Haptic Virtual Prototyping of Buttons

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Abstract: The design of any physical product involves prototyping. Building physical prototypes of the products can be expensive and time consuming. An alternate to physical prototyping is haptic virtual prototyping, which simulates the product using a computer and a haptic device. A haptic device is one that produces the forces similar to that of the product, giving the user a realistic feel of the product. Since the feel of a product plays a significant role in its commercial success, the importance of haptic virtual prototyping as a design tool is increasing. This paper discusses the haptic simulation of a push button on a low cost and commercially available haptic device called Novint Falcon. Two different models were created – the first one was a simple push button, and the second was an on/off click button. The parameters of the two models were selected such that they have the most accurate tactile response or feel of the product. The two models successfully simulated the feel of the buttons, and it was found that haptic virtual prototyping of buttons is achievable using a low cost haptic interaction system.

Key Terms: haptic simulation; haptic virtual prototyping; physical prototyping; Novint Falcon; buttons; force feedback

Introduction

The increasing use and advancement of computers has created the opportunity of building virtual objects that mimic real life objects. Computer simulations usually mimic real life objects using human senses of sight and sound. The sense of touch is added to computer simulations using haptic simulation with the help of a device called a haptic device. By incorporating touch into simulations, haptic technology makes the virtual products feel more realistic than computer simulations. The haptic device produces forces and vibrations similar to the physical product, which gives the user a realistic feel. For instance, if a user compresses a virtual spring using a haptic device, he/she would *feel* the spring pushing back just as expected in reality.

One of the uses of haptic simulation, haptic virtual prototyping, allows users to create and test virtual prototypes using the haptic device. Physical prototypes of products are usually expensive, take time to build/assemble, and include additional costs that come with any successive design changes.

Virtual prototyping, unlike physical prototyping, enables quick modifications and design changes to the prototype (Colton & Hollerbach, 2007). Once the dynamics of a product are properly modeled for virtual prototyping, the model parameters can be changed easily to modify the physical properties, and hence the feel of the product. Along with the advantage of faster implementation and rapid modification, virtual prototyping also involves lower costs compared to physical prototyping, due to the absence of material, machining and assembly costs of the prototypes. The only major cost involved in virtual prototyping is that of the haptic device. Consider the prototyping of a spring involved in a product, such as a button. If the product was too hard and needed a spring that was less stiff, a completely new spring would be required for the physical prototype. The spring would either have to be ordered, or manufactured, and then assembled with the rest of the components of the prototype. For virtual prototyping, however, altering a few parameters in the computer could change the stiffness of the virtual spring, and the change would not affect the other components of the product.

This research paper discusses haptic virtual prototyping of a button, and shows the possibility of implementing it using a cheap, commercially available haptic device. The idea of virtual prototyping of a button can be extended to complicated products, including automobiles, musical instruments, and surgical tools. As with the virtual spring, the design of virtual prototypes can save time and money for the development of a wide variety of products.

Related Work

Previous research has applied many different approaches to simulate the feel of buttons and switches. Some researchers have generated models of push buttons and knobs using first principles, and implemented these general models (Allotta, Colla, & Bioli, 1999). Other researchers have based the models on experimental data gathered using an instrumented probe, creating a position and direction dependent model that was played back on a haptic device (Colton & Hollerbach, 2007). To accurately capture the feel of switches, some researchers have used human actuation to record a haptic profile.

This haptic profile uses the projections of the plots of force, position, and velocity to derive meaningful relations between the graphs and the characteristics of different buttons (Weir et al., 2004). Unlike most of the work done for virtual prototyping of buttons, the models created in our research were not played back. The forces applied by the haptic device were calculated in real time using the position and velocity at the current instant. Related work done by past researchers was, though, helpful in recognizing the salient features and the variation of characteristics, like the stiffness and damping of different types of buttons.

Novint Falcon

The haptic device used for the research was the Novint Falcon, a 3-D device developed by Novint Technologies, Inc. The Novint Falcon is commercially available as a 3-D game controller that applies forces and vibrations according to different events in the game. The application of force is called force feedback, since it is directly related to the visual actions in the game. The device provides force feedback in all three spatial directions and is particularly popular for first-person shooter games, where the normal grip for the controller can be replaced with a pistol grip. Haptic simulation of a button requires only one degree of freedom, and movement in the other two directions should be restricted. For the purposes of the research, the users operate the Novint Falcon by holding the Novint grip, and pushing it like they would push a normal button. The workspace of the Novint Falcon is 4”X4”X4,” and the update rate is 1 kHz (Martin & Hillier, 2009), which are sufficient for the application of the research. It is also a good choice for this research, since it is relatively inexpensive compared to high-end haptic devices, costing only about $250.

