCE FEEDBACK HAPTIC TECHNOLOGIES

Understanding of the world starts with touching since the existence of the mankind. People touch the objects to discover the warmth, stiffness, rigidity and softness of them. Traditional education systems are based on two fundamental senses, listening and looking. Unfortunately, these education systems mostly ignore the power of the sense of "touching" on human learning.

Haptic can be determined as sense of "touching". Haptic devices are robots which are designed to give this sense of touching to the user. These devices provide human-computer interaction between objects and the user with touching[34]. Haptic devices enable to manipulate the objects in virtual reality simulations or real object during teleoperation.

One of the main principles is sense of touching for the education with haptic supported environments. Haptic supported Education is differentiating from the other education systems not only with user-computer interaction but also with the usage of the sense of touching[35].

Haptic technology is used in many fields such as medicine, dentistry, military, education, engineering, nursing, chemistry, and neuroscience. Much of the work done in these areas constitutes educational simulations developed in virtual reality environments.

Haptic devices and virtual reality environments are a part of medical and dentistry education of universities in developed countries. However studies on haptic devices and virtual reality environments in universities of Turkey are behind of the developed countries. Human- computer interacted virtual reality environments are critically important to increase the quality of education and catch the technology of the developed countries.

3.1 Haptic Technologies

During the thesis study, a virtual reality simulation with haptic support was designed. This virtual reality simulation is where humans can interact with virtual objects through haptic devices. These virtual environments that haptic devices interact with have a certain working space and volume(Figure 3.1). This workspace is limited and virtual objects can only be haptically visible within this area.
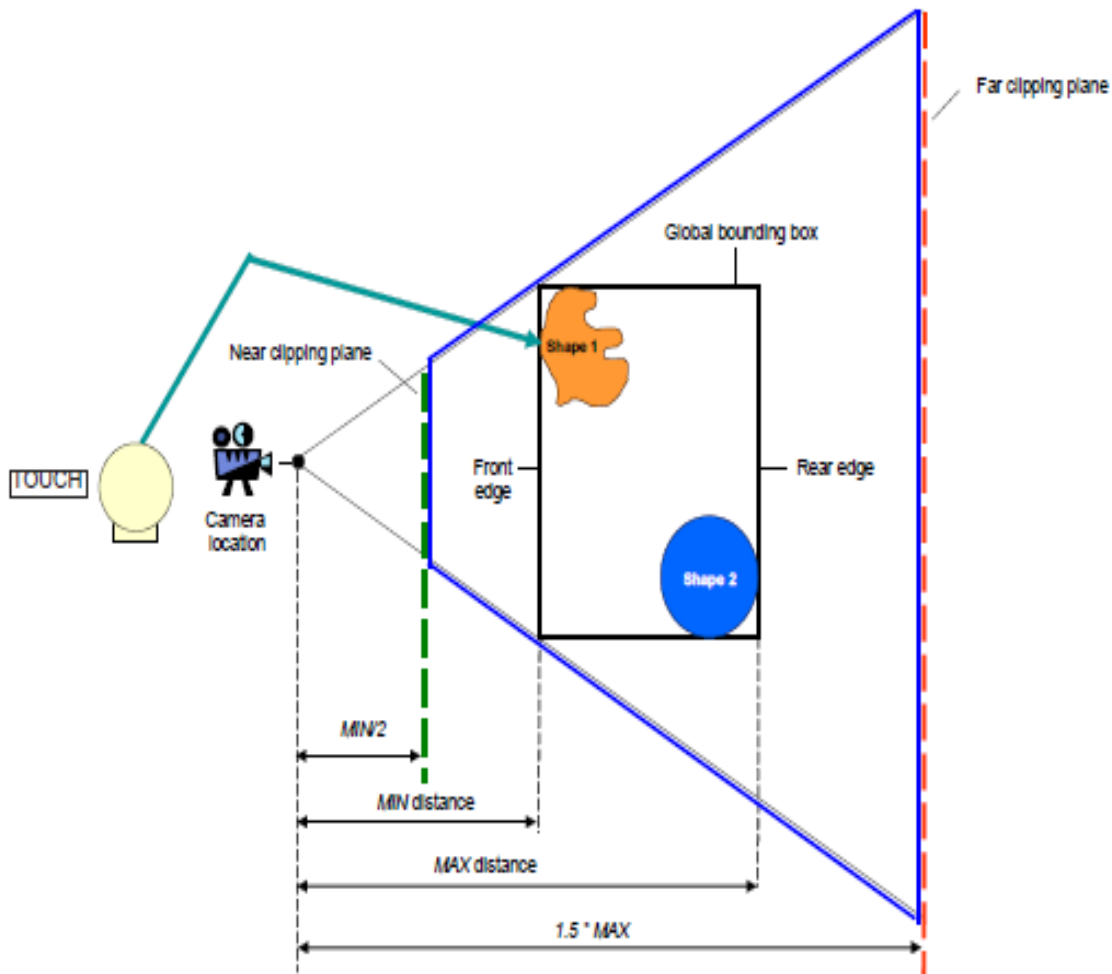
Figure 3.1 Haptic device, Virtual objects, camera position and working space[17]

Haptic concept can be considered as human machine interaction (Figure 3.2). The user can perceive the rigidity, surface friction, weight and shape of the virtual objects with force and tactile feedback in the haptic devices. Force feedbacks are related with object's mass gravitation and velocity whereas tactile is related with the objects shape and friction on its surface[36].
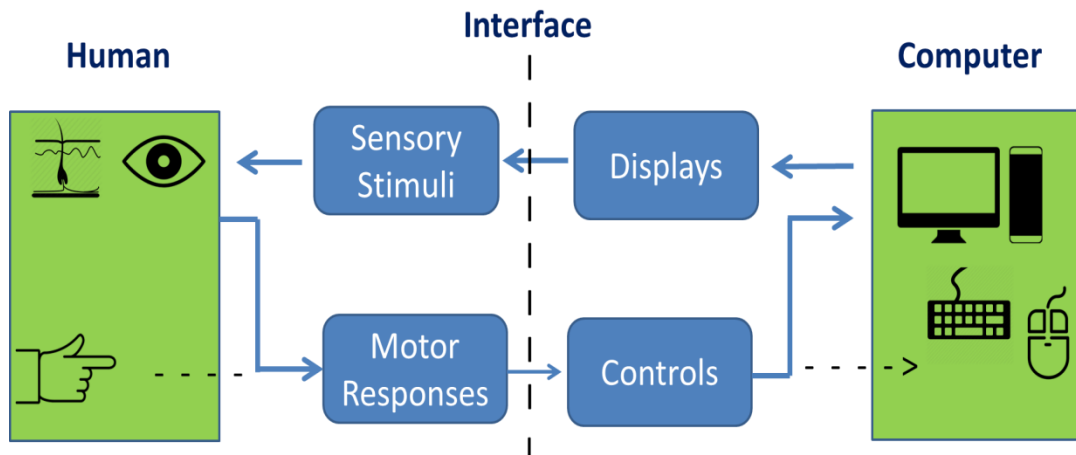
Figure 3.2 A general diagram showing the human-machine interaction scenario.

3.1.1 Force Feedback

When we touch objects, we also perceive many properties such as flexibility, hardness, friction, and temperature of them. For example, when we touch the sponge and stone, we can easily perceive their physical differences (Figure 3.3). It is observed that the sponge's shape changes when a small magnitude of a force applied because of the soft texture. On the other hand, when a force is applied to the stones, it is observed that the hard surface does not stretch even if the applied force is increased.

Figure 3.3 Touching a sponge and a stone to feel the physical differences.

While identifying objects in virtual reality environments, the true definition of physical properties significantly increases the sense of reality during the perception by haptic devices. These physical properties described allow users to perceive objects in the virtual environment by means of force feedback of haptic devices.

Force Feedback allows objects in the virtual environment to be physically detected and matches input-output elements with human-machine interaction. Force Feedback has a very important role in turning the force applied by the user to an action on virtual objects and creating a reaction to this action to move, return, and change the shape of this object. Working principle of force feedback haptic devices is given below in the Figure 3.4.
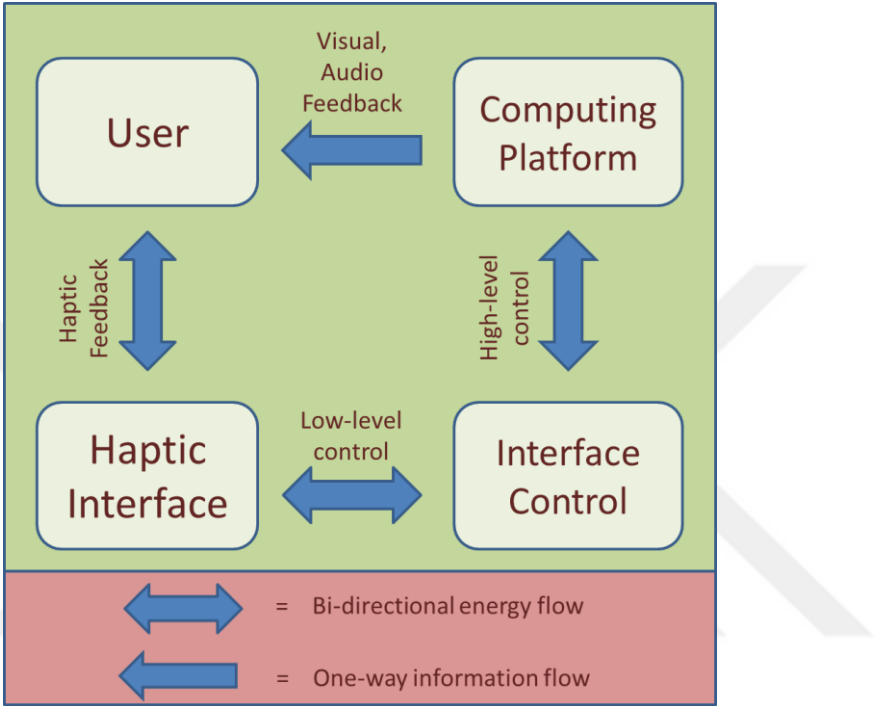
Figure 3.4 Haptic Feedback scheme in VR[37]

A force is applied to the user in response to the system inputs which are position information of the device and the applied force. This is the general working principle of force feedback systems.

3.1.2 Haptic Devices

Phantom Geomagic® Touch™: Geomagic® Touch™ (Figure 3.5), a haptic device produced by Phantom, was selected for the thesis work. The 6DOF robot is preferred because it responds to all the operations (drilling, haptic interaction, buttons etc.) that need to be done. During the drilling (resection of tumors) process position information of the device is very important for a realistic simulation. Position (for X, Y, Z axes) error margin of Geomagic® Touch™ is less than 5% which is an acceptable value for the study.

Figure 3.5 Geomagic® Touch™

Geomagic software and haptic devices are being used by the following industries.

