

HAPTIC INTERACTIVE MECHANICS MODELS

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Haptic Interactive Mechanical Models

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Haptic devices are devices that emulate the sense of touch through a force feedback mechanism that enables users to physically interact with virtual objects. This supplementary element of interaction allows users to experience and understand phenomena in a manner previously unexplored. By allowing users to receive kinesthetic and tactile feedback, haptic devices can improve design and decision-making. Utilized in industry for purposes such as: training doctors for surgery in non-invasive method, virtual design of 3-D models by designers and artists, and site characteristic exploration by geologists; haptic devices have been employed to improve understanding of systems. To extend this endeavor to the field of engineering, an application to bolster engineer students' comprehension of common mechanics concepts is developed.

The goal of this application is to allow users to interact with common mechanics systems, such as: a cantilever beam, a tie bar with circular connections, or a hinge system and consequently observe the system responses as a function of the design parameters. By allowing students to choose design parameters in advance of interacting with the models, they will develop an understanding of the parameter's role in the system as a whole. Through moderating the feedback the haptic device outputs to the user as a function of system properties, the user will

physically experience the changes in system dynamics. Furthermore, by allowing users to change the combination of chosen design parameters, the application will foster student's understanding of the influence of parameters on the system as whole. Ideally, this application will boost student's learning comprehension of mechanics of materials and demonstrate an innovative interactive method to teach engineering students.

DEDICATION

I dedicate this research to my parents. Without their continued support this opportunity would not have been possible.

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I would like to thank Dr. Medina for his tremendous support. His insight and teaching has been paramount to the production of this thesis and my improvement as a student and person.

CHAPTER I

INTRODUCTION

Applications that incorporate haptic devices operate in a cycle, much like the human kinesthetic information processing system. As illustrated in Figure 1, the human progression for understanding tactile feedback and the machine process for emulating this sense of touch both require an input, analysis, and feedback.

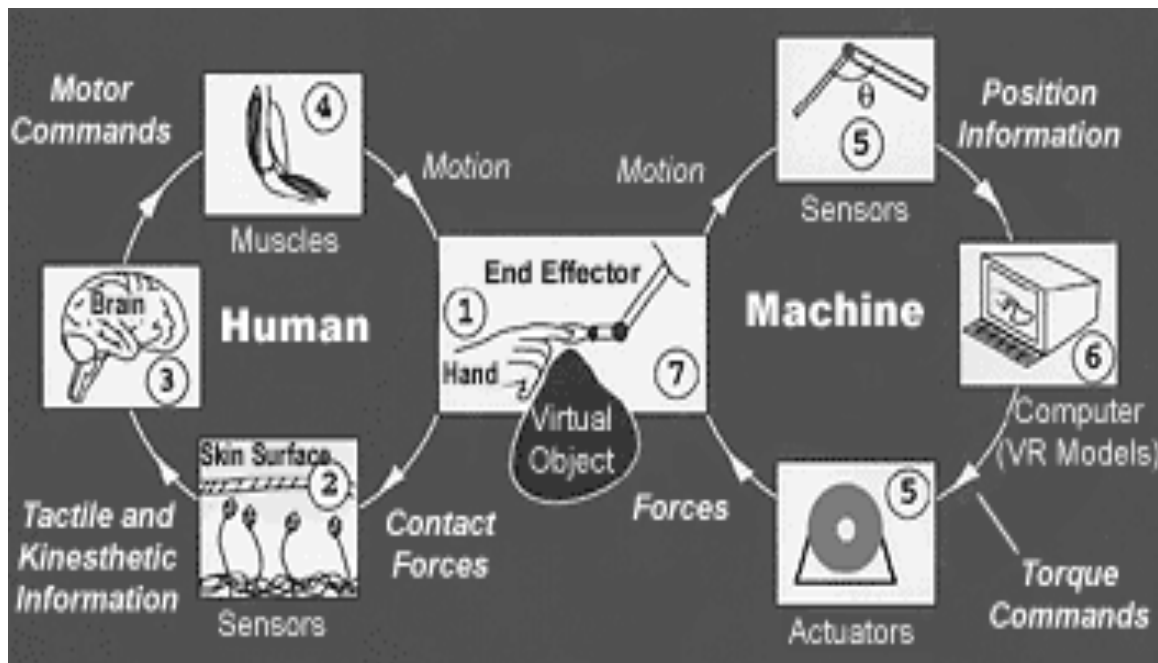


Figure 1: Haptic- Human interaction cycle (Carts-Powell, 1999)

