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WIP: Building Intuition in Mechanics with Haptic Feedback

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Work in Progress: Building Intuition in Mechanics with Haptic Feedback

Introduction

People learn best by interacting with physical systems: by exploring and receiving rich sensory feedback. In engineering education, this sensory feedback is provided best by laboratories and projects. However, it is not possible or practical to build physical systems for every engineering problem that students encounter. Because of these practical limitations, much of an engineer's education comes through analyzing systems drawn on paper or projected on a screen.

One solution is to use haptic devices to simulate physical interaction. Haptic devices make it possible to rapidly create and interact with a wide range of physical systems. When the user interacts with a haptic environment, they receive correlated visual and tactile sensory feedback. Richer and more complex sensory feedback gives the user a more immersive experience. Furthermore, the user may have control over changing the properties of the haptic environment and exploring the effects.

Haptic technology has the potential to enhance the engineering classroom in several ways. First, increased sensory feedback can improve retention of engineering concepts [1]. Second, haptic feedback can improve intuitive understanding of complex systems and environments [2]. Third, tactile information creates learning opportunities for students who are visually impaired [3]. Fourth, involving students in coding of the haptic system may improve algorithmic thinking.

This study involved developing haptic learning tools for students using the Haply robot, a low-cost, commercially available haptic device. The device was programmed to generate two virtual models: 1) a static beam subjected to shear force and bending moment loads, and 2) a block subjected to acceleration and frictional force on contact surfaces. In response to user inputs, the system then returns force feedback to the user via the Haply manipulator.

The goal of this study was to examine the effects of an educational haptic device on the students' algorithmic thinking as well as intuitive and conceptual understanding. The haptic device provided tactile information that reflected the real-world systems. Such hands-on learning experience supports integration of knowledge and skills. While this method of learning can be directly applied to engineering education environments, the experimental framework was developed for students with no required specialized knowledge to make the lesson activities accessible to a variety of audiences. Unfortunately, the study was disrupted by the COVID-19 pandemic and the team was unable to conduct in-person experiments as planned. Instead, the team conducted a remote pilot test.

Methods

Two examples from a typical Engineering Statics course (moment of force, and friction of a sliding block) were selected to model in the haptic environment. The models were made using the Haply Development Kit and the Java programming language in Processing. For the Moment Lab, a beam overlaid with hash marks was subjected to a normal force that could be moved to increase or decrease the distance from the beam's point of rotation. The user operated a cursor, which allowed them to apply forces to the virtual beam. The applied perpendicular force and moment were updated in real time to provide feedback to the user as shown in Figure 1.

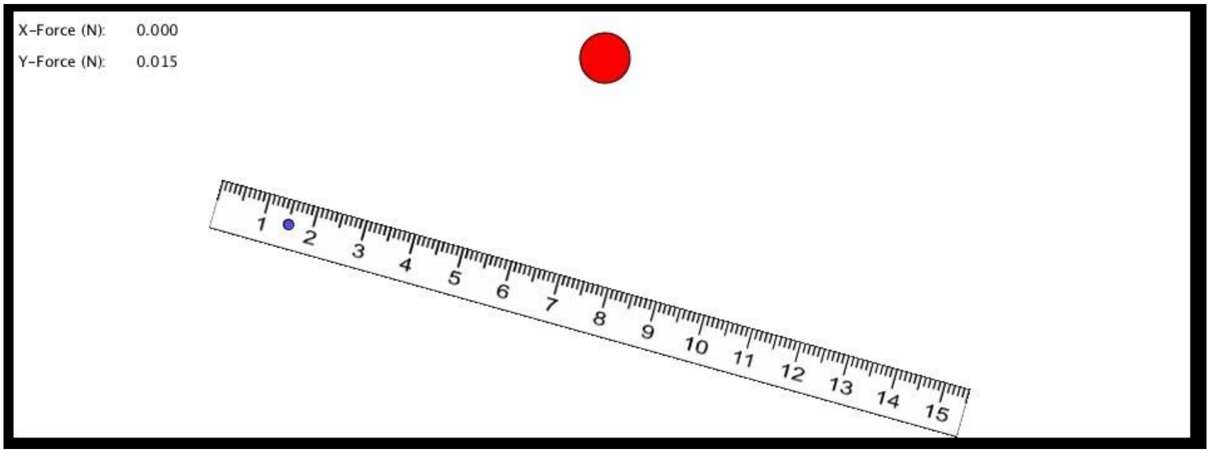

Figure 1. The Moment Lab canvas as viewed by the subject. Note the horizontal and vertical forces applied by the cursor are displayed in the upper left-hand corner.