- Medical and surgery
- Toy and action figurine manufacturing
- Jewelry design
- Artwork and sculpting
- Automotive parts and products
- Bakewear and cookery molds and dies
- Architectural hardware products
- Forensic reconstruction
- Shoe design and manufacturing
- 3D Game development[38]

ForceDimension omega 7: Omega 7, a 7-DOF structure produced by the development of the properties of Omega 3, is one of the most advanced haptic interfaces. This device has the features of position detection and active high precision. Sensitivity of the omega7's force feedback feature, which is used in important studies in medical and aeronautical fields, raises the haptic perception to higher levels. Compatible with both right and left hand, this device is also adjustable for dual work. Software development kit has a lot of basic application examples about force and position programming(Figure 3.6).[39]

Figure 3.6 a 7-DOF haptic device ForceDimension omega 7

The Novint Falcon Haptic System: Novint Falcon which was developed as a desktop haptic robot is called as a 3D mouse in some articles. It is a device that physically senses objects in virtual reality environments(Figure 3.7). This device, which is mostly used as a game console, provides a touch output to the hand by its force feedback feature. End-effector of the device is a ball grasp which is attached to a 3-dof arm[40]. This device is prefered to use for the low cost in the development of simple applications.

Figure 3.7 a desktop haptic robot Novint Falcon

MPB Freedom 6: Freedom6S is a 6dof haptic device with high-precision force feedback. The user is able to perceive objects in the virtual environment in a realistic way. This low-friction, high-resolution device is ideal for use as a medical robot. One of the most important features that make the device useful is its high accuracy(Figure 3.8).[41]
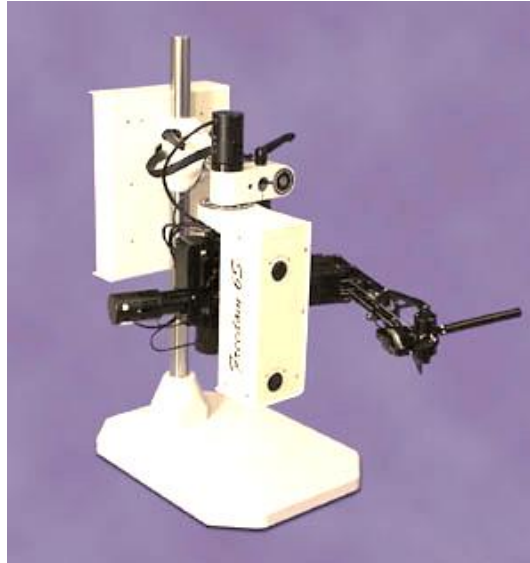
Figure 3.8 MPB Freedom 6

3.2 OpenGL

The OpenGL graphics system is a special software interface used in graphics hardware. OpenGL does not consist of top-level commands that enable you to define models of three-dimensional objects. You need to create objects using a small set of geometric primitives. These primitives are points, lines and polygons.A starting example is given in Apendix1 to observe OpenGL codes. This code is creating a white rectangle in a black background[42].

3.3 Applications with Haptic Devices in VRE

Haptic devices are a very important technological advance that physically connects the virtual world with the real world. Thanks to its physical feedback feature, it is being used in many areas such as art, science and entertainment sector. Haptic device and virtual reality environment are being widely used especially in the fields of education and training of medicine, dentistry, nursing, engineering, military, and chemistry. Haptic supported Virtual reality environments are often used to develop training simulations in these areas.

Dentistry Education: Dental education is one of the most costly areas of education. Materials are very expensive, and when they are not available, they make education harder. Also, dentistry is a field where the mistake to be made will cause serious trouble. For this reason, novice students and interns need to have a good education

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before they meet with the patient. Otherwise, great distress may be caused by patient health. Haptic-assisted virtual reality environments have the potential to significantly support dental applications with force feedback and 3D simulation capabilities. These environments provide unlimited possibilities for students and trainees to train themselves. In the literature study, it has been seen that there are many studies on dentistry, such as tooth scraping, implant placement, examination of the mouth. Thus, students will be able to perform many applications such as tooth extraction, tooth carving, implant placement, tooth filling, etc. in the virtual environment without risk.
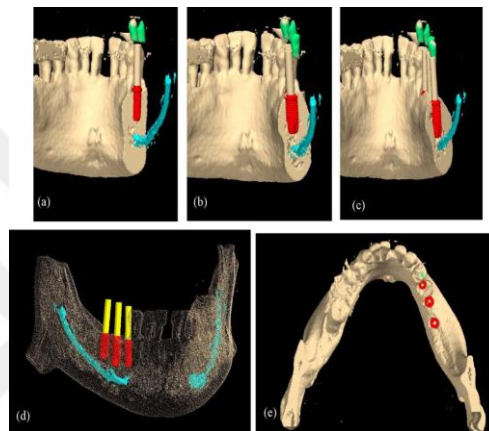
Figure 3.9 Simulation of Implant Placement

Sohmura and Kumazawa carried out a virtual operation simulation study involving implant placement (Figure 3.9), bone drilling, etc. in collaboration with Osaka University and the Dental Prostheses Fabrication Company. A surgical simulation was designed using computer-aided design (CAD) and computer aided manufacturing (CAM) methods with the help of a touch-sensitive haptic device[43]. PAVALOIU and colleagues presented a haptic-assisted virtual reality application to be used as an e-learning tool in dental education in Romania. The basic idea of this work is that the two-dimensional images in books will not be sufficient to learn, so the theoretical knowledge will be better enhanced through 3-D visuals. The Blender application was used to create 3D objects such as teeth, gums and some set of dentistry tools, for use in virtual reality simulation(Figure 3.10). Unity application was used as a software development environment, and the haptic device was introduced by coding in C # language and various applications such as drilling, displaying of mouth were developed[44].
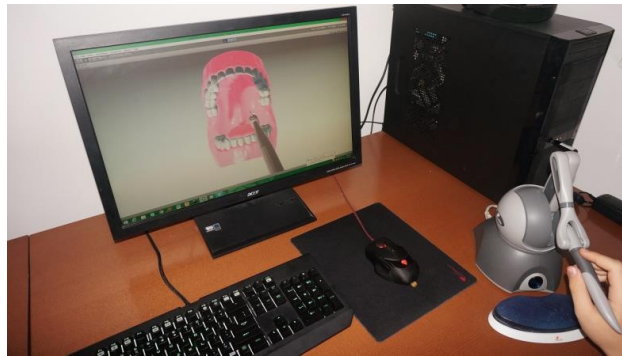
Figure 3.10 A dentistry simulation for training

Medical Education: Surgical operations have many risks as infection or even death. For this reason, surgical education is a very serious issue that needs many practices. Because of this, it is very common to work on surgical surgery simulations in haptic supported virtual reality environments. The greatest advantage of surgical education supported by virtual reality environments is risk-free. Because the patient is virtual, there is no risk to damage patient. Also, the limitless training opportunity helps the novice surgeons to enhance their abilities.

Zhe Xu and colleagues designed a virtual rehabilitation simulation which has a haptic-based phantom robot and a user-friendly software interface to prevent infections that could occur during critical rehabilitation after finger surgery(Figure 3.11). Surgeons and therapists have stated that post-operative therapy is very critical for the complete healing of the patient. It was said that this contact was designed to be minimal, since physical contact after surgery would be painful to the patient. A finger model with anatomical realism has been developed to determine the joint angle and finger position of the patient and a virtual reality environment designed to perform exercises such as music or game control with the aid of this determined angle and position information[45].
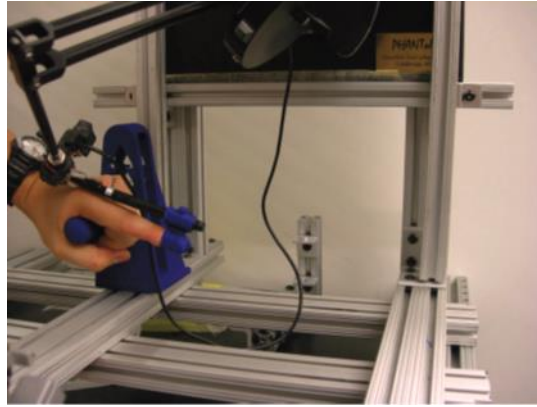
Figure 3.11 Virtual Terapist

Te-Yung Fang and colleagues designed haptic-assisted temporal bone simulations in the virtual reality environment for anatomy training and preoperative preparation (Figure 3.12). They point out that the basis of this initiative is to reduce the use of cadavers and make a more economical and more hygienic virtual work. In the scope of the study, a computer including the software is connected to the phantom Omni device, which is a force feed-backed haptic device. This system includes temporal bone images close to real life colors with high-resolution images. This program offers the opportunity to examine the sinus, inner ear, etc. by adjusting the bone transparency to the user, and also allows the user to observe changes in the temporal bone and the tissue by performing the haptic drilling operation which gives force feedback and lets the user feel the pressure. There were 14 subjects in this work: 7 otolaryngology residents and 7 medical students. These subjects had been taught to be familiar with the simulation. After the education subjects completed a questionnaire about the system. Questionnaire was analyzed with spreadsheet software Microsoft Excel 2010. The results show that the system is highly informative in the field of otology, which is quite satisfactory in terms of usability[46].
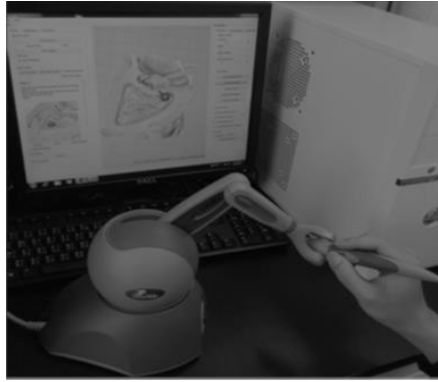
Figure 3.12 Temporal Bone Simulation.

Rasool and colleagues have studied a haptic-assisted simulation of virtual reality environments for invasive arthroscopic surgery, which has a significant impact on the development of motor skills of medical students. Joint image simulations are a work that requires serious effort for program developers in terms of similarity to reality (Figure 3.13). They have succeeded in achieving a realistic solution to this problem using the augmented reality method[47]. Shin and colleagues point out that virtual reality based rehabilitation do not have much work on the effects of the distal upper extremities, and that their studies examine these effects. The overall aim in the study is to examine the effects of virtual reality-assisted rehabilitation and traditional rehabilitation and to compare the findings of stroke patients. Forty-six stroke patients were randomly divided into two groups: Smart Glove (SG) group or a conventional intervention (CON) group. As a result of the studies and test they have predicted that virtual reality assisted treatment can be more effective than traditional treatment[48].
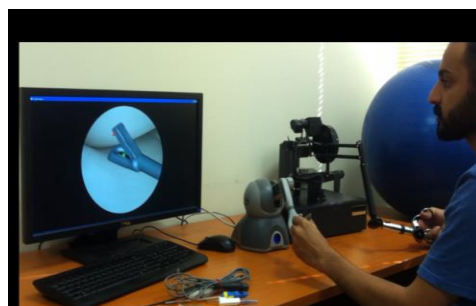
Figure 3.13 A surgery application with two haptic devices