The loop begins with a user manipulating the pen-like joystick of the haptic device in the 6 possible degrees-of-freedom directions. Once the joystick is active, encoded signals relating the position of the pointer are continually sent to the haptic rendering program. The rendering program then assesses if the virtual position of the pointer is in contact with any virtual surfaces

or objects. If the virtual pointer is in contact with a virtual object, the application will send commands to the haptic device to engage its motors and recreate the sensation the virtual pointer is experiencing. Through this continuous cycle of input and feedback, the haptic device facilitates real-time manipulation and rendering of objects.

This newfound capacity to interact and manipulate virtual systems in real time has not gone unnoticed by researchers; software developers have created a multitude of applications in which the use of haptic devices is advantageous toward concept mastery. Compounding on this initiative to utilize haptics in circumstances where physical interaction is valuable, this application seeks to allow engineering students to interact with mechanics models in order to supplement their understanding of mechanics of materials. The use of haptic devices to improve learning comprehension of mechanics of materials is suitable because mechanics concepts describe real world behavior and emulating these effects will strengthen one's understanding.

This application allows users to choose design parameters for a certain system, apply a force to the system, and feel and visualize the corresponding material response. Additionally, users can alter the combination of parameters to understand the influence of each on the system as a whole. For example, the user can choose a cantilever beam system, apply a force, and feel the amount of deflection the beam experiences. They can then change the length, or any one of the other design parameters, and re-evaluate the system response. By allowing users to experiment with combinations of parameters for the system, an understanding of the system as a whole is developed.

In order to recreate the true behavior of the mechanics systems in question, a finite element analysis (FEA) is performed and the corresponding responses are translated. This assures that the system is in accordance with mechanics laws and additionally generates models that can be directly manipulated. These models are created and processed in the FEA software, Abaqus, and then exported to the haptic rendering program. The haptic rendering program displays the models, the haptic pointer, and updates the application continuously. The haptic rendering software chosen for this project is chai3d3d (Computer Haptics and Active Interface), an open source set of C++ libraries with excellent application development capabilities. Chai3d3d is extensively used by developers due to its wide range of levels of control and inbuilt haptic handling algorithms. To consolidate these libraries and modules to deliver a seamless application, Microsoft Visual Studio 2015 is utilized for application development. The haptic device used in this project is the GeoMagic Touch Robot from Sensable Technologies, pictured in Figure 2 below.



Figure 2: Geomagic Touch Haptic Device

With all of the application components in place, the aim to improve students' comprehension of mechanics concepts can be advanced.

CHAPTER II

METHODS

Haptic application architecture

The haptic application architecture is characterized by a flow of information from the human to the haptic (i.e., manipulation of joystick), but simultaneously also from the haptic and visual program to the human in the form of feedback. The different parts of the haptic application are shown in Figure 3 below and must all be satisfied in order to have an operational application.

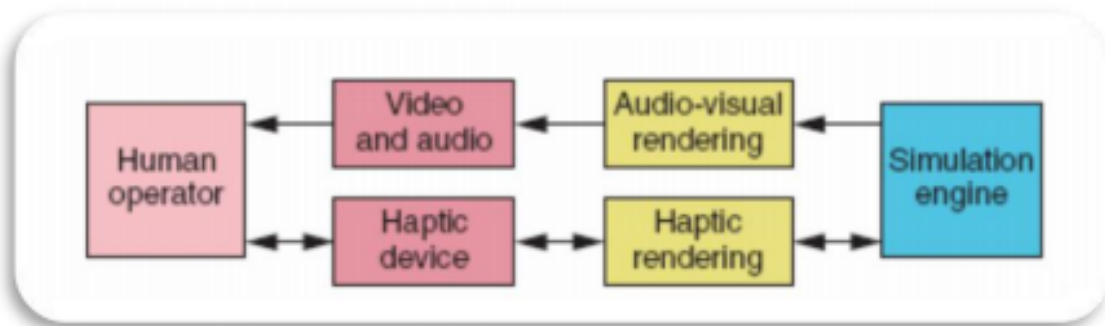


Figure 3: Haptic application architecture (Granados, 2008)

The elements of this application include the aforementioned programs: chai3d3d, Abaqus, and Microsoft Visual Studio 2015. The use of these libraries allows high level application development and expedited integration. After outlining the various components that comprise the application architecture, the important task of developing and analyzing the models is undertaken.

