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HES : : Haptic Elasticity Simulator

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HES: Haptic Elasticity Simulator

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in

Computer Science

by

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The Thesis of Amell A. Alghamdi is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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Table of Contents

List of Figures

List of Tables

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This thesis, in whole is currently being prepared for submission for publication of the material. Alghamdi, Amell; Schulze, Jurgen; Loomba, Rohit,. The thesis author was the primary investigator and author of this material.

ABSTRACT OF THE THESIS

HES: Haptic Elasticity Simulator

by

Amell A. Alghamdi

Master of Science in Computer Science

University of California, San Diego, 2014

Professor Jurgen Schulze, Chair

Professor David Kriegman, Co - Chair

The pattern of fast paced life we live those days has a great affect on our health. Most of today's diseases are tied to bad eating habits. The increment happened in last years for this type of diseases grasps the attention towards increasing the awareness of adopting a healthy lifestyle .On the other hand, some of the disease, if are not taken seriously, will lead to severe situations. As we believe in the importance of

increasing the awareness of the patients towards their health, we provided a system that could be used in the hospitals and clinics as a tool that shows the patients the extent of the damage they have in the affected organ of their bodies, such as the liver or the kidney, to encourage them to put more effort in adopting healthier life . Haptic Elasticity Simulator (HES) was designed and developed to solve this issue and to bridge the gap between the patient and his/her physician. Moreover, HES encourages the patient to change their life style and helps maintaining a healthy record by allowing the patients to visualize an organ and feel its elasticity in virtual reality environment.

1 Introduction

Organ elasticity has been an indicator for the healthiness of that organ. Lung elasticity, for example, is the ability of the lung elastic tissues to recoil during expiration. This elasticity comes from the elastic fibers in the connective tissue of the lung. The elasticity changed because of the changes in the organ tissues. Some defects of the components of the elasticity matrix may impair and alter the structural appearance of elastic and collagen fibers [Abraham and Hogg 2010]. The tissues got changed because of many reasons such as aging [Fleg and Strait 2012], direct and indirect diseases [Wachi 2011]. Some of theses disease may lead to fibrosis, cancer and other diseases [Egeblad et al. 2010]. Vast majority of health care dollars spent in the United states are for people with chronic conditions and the percentage has been increasing over time. In 1998 the care given to people with chronic conditions accounted for 78 percent of health care spending and in 2010 it became 84 percent [Anderson 2010]. Many of these diseases are responsive to lifestyle modification. The authors of *Tackling of unhealthy diets, physical inactivity, and obesity: health effects and cost effectiveness*, discussed chronic disease prevention model (CDP). They studied three chronic diseases: stroke, ischaemic heart disease, and cancer. They showed that factors like high blood pressure, and cholesterol increase the probabilities to develop these three diseases. On the other hand, risk factors such as low intake of fruit and vegetables and insufficient physical activities have an indirect effect on chronic diseases. The model simulates the dynamics of a regional population over a lifetime. Moreover, they adopted several strategies for preventing those risk factors and study their effect. This study was conducted in several countries, and the result showed that the health gain for people between 40 and 70 years is much higher than people under 40, and using multiple intervention strategies generate roughly twice the effectiveness of a single strategy [Cecchini et al. 2010]. Another pilot study conducted on 225 persons with chronical diseases, and 95 present of them showed positive clinical changes in almost all risk factor that are related to lifestyle [Drozek et al. 2014]. Moreover, there is an updated evidence in support of diet and exercises interventions with cancer survivors[Pekmezi and Wanhnefried 2011].

One of the major diseases' types that causes mortality is Chronic Liver Diseases (CLD). There are many types of CLD such as hepatitis B virus infection, hepatitis C virus, and alcoholic liver disease.

According to National Health and Nutrition Examination surveys between 1988 and 2008, the prevalence of Nonalcoholic Fatty Liver Disease (NAFLD) has increased steadily with prevalence of metabolic conditions. In the period between (1988-1994), the prevalence rate was 5.51%, and it increased to 9.84% in (1999-2004), then it continued to increase to reach 11.01% in (2005 -2008), while the alcoholic liver disease remained stable in the same time periods (1.38%, 2.21%, and 2.05%) [Younossi et al. 2011]. The studies showed that adopting healthy lifestyles has a great impact on preventing some diseases and enhancing health in general [Drozek et al. 2014]. Some health programs started to prevent these diseases or stop their prevalence [Small et al. 2006] [Hassed et al. 2009].

As a part of the solution, HES system involves the patient in the process of the treatment by providing the patients with the tool that can help them to monitor their health performance periodically and see their progression. The system gives the ability to the user to extract the organ model from his/her own MRI images and feel the elasticity to evaluate the damage he/she has. This could be done in monthly basis during the usual visit to the clinic to see the progression he/she did and how it affected his/her record positively. Having this done will encourage the patients to change their lifestyle and build new healthy habits.

In general, the system allows the user to extract 3D model for the organ from Magnetic Resonance Imaging(MRI images), shows it with a virtual holographic 3D display, and allows the user to manipulate the organ and feel the elasticity of it using a haptic stylus.

This paper starts with providing some related work and researches in areas such as: patient-specific simulation, using zSpace or holographic display as the main display, using of haptic feedback devices, and segmentation process. Then we talk in details about the implementation of our system and the work flow in the implementation section. Primary software and hardware used are discussed in two different sections. In the results section, we will present some figures that shows the overall performance of the system. The discussion sections will talk about the project requirements, measurements, and results.

This chapter, in part is currently being prepared for submission for publication of the material. Alghamdi, Amell; Schulze, Jurgen; Loomba, Rohit,. The thesis author was the primary investigator and

author of this material.

