Haptic Learning Tool for the Visually Impaired, ”Haptic Mouse”

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***Abstract*— Learning is typically highly dependent on visual representations of information. Thus, visually impaired students struggle more in standard school environments. We present a new device, Haptic Mouse, to aid in teaching visually impaired students mathematical and geometric concepts such as line angles and shapes. In this paper, we will discuss the device's hardware, rendering capacities, software, and user interface. We will also cover the preliminary user studies that have been performed.**

I. INTRODUCTION

Learning process for sighted people heavily depends visual stimulus. About 80 percent of the information absorbed us through sight [1]. Therefore, visually impaired students have a harder time on learning in general. To enhance the learning experience for the visually impaired, the team designed a device called **Haptic Mouse**, showcased in Figure 1. This was designed to present the visually impaired with an alternative to vision through the kinesthetic sensation. It has a mouse shell which contains a position tracking circuit and the delta mechanism platform which provides the haptic feedback to the user's fingertip. It communicates with visual software letting the user feel the haptic feedback at the same time showing the administrator or teacher the current environment's configuration. The optimal conditions of virtual environment is still being studied to find the optimal methods to convey the information. To define the optimal condition, a user study on stiffness and element width has been initiated.

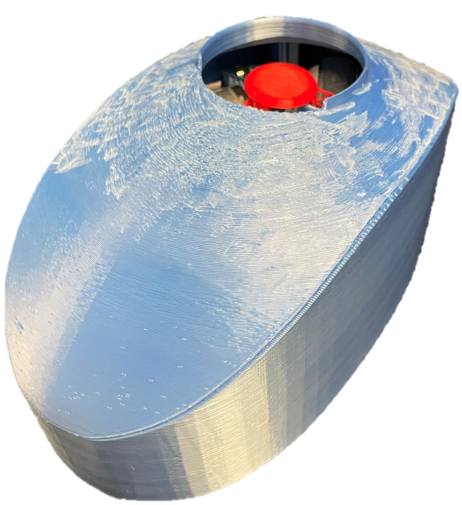

Fig. 1: Haptic Mouse

II. RELATED WORK

A number of studies have been done on the delta mechanism. “Delta robot: Inverse, direct, and intermediate jacobians” proposes a widely used way of calculating Jacobian for the mechanism [3]. Since the mechanism has only three controllable angle, each controlled by a motor, the relationship between velocity of the end-effector and the controllable angle is essential. In general, arbitrary angles other than the controllable angle are included in the kinematic equation. Their work presents a way of separating the differentiated version of the kinematic equation into two matrices that relates each motor's angular velocity to the end-effector velocity.

Vision is typically the quickest way to present information, however haptic devices can use computer-generated forces convey information and take advantage of the two-way nature of kinesthetics to provide information dynamically. Specifically, data can be difficult to represent in a non-visual manner so there is much interest in finding methods of rendering mathematical objects such as lines or parabolas with haptic devices for the visually impaired [4]. This paper presents methods for rendering such objects through the use of a haptic device.

Another aspect of haptics devices we need to consider for our design is the system software architecture. Specifically, a more efficient implementation of the key algorithm or system pipeline can increase the frequency of the haptics device, providing users a better haptics experience [5]. We gained some insight into the design of efficient haptics feedback loops after reading some papers in this area.

Some other prior work has focused on position based feedback and tracking with expensive touchpads[6]. This method, however, had limited success among visually impaired users.

Compared to another similar delta haptic device[7], the use of ball joints in its design provides the system with more degrees of freedom (DOF). The addition of a safety layer also ensures the safety of both user and the entire mechanism. This offered valuable insights for the direction of the design.

III. METHODS

A. Delta Mechanism

The haptic mouse is based on delta mechanism which can be generalized as parallelogram mechanism, as shown in Figure 2. The model consists of two platforms and three legs which link the two platforms. The base platform includes motors that actuate each leg, driving the upper platform that acts as the end-effector for the user. In order to perform any analysis on the mechanism, the position of the end-effector is needed. Therefore, the analysis of the mechanism starts by relating elbow positions of the links to the end-effector position through virtual spheres. Each of the elbow positions makes a sphere with respect to the end-effector which leads to collision of the three spheres at a single point that refers to the end-effector position [2].

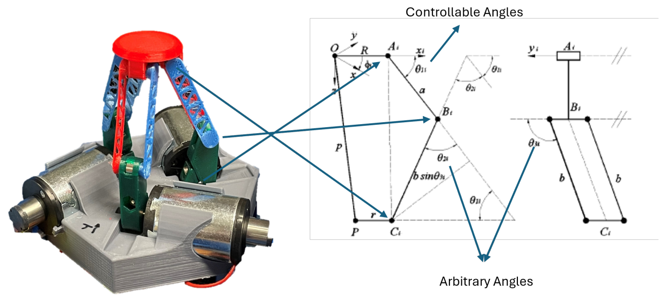

Fig. 2: Delta Diagram

The position of the end-effector is then used to calculating the Jacobian matrix of the mechanism. The Jacobian matrix is necessary to implement any haptic feedback to the user by relating desired forces to motor torques. To achieve the Jacobian matrix, the position of the end-effector is calculated in two different ways. One of the two equations represent the end-effector position calculated from previously explained kinematics and the other being calculated with the geometry and vectors. Setting those two equations equal and differentiating the whole equation gives us a relationship between the angular velocity of the controllable angles and the velocity of the end-effector. This relationship is applied to adjust the mechanical impedance of the end-effector experienced by the user.