POPOVICI and his colleagues conducted a study on the selection of the appropriate device and system according to the work to be done in the technology of virtual reality environments used in education. In the scope of the study, the

successful works performed in virtual reality environments in the field of education have been underlined, the haptic concept has been defined, various haptic devices have been discussed, and open source software development environments have been introduced. Finally, their past two projects; Virdent (a dental haptic application) and HapticMed (Haptic Liver palpation simulation) have been introduced[49]. Barrow and colleagues point out that there is not much work on orthopedic trauma surgery and the existing studies are usually lacking in true haptic and force feedback, providing only basic visualization, rather than focusing on anatomical knowledge. In order to solve this problem, it was aimed to measure the average force and torque required by drilling the femur with 5 surgeons who are experts in orthopedic trauma surgery. As a result, it has been reported that the measurements is being used to create a more realistic simulation[50].
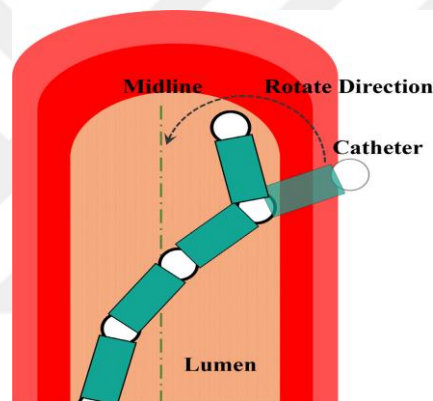
Figure 3.14 The action of catheter during collision

Chen and colleagues designed a haptic assisted and visual feed-backed virtual reality simulation for novice surgeons on the cardiac catheterization which has become an important treatment of atrial septal defects (ADS). The general working principle of the simulation is to give force feedback in case of collision of the catheter with the vessel walls and to change the direction of the catheter after this collision (Figure 3.14). The results show that the resistance generated on the vessel walls during catheterization is very close to reality and that these simulations can be used to achieve the desired output of the training of treatment for atrial septal defects[51]. In another study, a hand rehabilitation glove(Figure 3.15) which is aimed to help the healing of disabled people's rehabilitation and can memorize their movements was introduced[52].
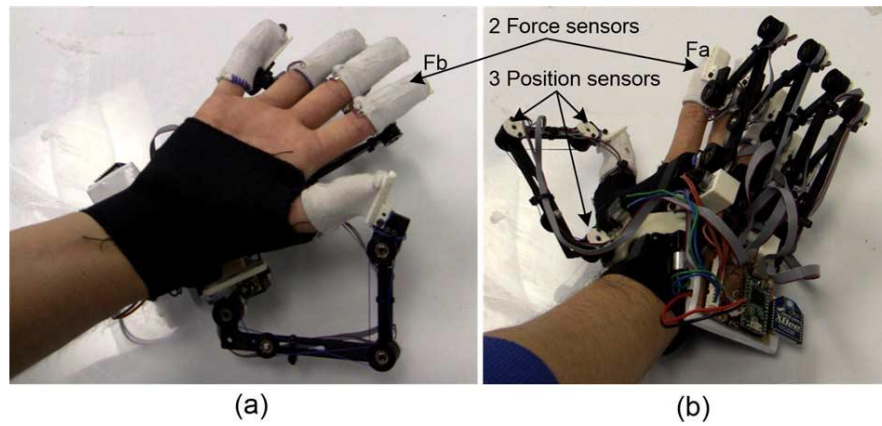
Figure 3.15 haptic-rehabiliation glove

The efficiency of haptic supported virtual reality environments was also seen in numerous medical training as data imaging[53], game development for rehabilitation [54], nasogastric tube placement[55], endoscopic surgery[56], robot-assisted surgery[57], Neurosurgery[58], Stereoscopy[59], and also in bone-sawing[60].

4. BENIGN TUMORS IN TIBIA AND TREATMENTS

In order to support medical education, it is aimed to make a study on haptic assisted surgical simulation design in virtual reality environments. The simulation scenario is determined as three-dimensional examination of the benign tumor placed in the abdominal tibial bone and the resection of this tumor with a high speed burr. In this section, a review of the literature on the medical aspects of benign tumors and treatment methods is discussed.

4.1 Normal Bone Texture

Bone is a mineralized, vibrant and dynamic tissue composed of metabolic cells. They are lined up in different shapes to support the soft parts of the body[61]. Their mission is to support the body, protect vital organs, and store many minerals, including calcium. Bone consists of organic and inorganic substances. 70% is minerals or inorganic matter, 5-8% is water, the remainder percentage is organic matter and extracellular matrix[62],[63].

4.2 Tumors

Many of the cells are uncontrollably proliferating in number and are the resultant ones that can exhibit a tendency to grow and spread according to the cecedium. It can occur in many tissues and organs of the body. Tumors can be benign and malign. Malign tumors tend to spread to other tissues and organs. Benign tumors do not spread, they can only grow in the area they are in [64],[65].

4.2.1 Musculoskeletal System Tumors

They are very rare tumors. It forms only 1% of all malignancies. Because the skeletal system is made up of different cell groups such as bone marrow, a wide variety of tumors are seen, making it difficult to recognize. They may damage normal tissues in the area. Benign tumors may have a direct impact on the patient's vital functions, but

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may also be required because of the complications they have created in the area and surrounding joints[66].
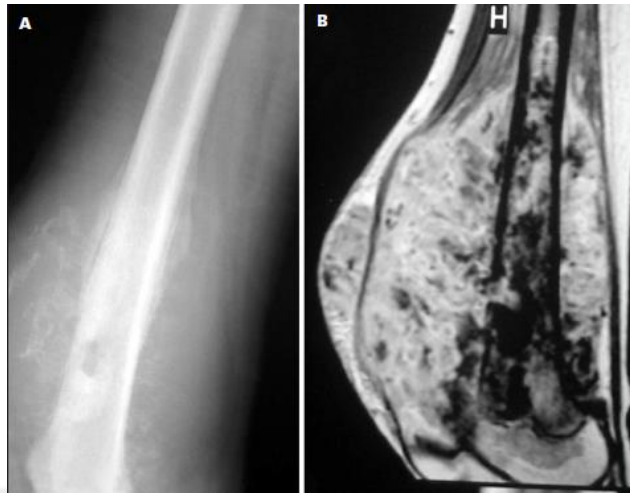
Figure 4.1 Direct radiography (A) and MRI section (B) of a 13 - year - old female patient with osteosarcoma diagnosed distal to the right femur[67]

4.2.2 Diagnosis

A careful anamnesis and physical examination is very important. Specific complaints and physical examination findings are very rare, so the first step to reach the correct diagnosis is suspicious. Initial complaints may include pain, swelling, and limitation of movement, atrophy in the muscles, deformity or pathological fracture. The duration of symptoms, symptoms and trauma story should be questioned in the detection of mass[64],[68],[69].

Imaging methods:

- Plain radiographs give findings such as lesion progression, growth rate, localization (Figure 4.1).

- Angiography is important to show the three-dimensional perception of the tumor and its proximity to the groom.

- Computerized tomography shows the relationship of the tumor to the surrounding tissues, its spread and localization.

- Magnetic Resonance Imaging shows tumor spread much more closely, neighboring joints and relationship are observed in more detail.

4.2.3 Treatment Principles in Musculoskeletal Tumors

Treatment consists of surgery, chemotherapy, radiotherapy, and protocols used together, depending on the tumor type.

Non-Surgical Treatments: Chemotherapy and radiotherapy can be used with or alone in surgery. Usage areas are decreasing day by day. Surgical intervention can be used alone with serious problems. When combined with surgery, chemotherapy significantly increases survival[64],[65].

Surgical Treatment: Amputation is the removal of the extremity from the most appropriate region in cases where tumor control can not be achieved. Ectremic conservative surgeons are practicing the removal of the tumor without disturbing the body image, but instead of grafts or prostheses in the most appropriate way. After resection, bone grafting or cementing should be performed[70],[71]. Allografts, autografts, bone graft materials, endoprostheses can be used as bone grafts. Synthetic mills used are natural or synthetic ceramics, demineralized bone matrix, bone morphogenic protein, growth factors[72]. (Figure 4.2).

Figure 4.2 Preparation of allograft, cancellous graft and DKM mixture during surgery[72]

Among benign tumors, tibial tumors are the second most frequently seen in the bones of the body[73]. Well-behaved, if insertion is close and affects especially the epiphyseal plates, if it results in loss of function it becomes compulsory to take due to long-term results. Considering the complications of benign tibial tumors, a number of surgical interventions are made after resection is decided.

Figure 4.3 Postoperative photograph showing the length of both skin incision after less-invasive[74]

Once the tumor is localized correctly, the necessary surgical procedures are started. First, the incision site is opened according to the size of the tumor (Figure 4.3). Since Tibia is lacking in muscle tissue, only the skin and fascia are opened and the bone tissue is reached[74]. Tumor material is first scraped with large curette, then curettage with high speed burr is completed (Figure 4.4,4.5). It is filled with grafting or cementing according to the situation. After the bone surface has been edited, the incision is sutured and closed[75].
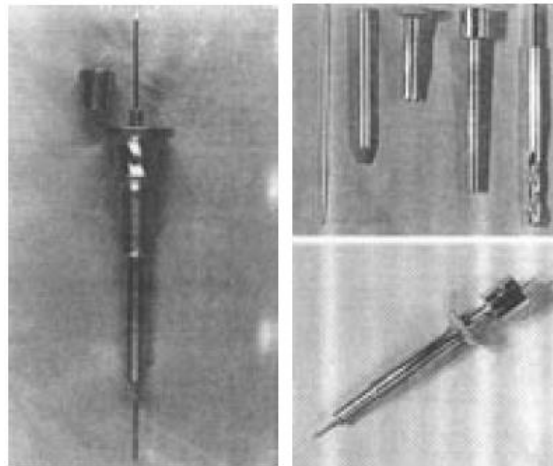
Figure 4.4 Drill, cannula, guidewire and biopsy needle used in excision technique[76]
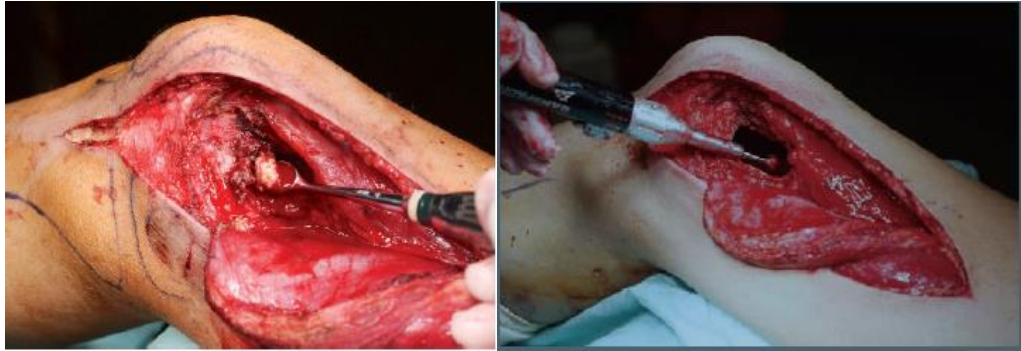
Figure 4.5 The tumor is first removed with hand curettes. Curettage is followed by highspeed burr drilling.[75]

5. RESECTION OF BENIGN TUMOR IN TIBIA WITH A HIGH SPEED BURR BY HAPTIC DEVICES IN VIRTUAL REALITY ENVIRONMENTS

The major aim of this study is to observe the effects of haptic supported virtual reality environments' usage in anatomy and surgeries. During this project a CT of tibia bone (Figure 5.1) with benign tumor is shaped and colored in Visual Studio with OpenGL codes to create a Virtual Reality Environment. Then a drilling tool which is aimed to be a high speed burr is scaled in Rhinoceros and added in this environment. This application has 3 working principle. First on is to give the chance for observation of the anatomy of a lower limb which is turned into 3D by coloring CT images. In this study, it is possible to obtain the colored state of each CT images in all x, y, z dimensions. This application is called 3D Slicing. The second principle is letting the user to observe anatomy of the lower limb either with muscle and skin or only as bones. Last principle is resection of a benign tumor located in tibia bone by drilling with a high speed burr.
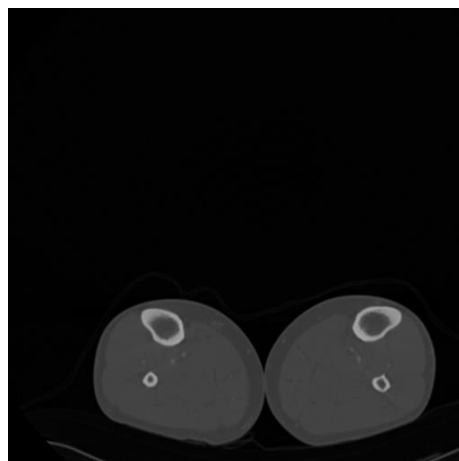
Figure 5.1 A CT image of lower limb.