2 Related Work

This section addresses the previous work that was done in areas such as: patient-specific simulation, segmentation, and virtual reality.

2.1 Patient-specific Simulation

Major goal for most of this type of simulators is to do specific type of surgeries or train surgeons to do it. The development of haptic surgery simulators has been increasing in the last few years especially for training purposes. One of the main issues with this type of simulators is the physical modeling of soft tissues, the authors of *Non-Linear anisotropic elasticity for real-time surgery simulation* proposed a new deformable model based on non linear elasticity, anisotropic behavior, and the finite element method[Picinbono et al. 2003].

One of the previous work in this area was a simulation for liver biopsy where a needle is inserted in the liver to get a sample from the liver's tissue. In this project. They did not apply the elasticity and response algorithms in the system because of the number of organs and the differences in the tissue type traversed by the needle between the layers, but they developed and calculated the force feedback in different way. The force is computed while the needle is inside the patient's body and not outside[Villard et al. 2011].

Another interactive simulation of liver resection is EU PASSPORT which is a project where they created a GPU-based interactive simulation of laparoscopic liver resection in real time. This system simulates multiple organs with high resolution deformations reproduction of patient's scenarios for pre operative rehearsal of complex medical cases [Courtecuisse et al. 2011]

Visuo-haptic simulator is another project that was designed to improve practice based education in laparoscopy. In this system, they provided a 3D visual and haptic simulator for liver diagnostic through palpation. The hardware components were two Phantom Omni devices and 3D visualization display with shutter glasses. The simulator was designed to be a preliminary step for surgical training in liver procedures [Hamza et al. 2012].

Casson and Laugier simulated the forces on the physical component of the liver by associating points masses to the nodes of the liver mesh using two types of connectors; linear springs and torsion springs [Casson and Laugier 1999].

All the projects above were developed for training purposes. Therefore, they are kind of complex simulators due to the number of organs exist to simulate a real patient's body with all the factors that could affects the organ like breathing ,for example, which cause the rendering rate to drop to lower levels. In addition, those systems have complex menus that are not easy to be used as they were developed mainly for professionals. On the other hand, our system was developed targeting the patients as the main users and non professional people or specialized trainees. Therefore we adopted a simple user interface that it is easy to be used by any body. Our focus was to build a system that encourages patients to replace the daily bad habits with healthier substitutions in order to maintain the physical well being. As a result, we designed the graphical user interface of the system to be simple to use. On the other hand, picking the zSpace as the primary display was to provide the patients with the ability to do this experiment, and interact with the 3D organ in real time environment. As much as we concentrated on having a simple system to use, as much as we enforced a high level of functionality to fulfill the requirements of the system by simulating the process of poking the organ and generating the corresponding feedback with maintaining a high rendering frame rate.

2.2 Segmentation

In the image segmentation domain, one of the largest project was done by a collaboration between different universities, clinical engineers, and psychologists. The project included segmentation, physically based modeling, and haptics rendering. The segmentation process in the system has been implemented with the narrow band level set algorithm in ITK-SNAP where seeds grow within locally competing regions. The segmentation process saves each level segmentation in different image to avoid the leakage; taking in consideration that the segmentation will be done for multiple organs in addition to having difficulties associated with segmenting specific organs such as the ribs [Villard et al. 2013].

Leo Grady provided a novel algorithm for performing multi label, interactive image segmentation [Grady 2006]. The algorithm he used does image segmentation with a small set of pre-labeled pixels, and uses a random walker that is biased to avoid crossing object boundaries.

In our system, the segmentation process is much easier since we do it for one organ only each time so there is no need to add the complexity that arises from segmenting multiple organs at one time. In addition, HES was developed for some specific organs such as livers which have a simpler shape than the rib cage for example.

2.3 Haptic Rendering

Haptic rendering is an important aspect when it comes to virtual reality applications. Adding the suitable haptic device to a system makes it more interesting and more usable. AIREAL, a novel haptic technology, gives tactile sensations in free air without requiring the user to wear a physical device. It uses also computer graphics to enable the users to feel virtual 3D object using free air textures and air vortex generation which allows for 75 degrees field of view for tactile feedback [Sodhi et al. 2013]. This is an interesting project and it uses a special devices that was designed for the project purpose to fulfill its requirements.

The type of projects, mentioned in the specific-patient simulation section, requirers the user to interact and manipulate parts of the human body to perform a certain task which usually done using a stylus to mimic the actual task in real life using a similar tool. The reason that Geomagic Touch(Phantom Omni) devices are used with medical application, is to enhance training process for some types of surgeries that ranges from complex to simple ones [Navkar et al. 2012] [Chang et al. 2008]. Although, using AIREAL haptic looks interesting and will be good to apply it to our application, it is not commercialized yet.

2.4 Virtual Reality

Virtual reality (VR) is used to to simulate physical presence in real or virtual environment. On of the advantages of VR technology is that this type of applications can promote understanding of complex concepts, therefore, the technology has been used in different areas such as industry [Manca et al. 2013], education [Huang et al. 2010], and interior design [Dunston et al. 2011]. In addition, VR has played an important role in medical treatment. One of the VR projects in this area was developed to enhance complex walking and reduce fall risk in patients with Parkinson's disease by different methods such as providing intensive treadmill training with virtual obstacles [Yen et al. 2014] [Mirelman et al. 2011] [Meldrum et al. 2012].