The Friction Lab consisted of an interactive exercise where the user not only interfaced with the block through the Haply manipulator, but also altered the program code to see the effects of changing the block's friction coefficient. Changing the coefficient resulted in different behaviors of the block in the environment. Consequently, two potential outcomes occurred based on the value of the coefficient: the block would either "slip" or "tiip" when acted on by the user. The haptic system relayed visual and tactual information back to the user to reflect the system's response.

To guide the user through the haptic environment, a procedural lab manual was provided while an instructor oversaw the subject's progress. The instructor was encouraged to help the subject should any technical difficulties arise as well as answer any general questions about the operation of the haptic device.

Results and Discussion

Despite the remote testing operations, the procedure was successfully completed and data was obtained for one subject. This data includes qualitative responses collected during the test to gauge the subject's understanding of the topics. These responses revealed a progression in understanding as the subject proceeded through the experiment. The two parts of the experiment (Moment Lab and Friction Lab) were tested in sequence, and the subject was recorded using knowledge obtained during the Moment Lab to predict the outcome of the Friction Lab. After the test was completed, a series of questions was asked to verify that the subject gained knowledge or intuition which was transferrable to other applications outside those encountered in the lab.

In the Moment Lab program, the subject used the Haply robot to lift the beam up with the cursor. The subject was able to comprehend how the forces acting on the beam changed as the cursor's position on those objects varied. This was made apparent to the subject when they felt greater resistance from the Haply robot's motors, representing a greater force. Since the force magnitudes were also displayed on the screen for the subject, they could reinforce their sense of touch with quantitative proof that the objects were easier or harder to move. The subject summarized this realization about the forces in a brief statement: "[C]loser to the pivot point the forces are greater and [they] decrease as the cursor moves toward the other end of the beam." This comment demonstrated that the haptic environment allowed the subject to develop their intuition about the relationship between the length of the moment arm and force.

When the subject recorded their thoughts about the Friction Lab, they were able to deduce the effects of changing the static coefficient of friction between the block and the ground. As shown in Table 1, the subject discovered that increasing the friction coefficient caused the block to tip sooner rather than slide. They also noted that applying the pushing force nearer to the top of the block influenced the magnitude of the force required to tip the block, similar to how cursor position was critical in the Moment Lab which they had just completed.

Table 1. Subject's responses to changing the static coefficient of friction of the block in the Friction Lab program.

Static Coefficient of Friction	Flip/Slide (F/S)?
0.1	Slide
1	Slide, unless force is applied near the top.
10	Flip

Overall, the subject followed the guiding procedures well without much instruction from the administrator, though there were periods when the instructor had to provide clarification due to some ambiguity in the procedure. The subject navigated the haptic environment with relative ease and quickly understood how the coded program was analyzing the on-screen operations.

Finally, as was mentioned earlier, some ambiguity in the procedure caused the subject some confusion which may have led to discrepancies in the results. This caused the subject to repeat a portion of the lab manual and rethink their answers to the guiding questions. Moreover, the data was collected from only one subject due to the gathering limitations. This small sample size did not represent the entire population; however, the test did yield some insightful data that would be beneficial for a future, larger experiment. The subject stated that they thought the haptic environment lent itself well to promoting a more intuitive learning environment, as hypothesized. More testing will seek to verify this conclusion.

The original goal of this project was to study the effects of using a haptic device with a two-part lab activity. The control group engages with traditional learning materials (text, illustrations, and examples) and a second group engages with the Haply robot. This work was interrupted due to limitations in data collection, and thus future work will build from this pilot protocol to conduct the planned study. If the study shows benefits, the haptic system can also be modified for a variety of engineering courses, K-12 STEM outreach, accessible learning platforms for visually impaired students, and more.

References

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