Applications

Haptic virtual prototyping has been employed in many industries and is becoming increasingly popular. It has already been used to model automobile systems (Buttolo, Stewart & Marsan, 2002) and dial knobs (Kim, Han, Shin & Park, 2008). Apart from haptic virtual prototyping, haptic simulation has a wide range of applications. Indeed, haptic simulation is currently being used in the field of medicine for surgical training, where prospective surgeons train in a virtual environment with force feedback, and gain motor skills beneficial for real surgical proficiency (Sewell et al., 2007). The Novint Falcon itself has been used to model street intersections as a haptic map for blind people (Mason & Manduchi, 2008). Haptic simulation is also being used to create haptic musical instruments that mimic the feel of real musical instruments (Berdahl, Niemeyer & Smith III, 2009).

Basic Model

A spring-damper model can be used as a general model to describe the non-linear behavior of a button. A spring-damper system is shown in Figure 1.

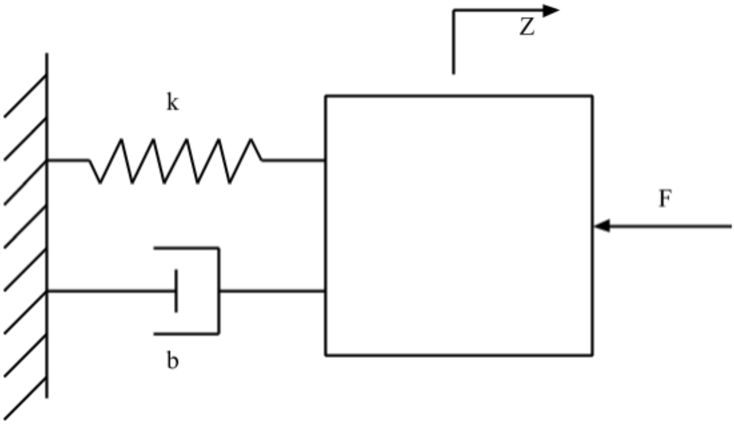

Figure 1: The basic model of a button

Any displacement of the button from its equilibrium or resting position causes the system to exert a force. The force depends on the stiffness (*k*) and damping coefficient (*b*) of the system. The force exerted by the button can be expressed as:

$$F_{button} = -kx - bv$$

where *x* is the signed distance from the equilibrium position (negative for compression and positive for expansion of the spring), and *v* is the velocity of the button at the current instant. The calculated force, exerted by the button on the finger, has a direction opposite to the force shown in Figure 1. The equation of the general model does not describe how the model parameters (*k*, *b*) vary with displacement (*x*). The choice of the model parameters decide the tactile response of the button, and hence, the feel of the button.

Since the Novint Falcon measures the position of the cursor, the distance from the equilibrium position can be calculated by setting an arbitrary resting position for the button as its equilibrium position. The haptic device, however, does not measure the velocity. The average velocity between the current position and the previous position of the cursor was used to approximate the instantaneous velocity of the cursor.

Motion of the Button

The button is modeled as a cube, whose center is taken as the origin for the coordinate system. The orientation of the coordinate axes is shown in Figure 2. The front face of the cube is taken as the front face of the button, and the equilibrium position is half the distance of the side of the cube from the origin along the positive *z* direction.

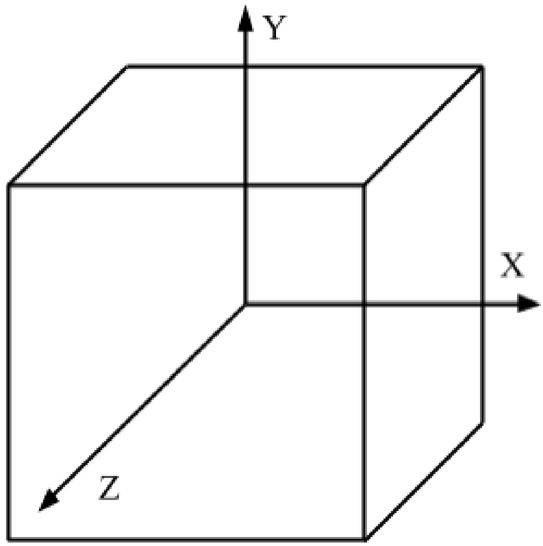

Figure 2: Orientation of the coordinate axes with its origin at the center of the cube (button)

The motion of the button is only in one direction (*z* direction), with the motions in the other two directions needing to be restricted. To restrict the motion along the *z*-axis, forces were applied to the Novint grip whenever the values along the x and y directions were not close to zero. This enabled the haptic application to have one degree of freedom, like that of a push button. The variation of the force along the *x* direction is shown in Figure 3.