On the other hand, engineers and designers shows an interest in prototyping techniques to either design a new product or optimize an existing one. This was the motive for the authors [Niebling et al. 2008]to present an augmented reality and interactive simulations to realize Hybrid Prototypes. COVISE (Collaborative Visualization and Simulation Enviroment)is one of the platforms that provide virtal reality environment and it has been used with different applications [Gallizo et al. 2009] [Kieferle et al. 2006] [Voigt et al. 2009]. Avango is another framework that was used with virtual reality applications[Nikitina and Nikitin 2003] [Zimmermann et al. 2003].

In HES, we used CalVR framework [Schulze et al. 2013] which helped us to build an application that engages the patient in virtual reality environment.

2.5 Holographics and zSpace Displays

To apply virtual reality concept on our system, we chose to make the interaction with the system happens through Holographic images. One of the latest technology developed in this area is a full high definition digital 3D holographic display that represents all depth cues without using any special glasses. It is can display both static and dynamic 3D objects that are reconstructed from computer generated holograms [Xu et al. 2010]. Teleoperation of robots in space from earth is another project that was done with integration of zSpace as the main display. It was desirable to command a robot in a very high level fashion, with the ability to interact with 6DOF input that could be used to track the position and do the rotation for the robot which solved the issue of the significant speed of light delay where the engineers have to stand next to the robot and call out how to move it [Goddard and Olin 2012]. In HES, zSpace was our choice to display the scene as it has the features of head and eyes trackers in addition to the stylus that provides the user with the ability to pick and manipulate the organ in 3D environment.

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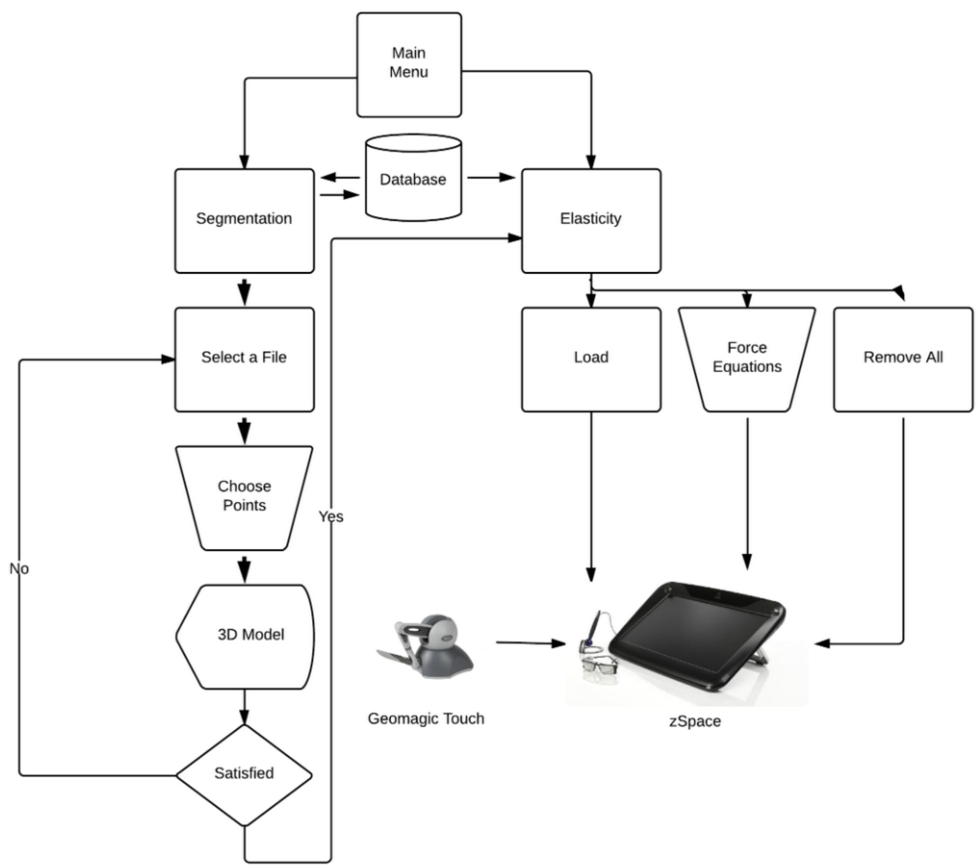

Figure 1: *HES Workflow*

3 Implementation

This section will talk about the implementation for HES system and its main components.

The system has been developed with CalVR framework. There are three main components for the system. First is the basic menu where the user can choose between two processes; either to perform segmentation process to extract a 3D model mesh values from MRI images, or to interact with an existing model and feel its elasticity through a haptic feedback device. More details related to software and hardware are mentioned in the corresponding sections. The following subsections will describe the workflow, usability, main features, and the code behind the main three components of HES.

3.1 Main window

The zSpace is the main display which starts by showing a 3D representation for the zSpace stylus where the user can use it to show the menus and do the selection. Pressing the right button on the stylus will show the menu and the main button makes the selection. The menu is CalVR basic menu which has options to move, scale, rotate, and reset the scene in addition to zSpace options to turn on and off Head Tracking and Eye Separation. Segmentation and Elasticity are two submenus that are attached to CalVR menu. We will go through each one in more details in the next points.

3.2 Segmentation

Segmentation is one important component of the system and it has several stages. First, we can choose the desired patient's file . Second, view MRI images(cross sections) for that patient and allow the user to select the needed input data for the next stage(segmentation process). Third, showing the resulted 3D model(segmented part).

Loading MRI images is done by selecting the segmentation submenu which will show a list of patients folders. Each one of those folders contains series of MRI images (dicom images). Once the user clicks on the patients folder, the system reads dicom images and stacks them into meta image file (.mha)

Table 1: *Main widget's controls*

Controls	
Left mouse button + move	show numbers
Right mouse button outside the widget	rotate all
Right mouse button on one corner+ move	rotate selected plane
Right mouse button on one edge + move	tilt selected plane
Right + Left and drag up or down	slide selected plane
scroll the wheel	zoom in and out

then it reads this image, and opens a new window to show three VTK image plane widgets for X, Y, and Z planes.