Mechanics models creation

In order to illustrate the engineering concepts of interest, systems of mechanics models must be developed. These models include examples such as a cantilevered beam fixed at one end or a screw connection, illustrating stress and torsion respectively. To develop the objects of interest a 3D Computer Assisted Drawing (CAD) program is used. In this project, Abaqus is employed to due to its capabilities to model connections, surface interactions, and kinematic behaviors. A model is created by the following the steps of a finite element analysis. The geometry of the part is described, material properties are assigned, and a section is defined. Next the interaction between different parts is specified and an assembly with constraints can be created. With the assembly in place, boundary conditions are specified confining the system to set limits. After the boundary conditions are locked in, loading the system can commence. After completing these steps to perform a finite element analysis, the job is submitted for analysis, and a robust analysis is returned. Because we are primarily interested in the maximum principal stresses at all integration points in the system, we request data output for each time step in the loading sequence. With the analysis complete and the knowledge of how our system should respond, we export the whole assembly as an object file (.obj) into our chai3d program.

Haptic rendering of objects

Although chai3d allows importation of objects into its application framework, the material properties from Abaqus are not directly preserved. In order to recreate the true behavior of the model, the use of the GEL module is necessary. This module works by using a series of mass nodes connected by spring to model deformable bodies. The nodes are available to be prescribed different properties such as mass, color, and size while the links can be manipulated by altering

spring stiffness and maximum elongation. Together with a series of springs and nodes, the surfaces of objects can be created and interacted with. Furthermore, chai3d has a built in function to build the vertices of any imported object that allows us to directly import an object and use the vertices defined in the FEA as nodes. By using this, “buildVertices” function, the framework for the system is rendered in chai3d. However, even though chai3d build all of the vertices of the object, there are still no links connecting them or the material properties reflected. To accomplish this, two sub-routines were developed. The first routine is a method to assign links to connect nodes which are near to each other, this was done through use of a for loop. The second routine applies the material properties exported from Abaqus to the object in chai3d. It works by cycling through the nodes on the object and assigns a mass value corresponding to the amount of deflection derived from the FEA analysis. Additionally, spring stiffness’s are assigned in the same fashion by averaging the mass between two nodes. With an interconnected system of nodes and links, the surfaces of the object are defined and the deformable body is created. While this method does not directly emulate the finite element response the system undergoes, it illustrates a mass-spring representation and an approximate behavior of the system. Upon completion of these steps to recreate the model, the haptic model can now be rendered and interacted with.

Chai3d program layout

Due to chai3d’s wide range of application interfacing, it is possible to develop a single application that can handle the low level inputs coming from the haptic device and simultaneously use high level programming to create a scene and graphically update the application.

To gain an understanding of the components of the main application, the sequence of events the program follows is detailed. The program begins with declaring the necessary libraries and variables for use later in the program. The libraries called include the chai3d library and GEL library while the variables declared include the haptic handlers and GEL objects. Next, the initialization and graphics of the program are generated; this controls the application window size and hotkeys used to manipulate the initialization of the program. We can then begin to create the virtual scene in our environment through the use of inbuilt objects in chai3d and the graphics library, OpenGL. After the mechanics models are created in Abaqus and saved into an exportable format, they can be loaded into the application as deformable objects. The objects are rendered in the front of the virtual world and prescribed system characteristics according to the data garnered from the FEA. Next it is important to handle the haptic device. This portion of the code allows us access to the haptic device and controls the input the application will receive from it. Chai3d uses a point-force algorithm to handle the haptic device and interpret its interaction with other virtual objects. With the identification and management of the haptic device completed, it is possible to graphically render the cursor of the haptic device and manipulate the virtual object. Lastly, a haptic thread is generated in order to keep the haptic device in constant contact with application until exiting. This loop handles the updating of the models, the force feedback returned to the device, and allows real time interaction. With the application developed, an analysis of the results of this application can commence.