5.1 Devices used in Application

In this section, the devices selected for use within the application will be introduced. These devices are;

- Phantom Geomagic Touch,

- VR 2000 Pro dual HMD.

In this thesis study, the VR2000 Pro dual Head Mounted Display with high resolution is used as an external 3D display unit for displaying the virtual environment. Benefits of VR2000 Pro dual:

- It gives a Wide 45 degree field of view.

- It allows Stereo 3D with Any Video Card.

- It works almost as compatible with all computers.

- It is compatible for 3D DVD.

- IPD adjustable to accommodate.

- It has a light weight and is small.

- Brilliant, high contrast 800:1.
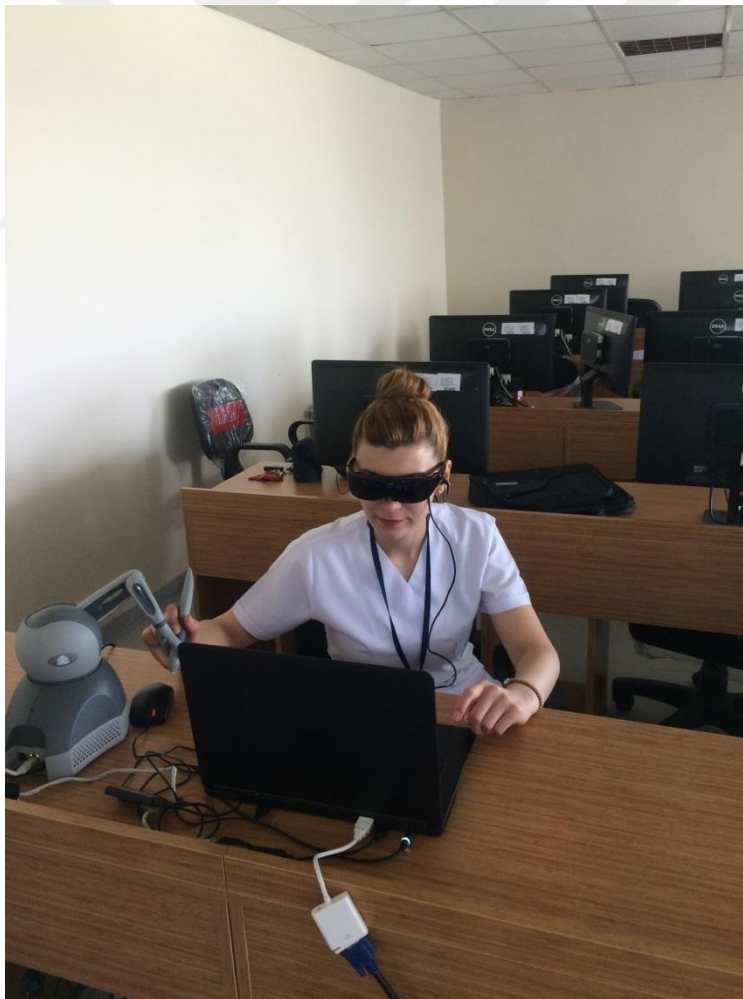
Figure 5.2 HMD and Haptic Device usage during the application

Geomagic® Touch™ (Figure 5.2), a haptic device produced by Phantom, was selected for the thesis work. The 6DOF robot is preferred because it responds to all the operations (drilling, haptic interaction, buttons etc.) that need to be done. During the drilling (resection of tumors) process position information of the device is very important for a realistic simulation. Position (for X, Y, Z axes) error margin of Geomagic® Touch™ is less than 5% which is an acceptable value for the study. Device's specifications are listed below in the table 1.

Table5.1 Haptic Device Specifications

Features	Geomagic® Touch™
Workspace	~6.4 W x 4.8 H x 2.8 D in > 160 W x 120 H x 70 D mm
Range of motion	Hand movement pivoting at wrist
Nominal position resolution	> 450 dpi ~0.055 mm
Maximum exertable force and torque at nominal position (orthogonal arms)	0.75 lbf/3.3 N
Stiffness	x-axis > 7.3 lb/in (1.26 N/mm) y-axis > 13.4 lb/in (2.31 N/mm) z-axis > 5.9 lb/in (1.02 N/mm)
Force feedback (6 Degrees of Freedom)	x, y, z
Position sensing/input (6 Degrees of Freedom)	x, y, z (digital encoders) [Roll, pitch, yaw (± 5% linearity potentiometers)
Interface	RJ45 Compliant Ethernet Port

5.2 3D Modelling

When a virtual reality simulation is aimed to design, at the beginning 3D models and view of virtual environment should be prepared. 3D colored image creation from CT and MR files has some different techniques. In addition to visual-based programs developed for users who do not know how to write code, there are programs that can be used to create 3D images with the help of software.
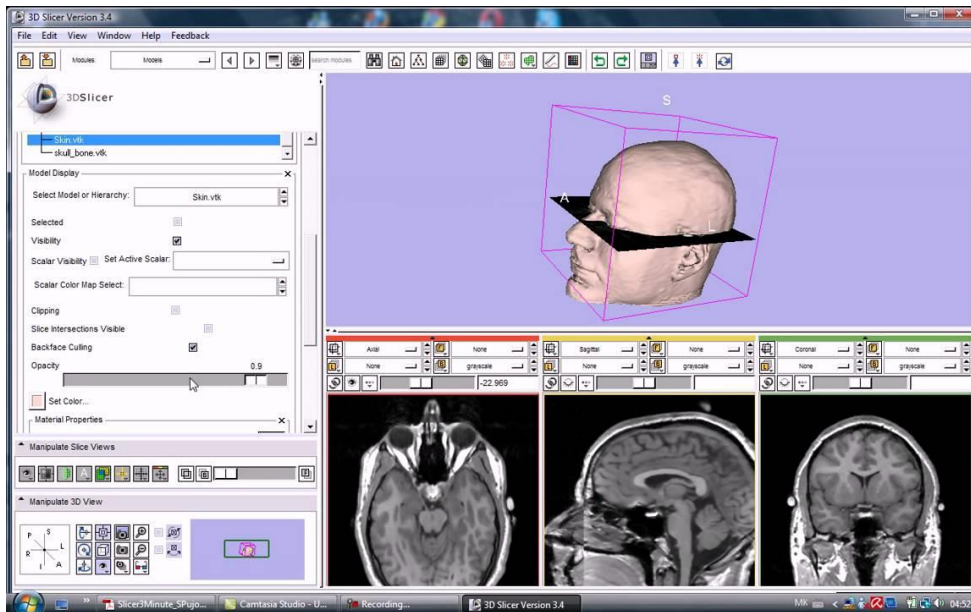
Figure 5.3 3D slicer creation of 3D images from CT and MR files

3DSlicer program is one of those programs (Figure 5.3). It is an open source program for image processing of CT and MR images. Ct and MR images are inverted to 3D images in this environment. Since the tinting can be done according to the gray tones, 3D image of each desired region can be obtained and saved as 3D file extensions. Thus, these images can be added to 3D design programs and used for many purposes.
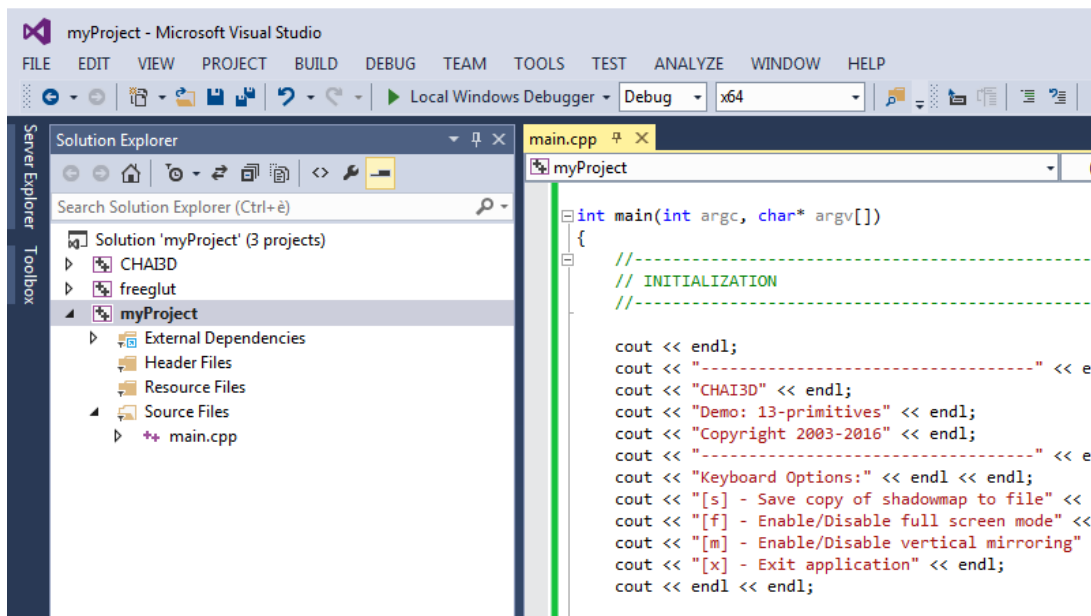
Figure 5.4 A CHAI3D based project view in Visual Studio

CHAI3D is a Visual Studio-based C ++ simulation framework. In many parts of the world organizations work in the medical, aerospace, automotive and entertainment sectors. It is an infrastructure program used to develop high performance haptic applications. This program, which is a useful program with its own software libraries and sample applications, has been chosen as the software platform for this thesis. Personal projects are created in the Visual Studio platform and CHAI3D libraries based on C ++ and OpenGL are included in the project.