The control during the segmentation is supported by the computer's mouse only. Sliding any plane will allow the user to see the cross section of the MRI volume in the direction of that plane and this could be done by right and left click buttons and move up or down. The user also has the ability to rotate the plane by right click one of the plans corners and moving the mouse. For rotating the three planes together at the same time, the user need to do right click on the corner outside the widget then all planes will rotate in that direction. Tilting one plan could be done by doing right click on one of the edges and moving the mouse. Zooming in and out could be done using the wheel .(Table: 1)shows all controls for the widget.

Segmentation menu is the menu that appears to the right of the segmentation window, this window pops up directly after clicking on segmentation button, and has 5 buttons to select five values. Making left click with the mouse and moving it will show a text on the screen with four values; the first three values represent the points coordinates and the forth value represents the threshold value at that point. These buttons and the MRI cross section planes help the user to pick the desired part of the volume to do the segmentation on. The segmentation menu starts with green buttons. The user is supposed to choose three points that can represent the organ but they must be within the boundaries of that organ. The green buttons means that the point is not selected yet. If you want to select a point then after choosing the point by the mouse, the user needs to click the green button. This will change the color of the button to red, which means the point is selected (Figure: 2 - 6). The user has the ability to repeat the process by clicking on the button again to unlock it. After choosing the three representative points, the user needs to choose the lower and upper threshold values using same technique. Once the user is done with choosing the five values, the user can safely close the segmentation window. The system will use these values as seed points for the segmentation process. After few seconds the system will be done from the automatic segmentation and will show a new window with the 3D model of the segmented organ. If the user is not satisfied with the result then he/she can close the window and repeat the process, otherwise it will be the time to go to the next step to load the model, poke it with the stylus and feel the force feedback. We chose to do the implementation for the segmentation using three seeds values only. For more complex organs, there may be a need to use more seeds points. This case is not implemented in our prototype. The code behind the segmentation process was done in four stages: first stage is to stack dicom images into one single image and this is done by using image series reader and writer from ITK library to read the series of dicim files and write the result in Meta-Image(.mha). Second stage is to show the resulted image in 3D and gather seeds values from the user. VTK was used to take the ITK resulted image and output a VTK widget that shows the MRI intersections in the 3 dimensions. Once the user provided three points within the organ boundaries, lower, and upper threshold, the system will use those three points to point to the desired organ, then it will use the threshold to define the range of intensity values that classify the tissue type of interest and use it to segment the connected tissues from the same type. In the third stage, ITK fast marching filter is used to do the segmentation using the seeds values. This will generate Meta-Image file(.mha). Last stage is when the system uses this output image and convert it to STL file(mesh values) and shows the final result to the user.

3.3 Elasticity

This submenu takes the user to another menu that has three options: ”Load” to load the patients folders, ”Remove all” to clean the scene and remove all objects, and the last thing is two options to choose either ”Linear Force” to allow the system to calculate the force feedback using a linear force equation, or ”Quadratic Force” where the system uses a quadratic equation to calculate the force. The default option is Linear Force. When the user clicks on Load the system will show a list that has patients folders where each contains mesh values file and elasticity file. Choosing a patient from the list makes the system reads the elasticity file and load the mesh points which represent the segmented organ and shows it as a 3D holo-