CHAPTER III

RESULTS

Returning to the aim of this project to develop an application that can bolster engineering students' understanding of common mechanics concepts, it can be concluded that the objective was achieved. A snapshot of the application is presented below in Figure 4; this snapshot reveals the node and link network present in the cantilever beam, the haptic cursor, and the basic appearance of the haptic application.

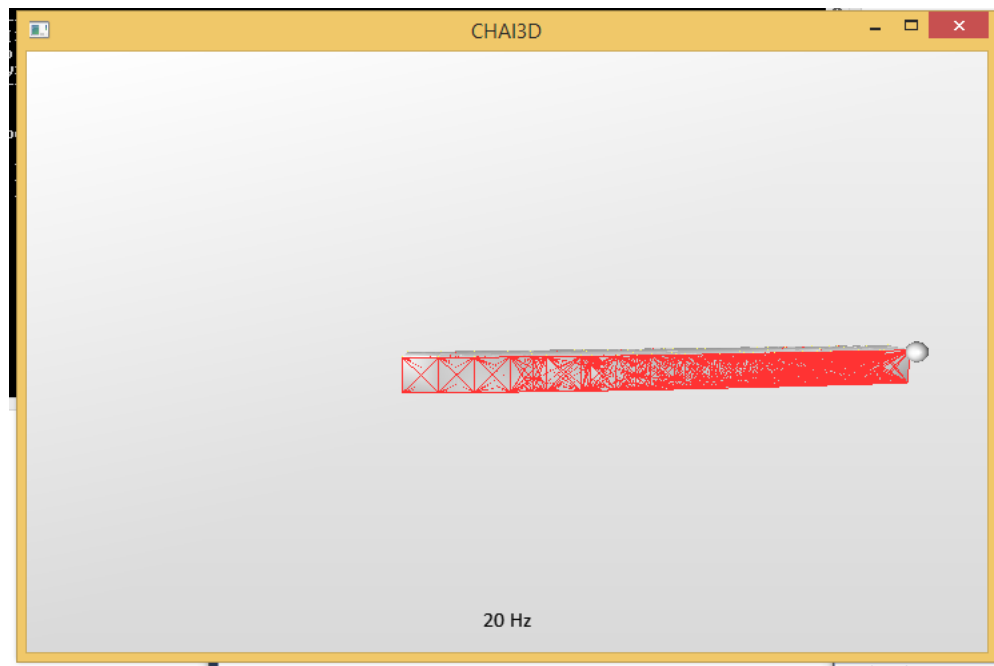


Figure 4: Haptic Interactive Mechanics Models

This application succeeds in allowing users to “feel” how different combinations of design parameters influence the system response as a whole. Additionally, by reflecting the FEA behavior of the system, the goal of recreating real system responses was achieved as well. The

task of importing an object from a FEA software and interacting with it via a haptic device was accomplished through the development of original subroutines. By bridging the gap between analytical concepts and real world responses, this application allows users to obtain a unique insight and consequently enhance understanding of the system.

CHAPTER IV

CONCLUSION

With the completion of the application, a review of the findings and methods will reveal the implications of this project. Firstly, the development of this application demonstrates an innovative and largely unexploited avenue to teach students through the use kinesthetic feedback and virtual technology. For students who struggle to learn from a traditional teaching approach, this application offers an alternative approach that can greatly help those inclined to kinesthetic learning. Secondly, although the application does not exactly replicate the true finite element responses of the system, the use of a mass-spring system demonstrates a heuristic method that suffices in illustrating discrepancies between systems. The task of performing real-time FEA is an attainable future development and would greatly improve the response of the system. And while chai3d is an excellent set of libraries for rapid application development and introductory haptic development, the simulation engine is limited and is not ideal for rapid real time haptic model interaction. In conclusion, the application developed provides an inaugural look into the future of interactive teaching and furthermore can be implemented to bolster students' learning comprehension of mechanics concepts.

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