5.3 Software Development

During this thesis a project has been created in Visual Studio platform and CHAI3D libraries based on C ++ and OpenGL programing codes were added to the project. Haptic supported virtual reality environment of benign tumor resection surgery was coded on this project. Images of computed tomography were converted to the 3D images. Algorithms of collision, force and tactile feedbacks were added in the project. Haptic device was defined and a high speed burr was added to the cursor of haptic device. An audio algorithm coded for the burr. 3D slicing opportunity was added to the program to observe the tumor and leg slice by slice in three-dimension with keyboard selections.
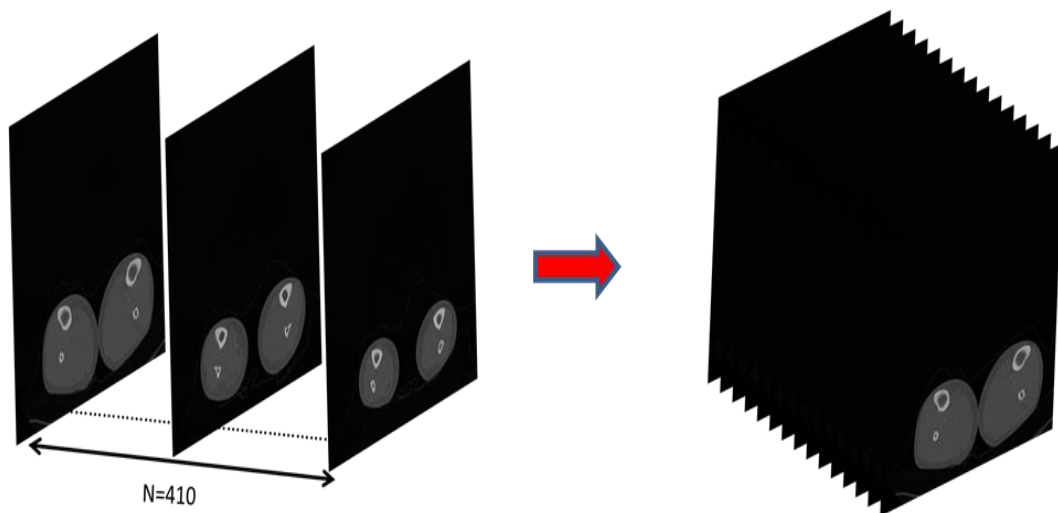
Figure 5.5 410 images of computed tomography

410 Images of computed tomography were added one by one to the developed program and piled up together (Figure 5.5). After that these images were colored with loaded color-map in software environment of Visual Studio (Figure 5.6). These

colored images get together and creates a haptically visible object in Virtual Reality Environments.
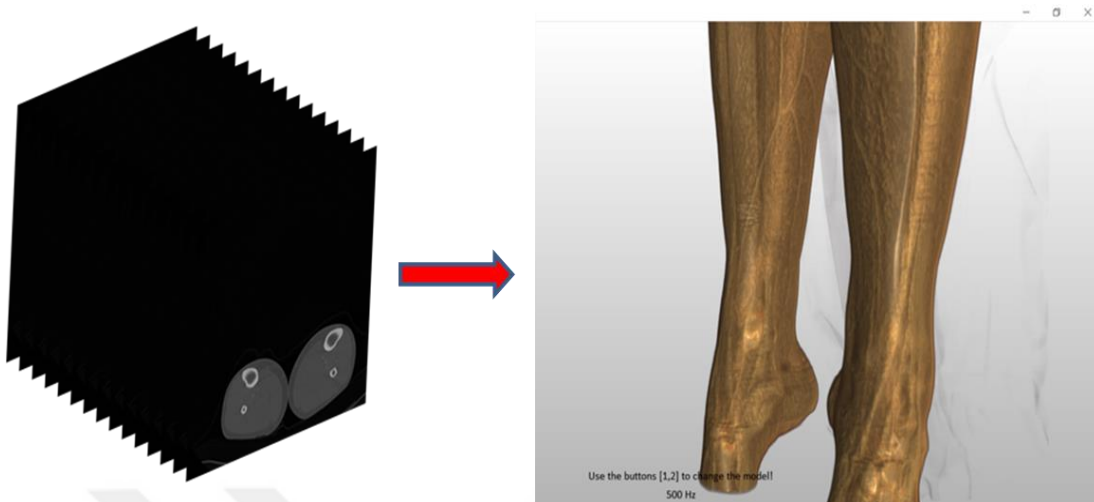
Figure 5.6 Colorization of the CT images

Two choices of color maps added to the system. Thus, according to the users' demand, bone model could be chosen without muscle tissue or both of them could be viewed (Figure 5.7).

(a)   (b)
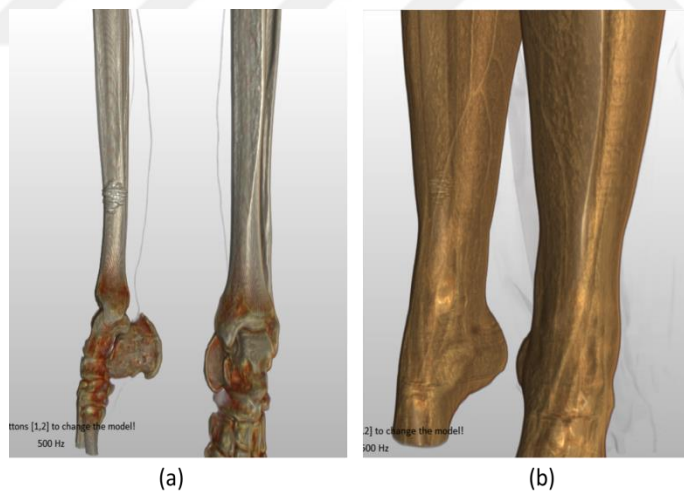
Figure 5.7 a-) Bone model **b-)** Model consisting all parts of the leg.

3D slicing opportunity was added to the system as shown in figure 5.8 below. Therefore, in three-dimension user can slice the model and observe each slice of the leg with keyboard selection.

Figure 5.8 Slicing opportunity for 3 dimensions

5.3.1 Tissue Stiffness

Each tissue has its own physical properties. We can list these physical properties as softness, hardness, flexibility, friction, weight. These properties allow us to distinguish the tissues from each other. When asked to design surgical training simulations in virtual reality environments, specifying these properties increases the sense of reality.
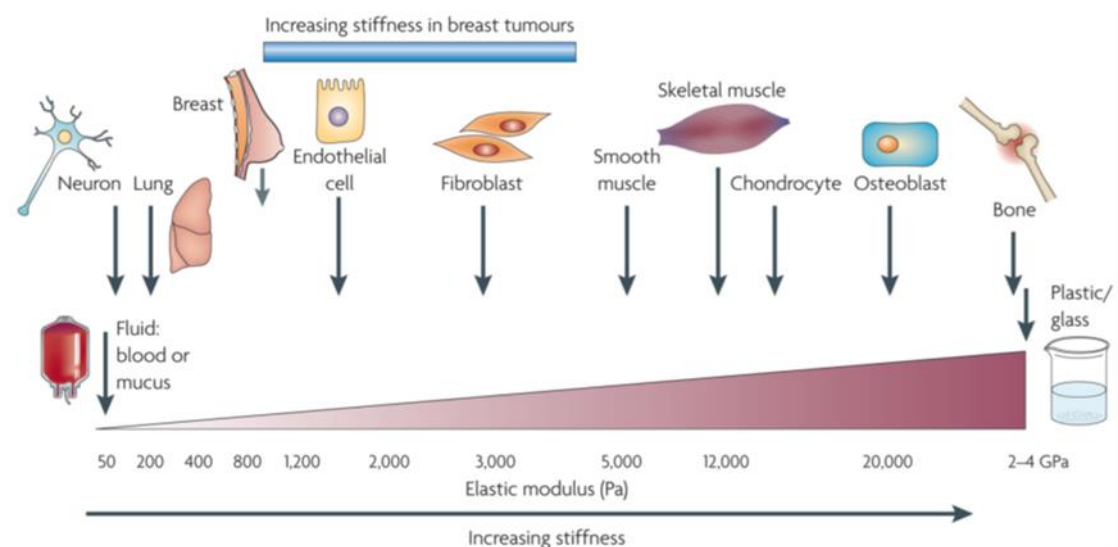
Figure 5.9 Stiffness of the tissues of a human[77]

In the developed virtual reality environment, it is aimed to increase the sense of reality by introducing the stiffness values of the tissues.

As seen in Figure 1, the blood has a value of 50 Pascal (Pa), skeletal muscles have 12000 Pa and bone 2 GPa. Pascal is the force per square meter (N / m2).

5.3.2 Virtual Drilling Process

As $\sum\vec{F}$ is the total applied force, "a" represents acceleration and "m" represents mass, Newton's second principle is;

$$\sum\vec{F} = m \cdot a \qquad\qquad\qquad\textbf{5.1}$$

F is a force that has a direction and magnitude. Equation 5.1 which is valid in any inertial reference system can be written in 3D space as its Cartesian coordinates components.

$$\vec{F} = F_x i + F_y \hat{J} + F_z \hat{k} \qquad\qquad\qquad\textbf{5.2}$$
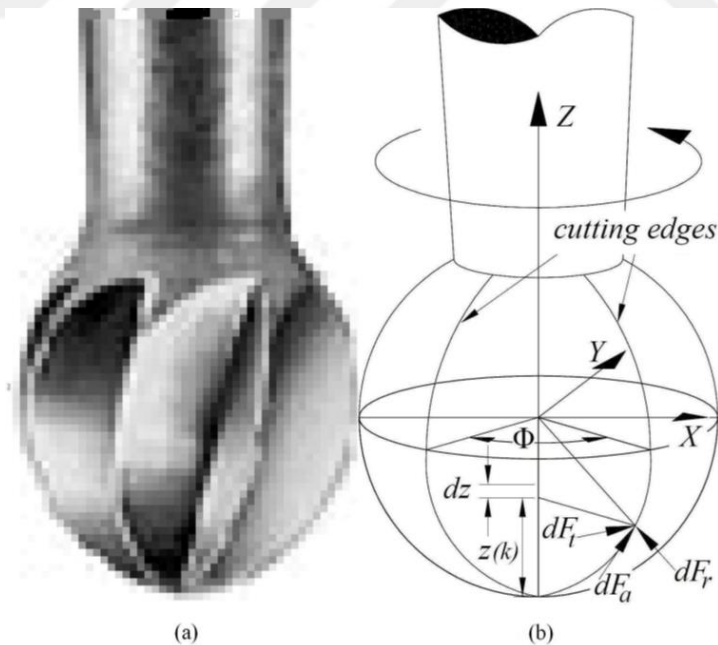
Figure 5.10 a-) Bone drilling tool (high-speed burr) **b-)**geometry of drilling tool and cutting forces on bone drilling burr.

Virtual cutting tool consists of three components(dF_t, dF_r and dF_a) which are main force orthogonal to the bone(dF_t), frictional force on the rake surface(dF_r), frictional force originated from the effect of the helix angle(dF_a)[78].