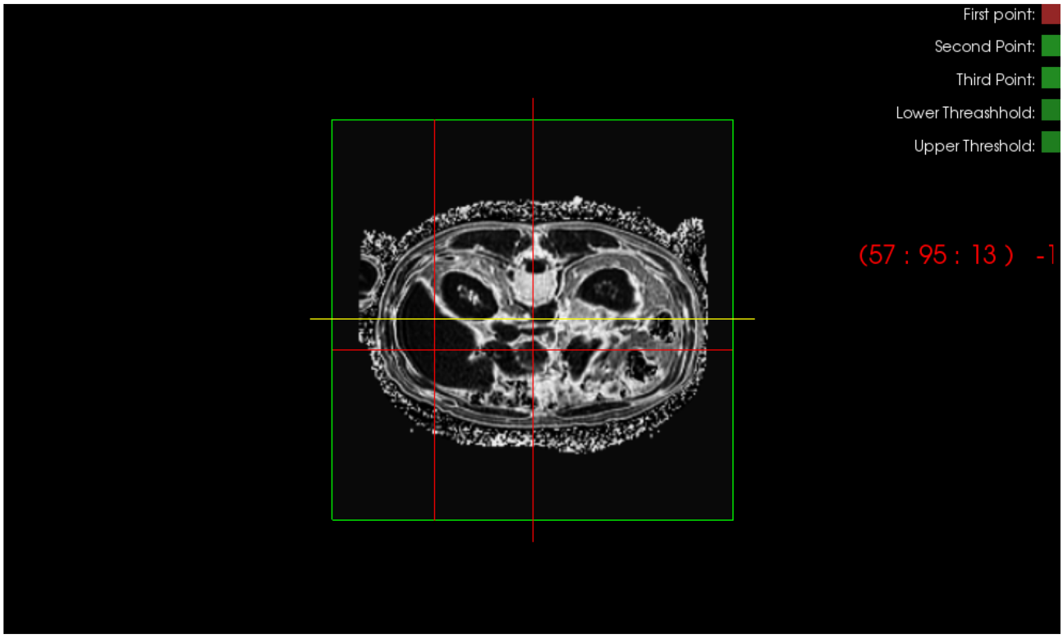

Figure 2: *First seed point selection*

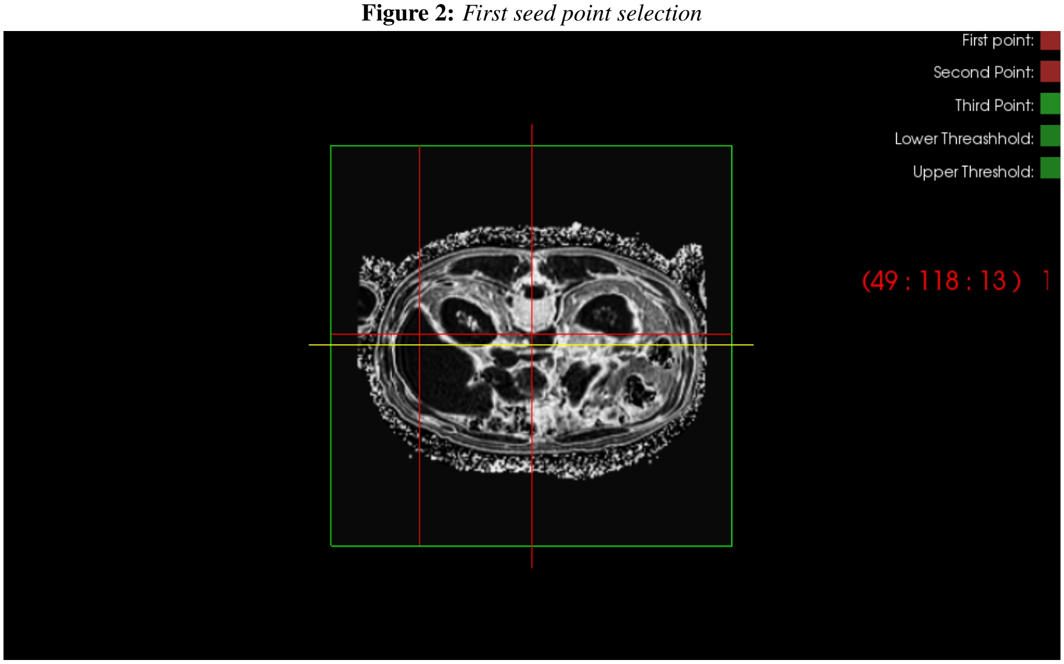

Figure 3: *Second seed point selection*

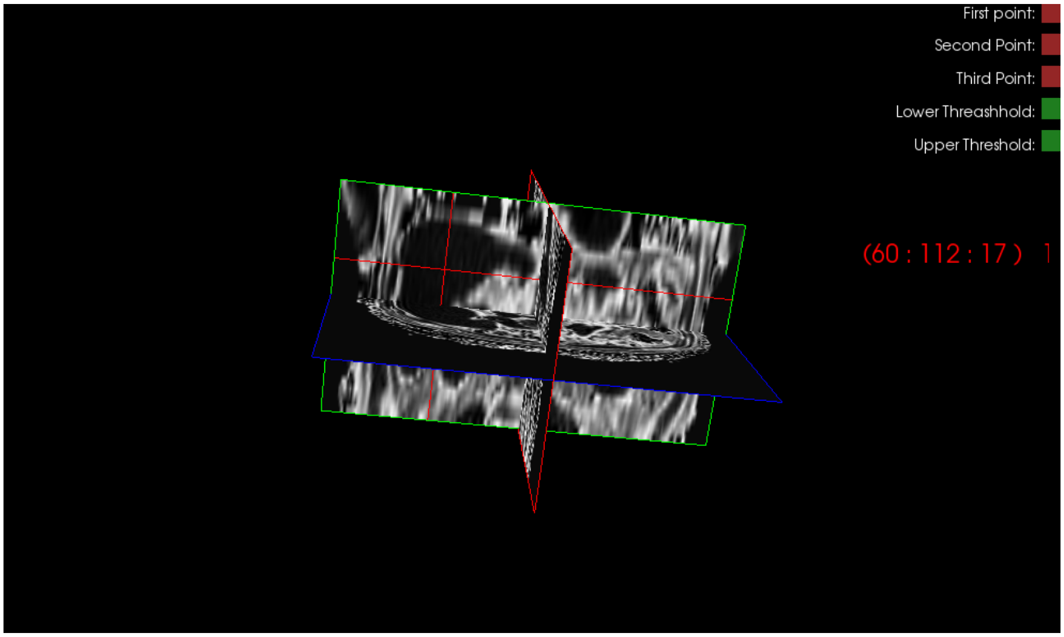

Figure 4: *Third seed point selection*

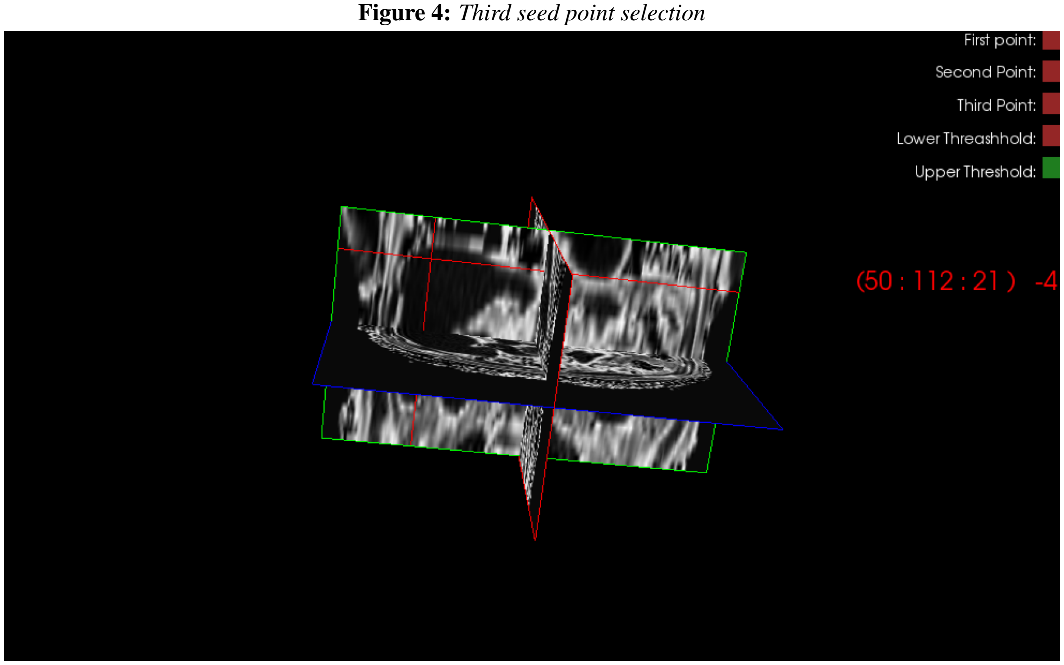

Figure 5: *Lower threshold value selection*

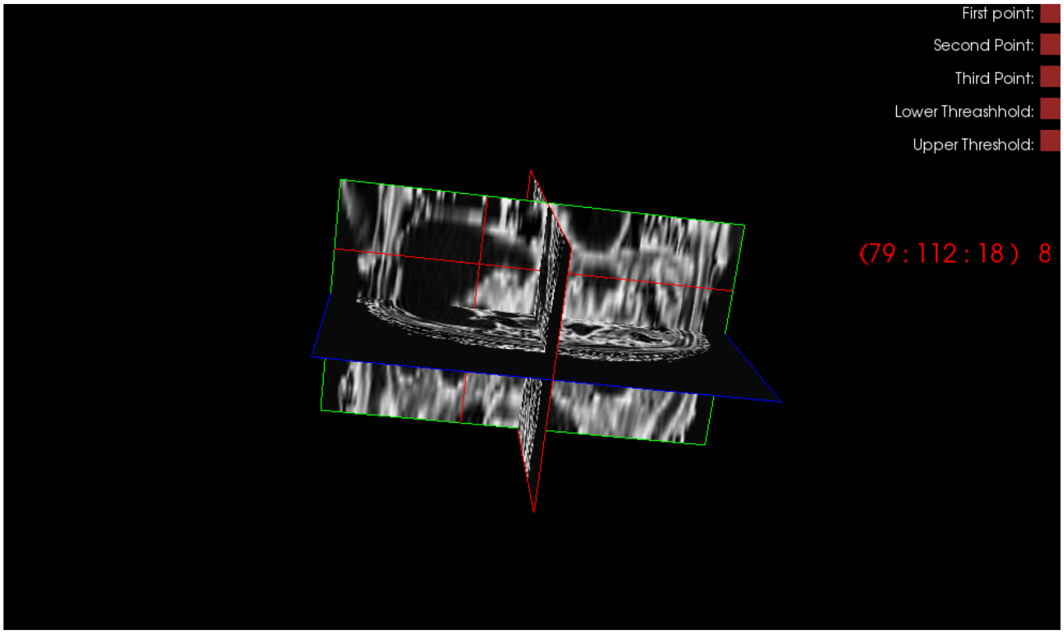

Figure 6: *Upper threshold value selection*

Figure 7: *Haptic feedback*

graphic image on zSpace display . At the same time, it will show a 3D cylindrical probe to represent the stylus of the Geomagic Touch (feedback haptic device). One end of the probe has a blue color sphere to represent the tip of the stylus . The representation will not show the actual position of the stylus, the Touch device and its stylus will be to the right of the zSpace display, or to the left of it, in case the user is left handed, but the visual representation will show it in the middle of the scene. At this point the user can use the zSpace,or the phantom stylus to move and manipulate the model and use the Touch stylus to poke the organ and feel the feedback force. To do this, the user needs to move the Touch stylus and approach the organ. The 3D representation of the stylus was designed to recognize the collision with the geometric component of the organ's model. Once this happened the system will use the collision point and fetch the corresponding elasticity value from the elasticity file, and calculate the force feedback, which could be done with a linear or quadratic function(it depends on the user choice). After that, the value of elasticity appears on the display in a position relative to the tip of the stylus, and the user will start feeling the force feedback on the Touch stylus in hand (Figure:7).

The code behind the Elasticity process starts with loading the resulted mesh values for the organ, and reading the elasticity file associated with it and provide a raw value array of the elasticity. The interaction with the organ is done within a collision detection loop between the Touch stylus 3D representation and the organ. Once the user approaches the organ, the system will use the intersection point and look up its corresponding elasticity values taking in consideration the conversion from raw value array to 3D array.To simulate the force feedback that is generated from poking the liver with the stylus we used two ways, and the user can specify which to use during the interaction with the organ in realtime. One of them is the following equation from [Vidal et al. 2007] where it calculates the force depending on the depth of the tip of the stylus inside the organ. The force is calculated as in (Equation: 1):

$$f(x) = E * x \tag{1}$$

Where E is the elasticity value of the voxel at the tip of the stylus, and x is the difference between the initial position of the tip when first intersect the organ, and the current position of the tip. The calculated force is used to set the feed back force to the stylus.