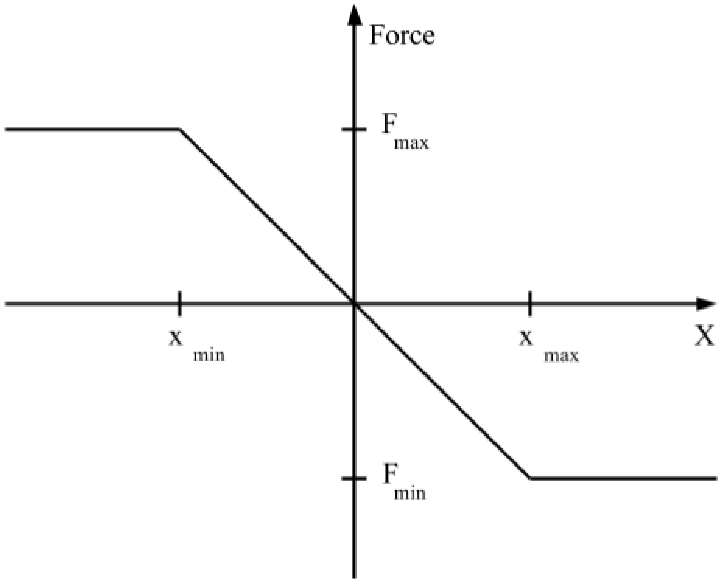

Figure 3: The variation of force with the *x*-axis for restriction of motion

If the cursor moves along the positive *x* direction, as seen in Figure 3, there is an increasing force in the negative direction (opposite to the direction of motion) on the Novint grip. This force tends to bring the grip back to its resting position, where the value of the x coordinate is zero. Similarly, if the grip is moved in the negative *x* direction, a positive force is applied that brings the grip back to the resting position. The force shown in Figure 3 is the force due to a spring, whose stiffness is modeled by the slope of the graph. Damping was also added to make the motion smoother. A similar variation of force with the *y*-axis was done to restrict the motion in that direction.

Models

By varying the model parameters (stiffness and damping coefficient) of the basic spring-damper model, two final models were created. The first one was a push button, and the second one was an on/off click button. The Novint Falcon could switch easily between the two models, showing the versatility of haptic virtual prototyping.

Model 1 – Push Button

A simple model to simulate a push button, like an elevator button, was created. The stiffness and the damping coefficients varied non-linearly with the displacement from the equilibrium position. They were modeled as opposite parabolas with the same axis of symmetry. The stiffness was modeled as a parabola that opened upwards, while the damping was modeled as a parabola that opened downwards. This was done to account for the detent, or the temporary resistance to motion, that is encountered while pushing this type of button. The experimentally determined variation of the distance from the equilibrium position with the damping coefficient and the stiffness are shown in Figures 4 and 5, respectively.

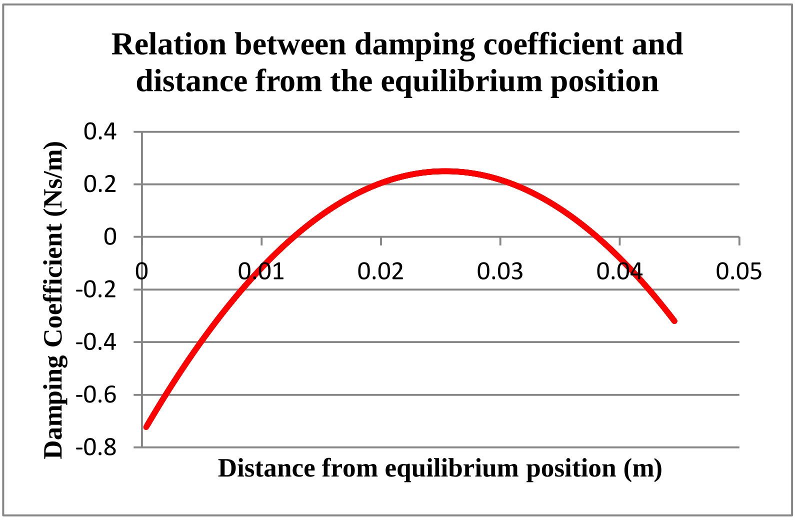

Figure 4: The variation of damping coefficient with the distance from the equilibrium position