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \left\{ \sum_{i=1}^{N\phi} \sum_{k=1}^{Nz} T(i,j,k) \begin{bmatrix} K_t \\ K_r \\ K_a \end{bmatrix} t(i,j,k) \, dz \right\} \qquad \textbf{5.3}$$

Net force applied from virtual cutting tool to the bone is obtained by multiplying the global transformation matrix. In this formula representation of cutting edge number is $N\phi$, the number of separated cutting edge elements is Nz, height of each element dz and ϕ is J. Cutting edge chip thickness is $t(i,j,k)$. Voxel-based chip thickness is the most effective factor for the calculation of the cutting forces. In consequence of tests, the bone cutting coefficients are $Kt=230$ N/mm2, $Kr=40$N/mm2 and $Ka=20$N/mm2[78]. While coding the drilling functions for the force interactions, the formulas above were used.
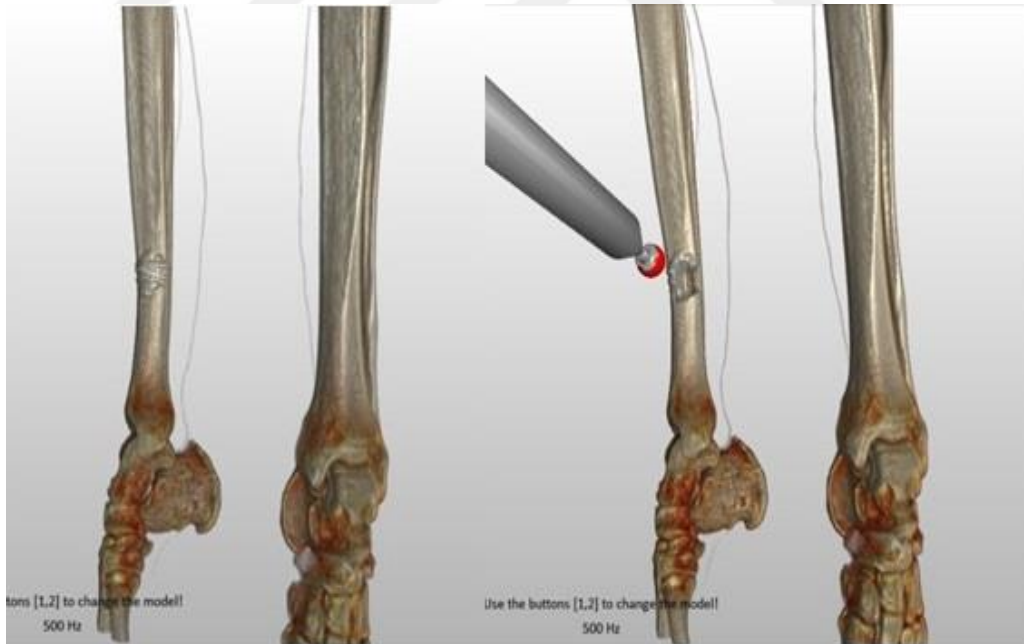
Figure 5.11 Resection of benign tumor with a high speed burr.

In this application, drilling object helps to resect benign tumor from the location. While the user drills with the high speed burr, with respect to the speed of the burr user hears a drilling sound. User takes force feedback from the model and with touching and clicking, the tumor is slowly resected. (Figure 5.9)
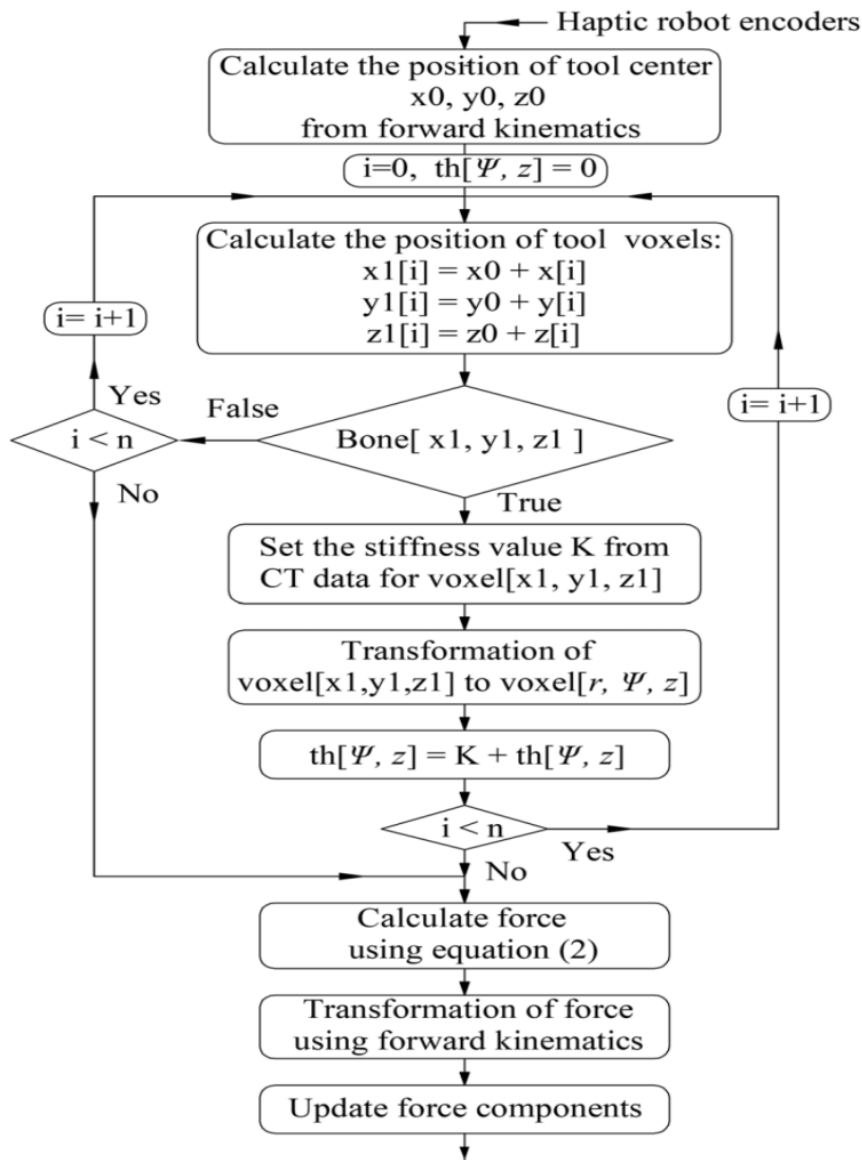
Figure 5.12 Flow chart of bone cutting simulation

Formulation and definition of bone cutting and force components of the drilling burr is determined above with details. The flow chart of cutting process is given in the figure 5.12[79].

5.4 Algorithm of the Application

In the process of coding the application haptic device is defined to the system and the futures of the simulation is determined. This Application is an example of human computer application. A scheme of human computer interaction model is shown in the figure 5.13 to make a better explanation.
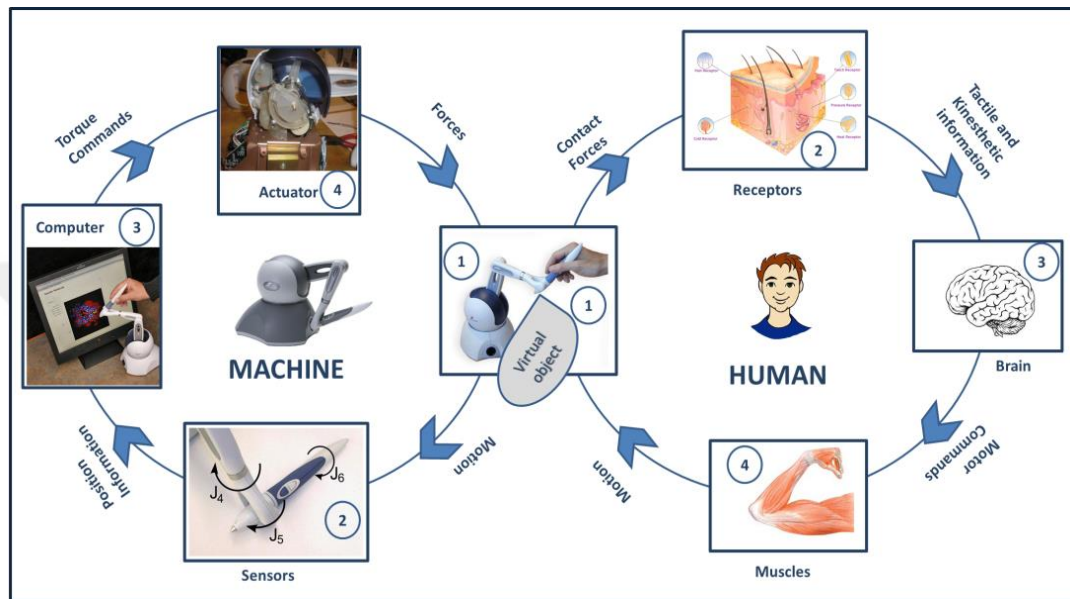
Figure 5.13 User-Haptic interaction

A cursor was created and matched with haptic device after the creation of display window. Haptic device's physical workspace was matched with its virtual workspace. Audio files were added to the haptic device for the drilling process. Coordinates and features of the object were defined for the workspace. Then, color texture was added to the object with respect to the volume. After the simulation starts, settings of sizes of the window, cursor, and screen resolution were left to user's choice.
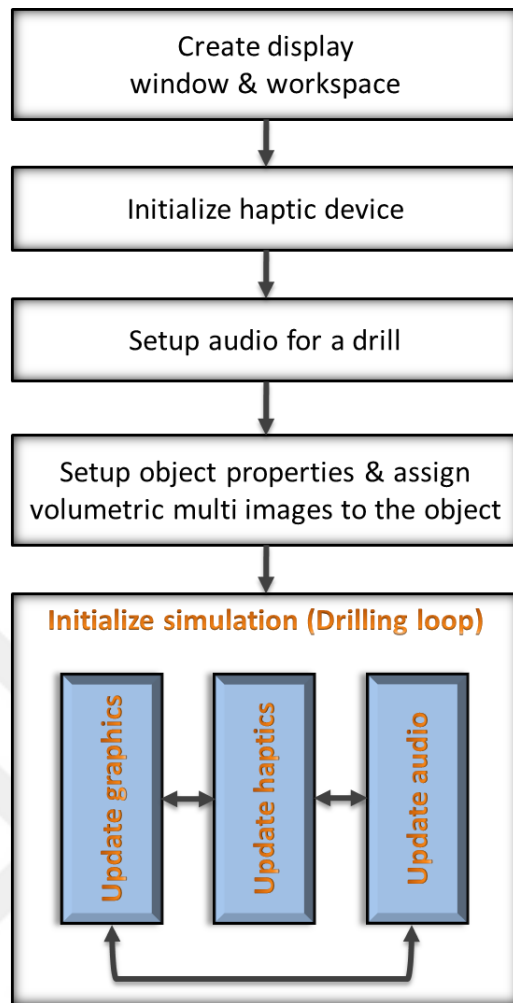
Figure 5.14 Algorithm scheme of the application

During the simulation, position of the cursor and object are always compared. After the collusion of object and cursor, drilling process, graphic rendering and reset clock which calculates the haptic force works synchronously. User's choices and sound and vibration that occur during the collusion with respect to the drilling speed are considered depending on the position of dynamic object. These processes are repeated as a loop. (Figure 5.14)

5.5 Implementation of Virtual Surgery

35 students from faculty of health in Kirklareli University tried the simulation as seen below in figure 5.15 and were asked to answer a questionnaire with 27 questions about haptic devices, HSVRE's, realization of the simulation. According to the questionnaire some analyzes were done to get the efficiency of the application and haptic devices in medical education.

Figure 5.15 Medical students during the implementation

During the application students had some strains because haptic device was a new phenomenon for their education sense. Basically, they were not able to move in 3D environment easily. Hence, it was hard to move the haptic device correctly in VRE. However, this hardness decreased with the repetitive usage.

6. EVALUATION OF THE RESULTS OF THE STUDY

A scaling study was conducted to examine the effects of haptic devices usage on education of health students with applications developed in virtual reality environments.