The second way to calculate the force was used from [Simone and Okamura 2002]. Simon and Okamura, the authors of *Modeling of Needle Insertion Forces for Robot-Assisted Percutaneous Therapy*, claimed that the second order force feedback equation they used (Equation: 3), gave fewer number of RMSD(Root Mean Square Deviation) error, than the first order equation (Equation:2), from [Aulignac et al. 2000]

$$f(x) = \frac{x}{\alpha x + \beta} \tag{2}$$

$$f(x) = \alpha x + \beta x^2 \tag{3}$$

where α and β are constants for elasticity. In [Simone and Okamura 2002], they used: $\alpha = 0.0020\frac{N}{m^2}$ and $\beta = 0.0023\frac{N}{m^2}$

In our case since we already have the elasticity value for each voxel, we replaced the α and β values with the actual elasticity values for the voxels at the initial position of the stylus' tip and the current position.

3.4 Files structure

The path to data directory should be stated in the config file of the project. The root directory consists of patients' folders. When the user wants to do segmentation on MRI images then, the system will look into the data directory and go through all the patients folders, if the patient's folder contains a folder with the name ”dicom”, that has series of dicim images, then this patients folder name will be included in the list of the patients when the user choose the segmentation tab in the main menu. If the patient's folder does not contain a folder called ”dicom” or the folder dicom was empty, then the system will not show this patient in the list. For feeling the organ elasticity, when the user wants to load the 3D model of his organ, then the system will search the data directory for the patient folder that contains two files; one with ”.xvf” extension, which is the elasticity file, and the other file has the extension ”.stl” for the mesh values. If those two files are found in a patient folder then this patient will be in the list that appears when the user choose ”Load” from elasticity tab, if one of those files does not exist then the patient folder name will not be included in the list.

This chapter, in part is currently being prepared for submission for publication of the material. Alghamdi, Amell; Schulze, Jurgen; Loomba, Rohit,. The thesis author was the primary investigator and author of this material.

4 Software

In order to perform each process in HES workflow, we used different libraries to perform different tasks such as: haptic rendering, volume rendering, user interaction, segmentation and feeling the feedback force. HES was developed on Windows operating system with Microsoft Visual Studio 12. The main programming language was C++. We used OpenSceneGraph as the main 3D graphics toolkit. ITK, insight Segmentation and Registration Toolkit was used to perform the segmentation stage. VTK, Visualization Toolkit was used to represent the cross section of the MRI volume and give the ability to the user to pick the right points accurately. The system was developed on top of CalVR(Virtual Reality framework) which has been developed in the Immersive Visualization Laboratory at Calit2. OpenHaptics version 3.0 is a software development toolkit, which has been designed to work with Geomagic force-feedback haptic devices.

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5 Hardware

The main display in this system is the zSpace display (Figure: 8a). zSapace technology creates 3 dimensional holographic images. The display is a high definition 3D monitor with full resolution images rendered for each eye, and uses sensors to track the viewing angle of the user. It comes also with a stylus tracking position and rotation with 6DOF, and 3D glasses. The system in general allows the user to see a scene in 3D and look around it easily [ZSpace]. The reason to use this technology is because we need to make this system more attractive to the patients so we can ensure that they will be welling to use it every time which will lead to maximize the benefit of the system. Researchers states that generated ghost like optical duplicates of 3D objects and scenes is regarded by general public as the ultimate viewing experience that attracted public interest [Onural 2007]. The refresh rate for zSpace monitor is 120Hz, 60 for each eye. The machine used for developing this project has a graphics card Quadro FX 5600.

To add more reality, haptic rendering of volume data is needed to allow direct manipulation of volumetric data. Therefore, we used Geomagic Touch (Figure: 8b)which is a motorized device that applies force feedback on the users hand, and comes with a stylus that has 6 Degrees Of Freedom (DOF) positional sensing and 3DOF force feedback [Touch]. We chose this device because it provides the user with the needed ability to move the stylus in all directions. Another reason to choose this version of the device is because it is cheap and dose the work. The main usage of Touch in our system is to allow the patients to pick, and rotate the organ, and feel the feedback when they probe it (Figure: 8).

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6 Data and Resources

The main data that was used to build the prototype was series of MRI images with dicom file extension for a patient's liver. Those MRI images come with the elasticity file that shows the elasticity value for each voxel. The files are used together in the system. All the files were provided by Rohit Loomba University of California at San Diego School of Medicine.

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(a) *zSpace* **(b)** *Geomagic Touch*

Figure 8: *Hardware*

7 Results

In order to test the system we measured the time duration for segmentation process with different sizes of MRI images. (Table 2) shows the result of the test. According to the result, we can see that the size of the volume has inverse proportional relationship with loading module duration and frame duration when there is a collision between the stylus and the module where the system needs to do a look-up process to get the elasticity value and make the needed calculation to get the force feedback value. Pushing the stylus inside the liver will show increment in the force feedback. (Figure: 9) shows the force feedback according to the depth of the stylus inside the liver.

From testing the models, we found that the force feedback that is generated by penetrating the organ, with the stylus, has proportional relationship with the depth. On other words, when we use the stylus to interact with the organ, as the tip of stylus goes deeper in the organ, the perceived force that is set to the stylus becomes larger.