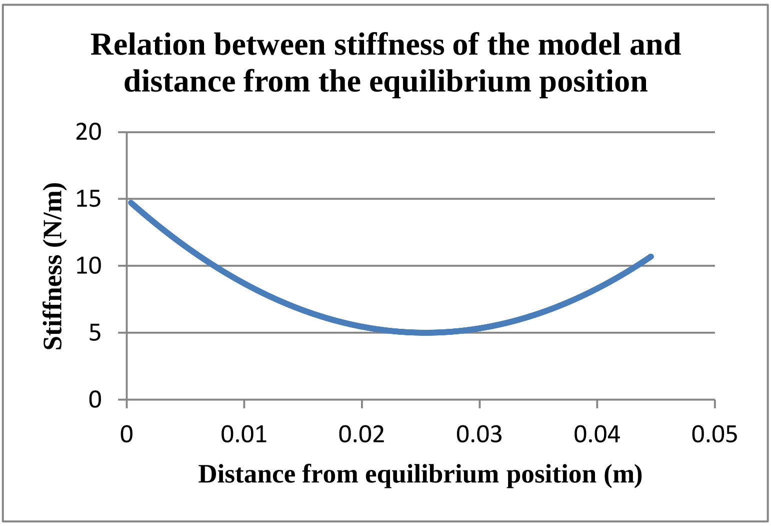

Figure 5: The variation of stiffness with the distance from the equilibrium position

Model 2 – On/Off Click button

The second model simulated a button with different on and off positions, similar to a button for a retractable pen. The button had two resting positions: the "off" position was the original equilibrium position of the button, and the "on" position was at a distance of about 0.9 inches (0.0229 meters) from the equilibrium. The force applied on the grip varied linearly with distance, thus only the stiffness of the spring was included in this model, while damping was ignored. A memory of the state of the button was recorded by triggering a flag whenever the cursor crossed the "on" position. When the button was in its "on" state, the motion back towards its original equilibrium position ("off" position) was restricted at the new resting position ("on" position). The restriction of motion was done in a similar way as was done for the *x* and *y* axes. The forces felt by the Novint Falcon grip, during the motion of the button were plotted, and are shown in Figure 6. The jump in force seen at around 0.0229 metres indicates the "on" position, while the "off" position is at zero (equilibrium).

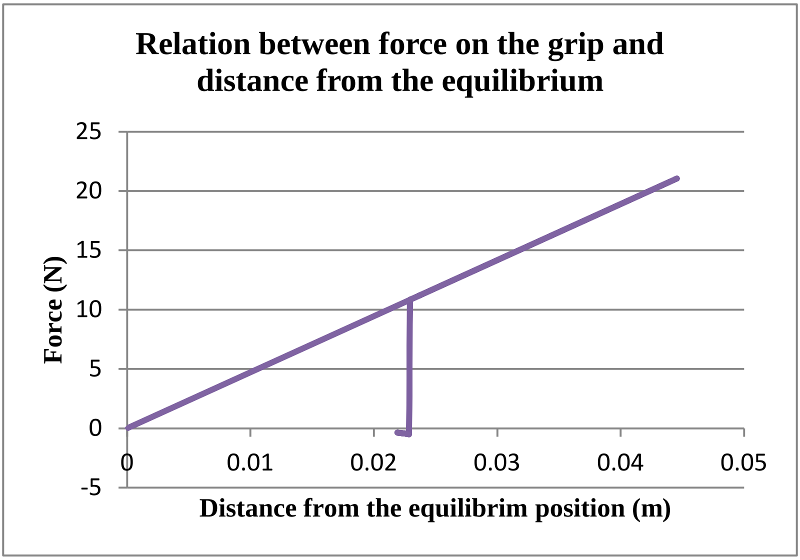

Figure 6: Variation of force with the distance from the equilibrium position

Conclusion

The models discussed in the paper successfully simulated both the buttons. The first button modeled was a simple push button, while the second one was an on/off click button. The model parameters of the buttons could be instantly changed to meet different design requirements for stiffness and damping of the buttons. By implementing haptic simulation of buttons within a span of a few months, it was found that haptic virtual prototyping of simple products could be easily achievable. An iteration of such a process using physical prototypes would require more time for assembling, and more money for materials and manufacturing. Moreover, by using the Novint Falcon, it was shown that haptic virtual prototyping of buttons could be implemented using a relatively inexpensive and commercially available haptic device.

The only major drawback of the models discussed was the unnecessary vibrations felt when the grip was close to the equilibrium positions. The vibrations were not accounted for in the current models, and by including them in future iterations, the feel of the buttons would be more realistic. To further improve the feel of the buttons, the model parameters can be chosen based on the parameters of a human-actuated physical button.

Virtual prototyping of buttons can be useful for appliances that constantly use buttons, such as washing machines, elevators, automobiles, computers, and so on. Additionally, the concepts of haptic prototyping done on a button can be extended to any kind of industry that requires iterative design processes. For instance, virtual prototyping can extend from the buttons of an automobile to the steering wheel, and ultimately, all the components of the vehicle involving the human sense of touch. Thus, haptic virtual prototyping can greatly improve the feel of products in a quick, easy and affordable way.

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