6.1 Methodolgy

6.1.1 Sample of the Study

Thirty-five randomly selected health students who attended surgery and anatomy classes at Kırklareli University formed a sample of the measurement tool used to evaluate the effectiveness of haptic applications developed in a virtual reality environment. These students were asked to answer a questionnaire including 27 questions for the scaling of the effectivness and usefullness of the developed virtual surgery training appilcation.

6.1.2 Assessment Instruments

A questionnaire with twenty seven questions was developed as an assessment instrument to evaluate the effectiveness of the haptic supported virtual reality application.

The questionnaire which was used as assessment instrument is given in Appendix with all questions.

As Civelek[80] transferred from Ercan and Kaan's study that the reliability values of the questions in the questionnaires were found to be $\alpha = 0.85$ for Haptic supported lectures in the virtual environment and $\alpha = 0.95$ for traditional lectures. Survey questions were considered reliable because the values were greater than 0.70.

6.1.3 Data collection procedure and Analysis

The data collection tool was applied to the health students who formed the sample with the permission and approval of the Directorate of Health School of Kırklareli

University. This implementation was carried out by making necessary explanations under the supervision of the researcher at Kırkalerli University Kayalı Settlement.

The study group that made the sample voluntarily participated in the study. The obtained data were analyzed statistically by using WEKA which is an open source machine learning software, and the results are presented as tables.

Kappa, F-measure and learning percentage values were analyzed by examining the results of the analysis to see if learning has come true.

6.1.4 Analysis of the data with using machine learning algorithms

WEKA is an open source machine learning software which has a common reputation among researchers. WEKA has lots of strong tools and algorithms for its usage to accomplish data analysis and predictive modelling. Also its user interface and graphical and visual abilities make WEKA a favorable option for machine learning. It's a fundamental necessity to learn achievement of algorithm usage to have opinions about results of research. There are some techniques for that purpose. Accuracy rate, precision, recall and F-measure are one of them [22]. Classification is undergone by the algorithm predict the class of data true or not. And a confusion matrix which can be described as a brief demonstration is generated by software and is used for prediction.

   Precision and recall are not enough alone to extract meaningful results in inter-observer comparisons. F-measure, which is harmonic average of precision (P) and recall (R), is defined to solve this problem [23]. F-measure value has better learnt the relationship between algorithm classes that are close to 1. F-measure is calculated as follows:

$$\textbf{F-measure } (F) = \frac{2 * P * R}{(P + R)} \qquad\qquad \textbf{6.1}$$

$$\textbf{Kappa value} (K) = \frac{(P_o - P_c)}{(1 - P_c)} \qquad\qquad \textbf{6.2}$$

   Kappa value (K) determines the concurrence reliability of comparison between observers [24, 25]. The interpretable interval of Kappa-value is between -1 and 1. K

is 1 when there is an exact concurrence comparison between observers. Negative values of kappa (K<0) are meaningless in terms of reliability. The range of 0.41 and 1.0 is acceptable value for K [26]. If P_o is acceptable rate and Pc is the expected rate, K is calculated as follows:

6.2 Findings

For above every question, true classification scores of J48 are better than scores of primitive algorithm ZeroR. Therefore, we can say, J48 algorithms succeed learning from samples. Kappa value is between 0.41 to 0.60 and 0.61 to 1.00 and it's also a sign that J48 algorithm accomplishes acceptable and successful learning.

In WEKA, for the questions of 8, 15, 19, 22, 23 separated classifications are made with ZeroR primitive algorithm, and for 35 samples are classified, respectively 19 ones 54.285%, 20 ones 57.143% 20 ones 57.142%, 16 ones 45.714%, 13 ones 37.142% of them accurately as seen in Table 1.

Table 6.1 J48 Algorithm

Question	Kappa Statistic	Accuracy	TP Rate	FP Rate	Precision	Recall	F-Measure	ROC Area
8	0.801	88.571 (31)	0.886	0.108	0.901	0.886	0.876	0.859
15	0.533	74.285 (26)	0.743	0.143	0.684	0.743	0.711	0.858
19	0.665	80 (28)	0.800	0.073	0.813	0.800	0.805	0.808
22	0.488	68.571 (24)	0.686	0.160	0.637	0.686	0.656	0.688
23	0.516	74.285 (26)	0.743	0.255	0.656	0.743	0.697	0.794

In WEKA, for the questions of 8, 15, 19, 22, 23 separated classifications are made with J48 primitive algorithm, and for 35 samples are classified, respectively 31 ones 88.571%, 26 ones 74.285% 28 ones 80%, 24 ones 68.571%, 26 ones 74.285% of them accurately as seen in Table 2.

When two tables are compared, it's obvious that F-measures of J48 algorithm are greater than the ones of ZeroR. This compression is a common way to see the

success of machine learning algorithm. Positive difference in F-measures on behalf of J48 algorithm is a quantitative proof of achievement of machine learning.

Questions which are used for the J48 algorithm:

Q7. Do you think using HSVRE with haptic devices in lecturing provides you more efficient learning?

Q8. Do you find HSVRE entertaining and interesting?

Q13. Does using HSVRE in labs make easy integration with lessons for students?

Q14. Does using HSVRE for applications make easy integration with lessons for students?

Q15. Can HSVRE make lessons more attractive?

Q18. Does HSVRE give opportunity to see materials which cannot be taken into classrooms?

Q19. Does HSVRE help you to get rid of monotonous state in classroom?

Q20. Do you get force feedback to your hand when you touch virtual objects?

Q21. Do designed VR environments provide you to objectify subjects?

Q22. Do you think working with haptic devices in VR environments can increase your success in medical education?

Q23. Does prepared HSVRE make you feel you're inside the environment?

Q24. Does HSVRE provide suitable settings for surgeries?

Q26. Can HSVRE be used before preparation of surgeries?

Q27. Does the Medical Education supported with HSVRE present a better opportunity than the traditional medical education?

 The algorithm classified to data set with choosing best root value. From top to down, for every question a learning process is performed and with every performance decision tree is constructed. According to gain condition, root values' levels are determined. Better gain, brings root value to upper levels. Thus, graphical demonstration of the decision trees is like in the following figure.
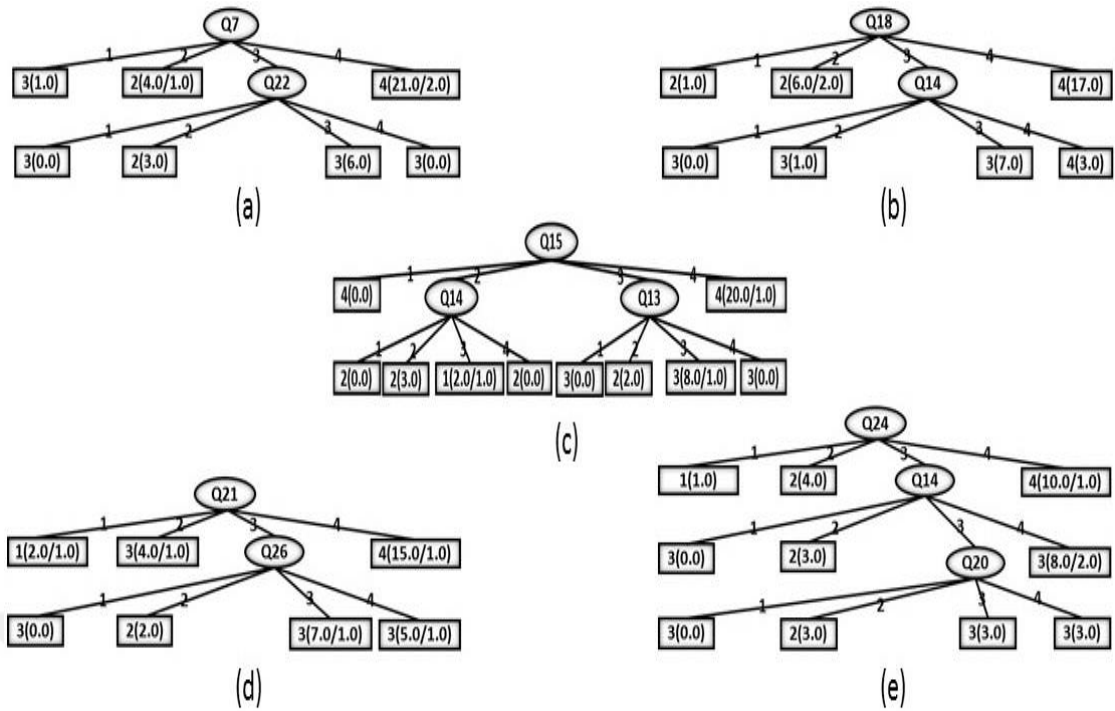
Figure 6.1 The decision trees of 8th question (a), 15th question (b), 19th question (c), 22nd question (d) and 23rd question (e)

Best root value was found as 7th question according to the analysis of 8th question that was done with J48 Algorithm. J48 algorithm learnt correctly that 25 students answered as 'good level' and 'very good level'. (Figure6.2)
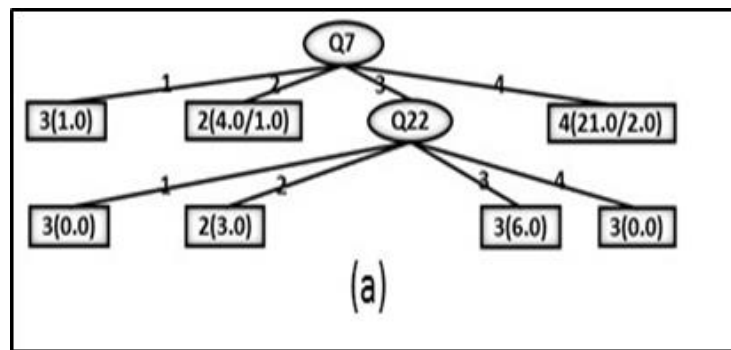
Figure 6.2 The decision trees of 7th question

Best root value was found as 18th question according to the analysis of 15th question that was done with J48 Algorithm. J48 algorithm learnt correctly that 27 students answered as 'good level' and 'very good level'. (Figure6.3)
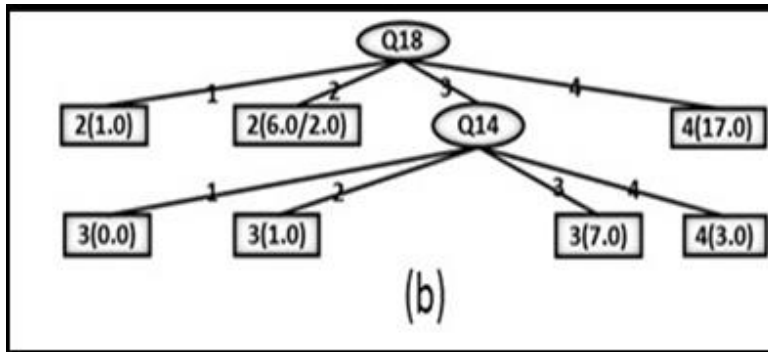
Figure 6.3 The decision trees of 18th question