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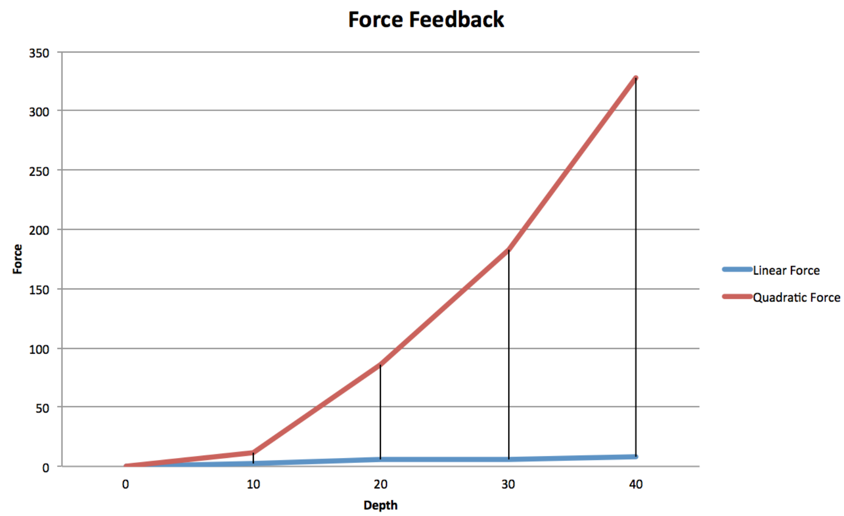

Figure 9: *Force feedback chart*

Table 2: *Mesurments*

Organ	size	Segmentation Duration	Loading Duration	Frame Duration(no hit)	Frame Duration(hit)
Liver	512 x 512 x 26	33.664 s	0.345 s	0.003 s	0.004 s
Liver	512 x 512 x 83	130.014 s	1.032 s	0.003 s	0.011 s

8 Discussion

The goal of the system was to allow the patient to feel the elasticity of different parts of his/her own organ and distinguish between the healthy and damaged sections. This can help the patient to know the extent of the disease and how it affects the organ, and change the elasticity. Once the patients have this knowledge, this will make them involved in the process of the treatment and work more seriously to either enhance the situation or at least to stop the damage from prevalence. This could be done by adopting a new healthy life style.

What we provided is a powerful and high impact tool for patients to monitor their health status in virtual reality environment. The thing that we did not provide in the mean time is a study that shows the change of the health situation of the patients after using our system. We considered this part to be in our future work. We believe that just knowing the extent of the damage is an important factor that motivate the patients to take a step forward , and be more careful about their health.

The major challenge was working with different peripherals and different operating system. The code was developed at the beginning on CentOS because CalVR currently runs on CentOS. When it was the time to integrate Touch device with our code, we found that the vendor provides only a beta version for the driver of the device that can work only with Ubuntu 12. Therefore, we moved to another machine with Ubuntu OS. Unfortunately, we contacted the vendor, after several tries to get OpenHaptics library to work with the Touch device, and they said that the only Linux version for OpenHaptcs does not support the new version of Touch device and they may release the compatible version by the end of 2014. Consequntly, we moved all the code to Windows machine as it was the only option since it supports zSpace, OpenHaptics, and Geomagic Touch.

The test result showed that HES is able to maintain a good performance during collision detection loop even with fetching elasticity values and calculating force feedback every frame. On the other hand, the calculating force feedback with the quadratic equation gave more realistic feedback than the linear one.

The prototype we developed needs to be validated by the experts. Since we were focusing on getting the technique working with the limited sources we have, we used the value of elasticity for each value in the mesh, calculate the force according to the depth , and set the resulted value to the haptic feedback device, taking in consideration that there is no other factors or organs that could cause the elasticity value to change like the case when developing simulator to do liver biopsy for example when there is more forces to be calculated for the needle to penetrate the organ.

Elasticity data that we are using now is not the real data. Instead, we read an xvf file that is generated by creating a volume from the MRI images.

9 Conclusion

This paper provides a detailed overview of HES system. In general, the system allows the patients to create a 3D model for their own organ, manipulate it in virtual reality environment and at the same time, they can probe it to feel the elasticity of that organ, and recognize the affected part of it. With the 3D glasses and zSpace display, the user can see the organ model floating in front of the screen which gives the feeling of interacting with a real object. Integrating the haptic device with these technologies and employ them appropriately and effectively helped us to build a complete reliable system. Going through the workflow of the system and doing the whole process could be done in less than 15 minutes. Therefore, allowing the patient to do this periodically can help them to monitor their health performance and encourage them to live healthier.

In conclusion, HES system is an important tool that could be used in each hospital or clinic to enhance the treatment process. The system is general enough to be used with people with different types of disease since it supports multiple organs. The intuitive and automated workflow allows a large segment of the society to be able to benefit from the system and not only physicians or engineers. Moreover, it helps to adopt a quality lifestyle. On the other hand, it adds another dimension to scientific visualization and opens a new era for research to study the affect of involving the psychological aspects of the patients into the medical treatment.

This chapter, in part is currently being prepared for submission for publication of the material. Alghamdi, Amell; Schulze, Jurgen; Loomba, Rohit,. The thesis author was the primary investigator and author of this material.

10 Future Work

The main goal for future work is to do a qualitative evaluation for the system. We will choose two different organs such as the liver and the kidney. For each organ we choose two diseases. Then we conduct a complete study that targets 60 patients for each disease. The study duration will be 6 months. We will gather the patients data before the study. Then we start by monitoring the patients health performance. After 3 months will gather the data again to see how each person did without using the system and see if the performance goes better or worse. For the second three months, we will make the patient use HES system and feel his/her organ in each visit to the hospital. At the end, we will gather the data and compare the results to show the affect of using HES system as a part of the treatment. In addition, we will improve the visual look of the organ and make it more realistic by smoothing the surface and and showing the deformation that is resulted from the force applied by the user. We also intend to make the system compatible with all operating systems. Because of the limitation we had, the system works with Windows OS only.

This chapter, in part is currently being prepared for submission for publication of the material. Alghamdi, Amell; Schulze, Jurgen; Loomba, Rohit,. The thesis author was the primary investigator and author of this material.

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