Best root value was found as 15th question according to the analysis of 19th question that was done with J48 Algorithm. J48 algorithm learnt correctly that 26 students answered as 'good level' and 'very good level'. (Figure6.4)
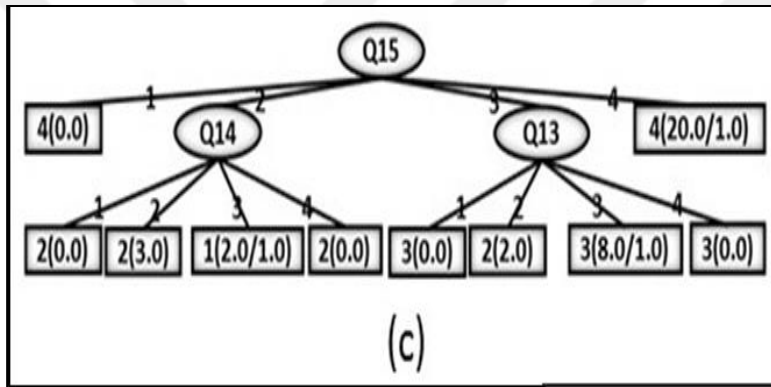
Figure 6.4 The decision trees of 15th question

Best root value was found as 21st question according to the analysis of 22nd question that was done with J48 Algorithm. J48 algorithm learnt correctly that 24 students answered as 'good level' and 'very good level'. (Figure6.5)
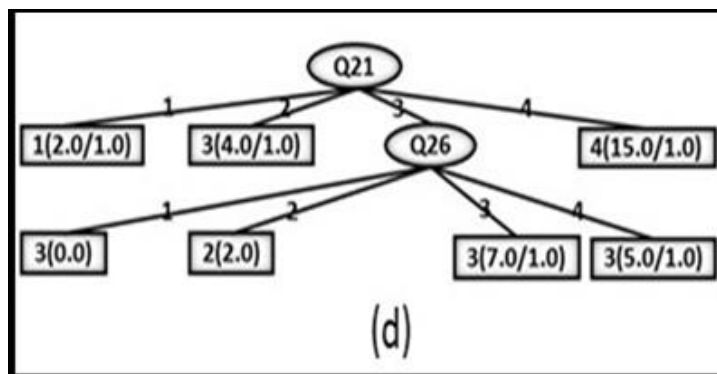
Figure 6.5 The decision trees of 21st question

Best root value was found as 24th question according to the analysis of 23rd question that was done with J48 Algorithm. J48 algorithm learnt correctly that 21 students answered as 'good level' and 'very good level'. (Figure6.6)
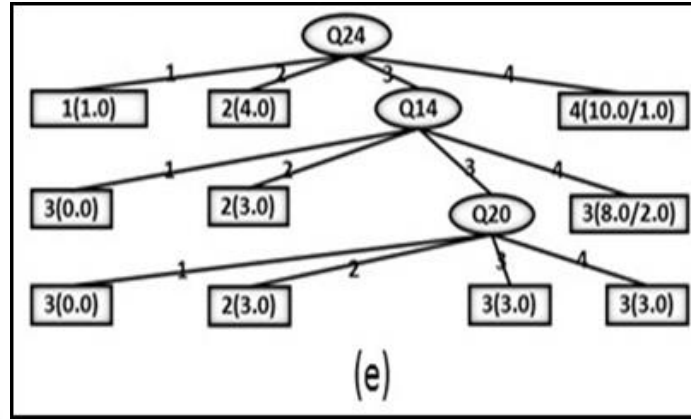
Figure 6.6 The decision trees of 24th question

27th question was answered as 'Yes' by the entire participant so, this question does not have an information value for machine learning.

7. DISCUSSION AND FUTURE WORKS

Medicine is totally bounded with information technologies nowadays. Computers, robots, microsurgery tools, lasers etc. are the part of surgeries and treatments. During last decades human-computer interacted device usage is widely grown. Especially for the education of medicine students' simulations and Haptic supoorted virtual reality environments has a very important contribution.

In this research, a simulation for resection of benign tumors of tibia bone developed in Haptic supoorted virtual reality environments. Literature review has been done on topics of virtual reality environments, haptic device technologies and medical education and interdisciplinary studies of them. Studies about medical education with haptic devices and VRE are increasing but not enough to respond the demands. Creating virtual organs having the same properties as much as similar to real life organism is a crucial issue for medical education with Haptic supoorted virtual reality environments. Also, it has been seen that the detection of the tumor zone will greatly facilitate the surgeons' convenience during the surgery. Taking these shortcomings into consideration, firstly the tumor regions to be transferred to the virtual center were determined and tomographic images were obtained. The objects to be used in the virtual environment were created and scaled. Appropriate software environment has been identified. Then, in the virtual reality environment, an application interface for tumor detection and resection was developed. Then the application for tumor detection and resection was developed and the user interface was created in VRE. Samples from health students who were getting surgery and anatomy (including orthoepy lecture) course performed the developed application and answered a questionnaire about the effects of the application. Statistical analyses of the questionnaire have been done.

In literature, the terms of bone drilling ([20], [19] and tissue cutting ([17], [18]) in Haptic supoorted virtual reality environments were studied. In this research,

a simulation for resection of benign tumors of tibia bone developed. In the beginning a 3D model of a lower limb was created from a real patients CT images.

During the resection of tumor with a high speed burr in Haptic supoorted virtual reality environments; collusion, audio and drilling algorithms worked as a loop and according to the process of drilling a sound and force feedback were given as outcome. Also the opportunity of 3D slicing was given to show any cross-section area of the object from three dimensions with keyboard selections that provide to change the slice view through inside and outside; this let the user to focus on interested location of the object. In addition to these, surgeons could carry out the surgery for a limitless trial as a simulation before the actual one.

With randomly selected students the developed simulation had been tried and afterwards a questionnaire was asked these participants. Questionnaire data were analyzed with machine learning by using J48 algorithm in WEKA software and from the results of analyzes the following inferences were obtained.

Medical students who think Haptic supoorted virtual reality environments;

- Must be used in lecturing also found these environments very entertaining and interesting,

- Gives opportunity to see materials which cannot be taken into classrooms also think Haptic supoorted virtual reality environments can make lecturing more attractive,

- Make lecturing more attractive also think Haptic supoorted virtual reality environments help them to get rid of monotony in lessons,

- Provide them to objectify the subjects also thinks applications had been done in Haptic supoorted virtual reality environments can increase their success.

27th question was answered by all participants as 'Yes'. It shows that students all agree that Medical Education supported with Haptic supoorted virtual reality environments provides a better opportunity than the traditional medical education.

Study proofs that Haptic supoorted virtual reality environments can affect the success level of medical education. Because, the outcomes of the study show that these environments motivate students while learning surgical and anatomical issues. Furthermore, it's clear that Haptic supoorted virtual reality environments can make

integration with lessons for medical students and also be used before preparation of surgery. (71.428%)

In the future surgical drilling, cutting and suturing simulations can be grown for the all specific parts of the body with creating 3D objects by using real patients CT images. Simulations designed in Haptic supoorted virtual reality environments can be used for Medical education and also for the preparation before real surgeries.

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APPENDIX-1

A starting example in OpenGL

```
#include <GL/glut.h>
void display (void)
{      glClear (GL_COLOR_BUFFER_BIT);
       glBegin (GL_POLYGON);
        glVertex2f(-0.5, -0.5);
        glVertex2f(-0.5, 0.5);
       glVertex2f(0.5 , 0.5);
       glVertex2f(0.5 , -0.5);
       glEnd ();
     glutSwapBuffers();            }
int main(int argc , char ** argv)
{     glutInit (&argc , argv);
     glutInitDisplayMode(GLUT_RGBA | GLUT_DOUBLE);
     glutCreateWindow("Hello World ");
     glutDisplayFunc(display );
     glutMainLoop();             }
```
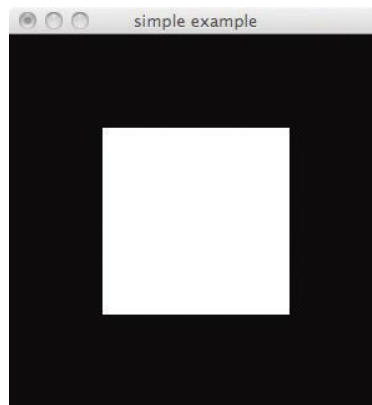

Figure A starting example for OpenGL

Questionnaire

N	Questions	Low Level	Medium Level	Good Level	Very Good Level
1	Do you find the virtual reality environments in which haptic devices are used adequate in terms of visuality and material?				
2	Do virtual reality environments using haptic devices motivate you?				
3	Do virtual reality environments used by haptic devices provide a suitable environment for surgeries?				
4	Do virtual reality environments using haptic devices provide you a rich content about the subject?				
5	Do virtual reality environments used by haptic devices contribute to the enhancement of teaching?				
6	Do the virtual reality environments in which haptic devices are used have a positive contribution to learning good and fast??				
7	Do you think using HSVRE with haptic devices in lecturing provides you more efficient learning?				
8	Do you find HSVRE entertaining and interesting?				
9	Do you find that virtual reality environments where haptic devices are used are realistic and workable?				
10	Do virtual reality environments using haptic devices provide a visual and dynamic work environment based on graphics and simulation?				
11	Do you think that virtual reality environments encourage you to lead research?				
12	Will virtual reality environments using haptic devices give you different perspectives to solve problems?				
13	Does using HSVRE in labs make easy integration with lessons for students?				
14	Does using HSVRE for applications make easy integration with lessons for students?				
15	Can HSVRE make lessons more attractive?				
16	Can virtual reality environments used by haptic devices be used as a source of information in teaching?				
17	Will virtual reality environments using haptic devices help you link existing information with new information?				
18	Does HSVRE give opportunity to see materials which cannot be taken into classrooms?				
19	Does HSVRE help you to get rid of monotonous state in classroom?				
20	Do you get force feedback to your hand when you touch virtual objects?				
21	Do designed VR environments provide you to objectify subjects?				
22	Do you think working with haptic devices in VR environments can increase your success in medical education?				
23	Does prepared HSVRE make you feel you're inside the environment?				
24	Does HSVRE provide suitable settings for surgeries?				
25	Do virtual environments provide better perception of concepts such as bone tumor retrieval?				
26	Can HSVRE be used before preparation of surgeries?				

27. Question	Yes	No
Does the Medical Education supported with HSVRE present a better opportunity than the traditional medical education?		

Scientific Publications in the Thesis Period

1. Civelek T., Kissaboylu H., Cokar D., Ustunel H., Injection of Proximal Interphalangeal Joint by Haptic Supported Virtual Reality Environments. Issues in Information Systems, 2016, 89-99.

2. Civelek T., Kissaboylu H., Dentistry Applications in Haptic Supported Virtual Reality Environment. 4th International Conference on Advanced Technology & Sciences (ICAT'Rome). 2016, 97-99.

CV

He was born in 1990 in Antakya. He completed his primary and secondary education in this city. He graduated from the Faculty of Engineering and Architecture of Istanbul Arel University with his BS degree in Electrical and Electronics Engineering. Still working in Kirklareli University as Research Assistant.

Civelek T., Kissaboylu H., Cokar D., Ustunel H., Injection of Proximal Interphalangeal Joint by Haptic Supported Virtual Reality Environments. Issues in Information Systems, 2016, 89-99.

Civelek T., Kissaboylu H., Dentistry Applications in Haptic Supported Virtual Reality Environment. 4th International Conference on Advanced Technology & Sciences (ICAT'Rome). 2016, 97-99.