B. Hardware Design

The mechanical design includes a delta mechanism arm optimized for toughness and strength through specific 3D printing orientations and specially designed patterns. The mechanism is showcased in Figure 3. A standard computer mouse PCB is used for position tracking.

The ergonomic casing, Figure 4, is designed to house the delta mechanism and PCB efficiently, focusing on user comfort. The addition of anti-slip textures improves grip and control, enhancing the user experience without unnecessary complexity.

C. Rendering

We wanted to determine the maximum stiffness that could be rendered by the delta mechanism without it going unstable and without any weight on the device. To do this, we started with no damping on the device and tested stiffness values until we found the maximum value before the delta started exhibiting unstable behavior. Then we incremented the damping value by 0.05 Ns/m up to a B value of 0.5 Ns/m,

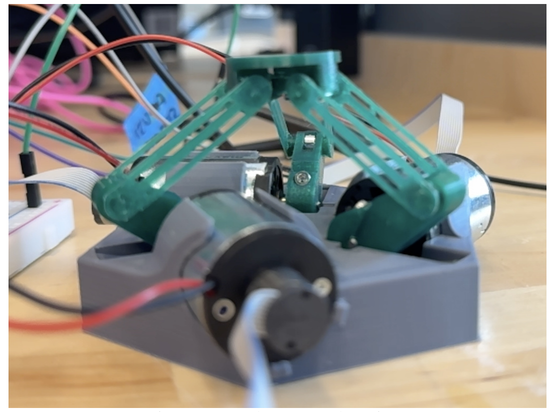

Fig. 3: Delta Mechanism

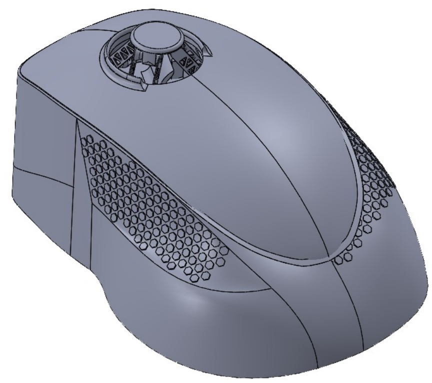

Fig. 4: Ergonomic Mouse Casing

At each damping constant, the maximum stable stiffness was determined to find the optimal stiffness and damping combination.

D. Communication

To activate or stop rendering force feedback when the user interacts with the rendered object, we implemented a uni-directional serial communication between the rendering computer and the STM32 microcontroller connected with the delta mechanism. The communication diagram is shown in Figure 5. When the cursor collides with the rendered object, the computer sends a ”u” message to the STM32 to increase the feedback force from the free space value of 20 N/m to 40 N/m. Conversely, the computer sends a ”d” message to the STM32 to command the feedback force back to the free space stiffness value when the cursor exits the rendered object. This toggling-style communication reduces the communication overhead, so that delta mechanism control loop can execute at a high frequency.

In addition to the rendering communication interface, we also implemented a message interface taking two digits from the computer to change the default stiffness value on the STM32.

E. Graphical User Interface

To enable an evaluator to administrate a test of the haptic rendering system, two graphical user interfaces (GUI) were

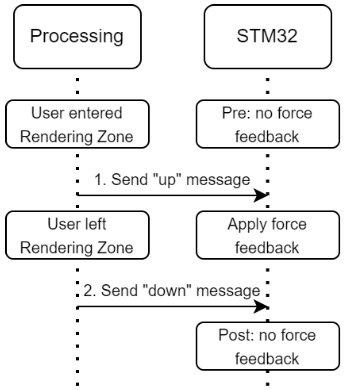

Fig. 5: Example Serial Communication Sequence Diagram

created using the Processing programming language. The first allowed the evaluator to enter a stiffness value to be communicated to the microcontroller. The second, shown in Figure 6, graphically rendered one of three shapes on the screen and detected when the cursor driven by the haptic mouse was in contact with the shape.

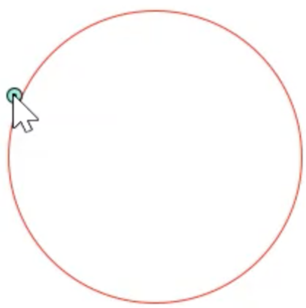

Fig. 6: GUI Rendering a Circle In Contact

The GUI rendered either a line, rectangle, or circle. When the user was in contact with the line or shape, the GUI changed the shape outline color to reflect that. In the case of the line, the evaluator was able to enter the angle of the line with respect to the horizontal. This permitted a study of the ability of a user to discriminate between lines of various angles.

F. User Study

We performed two user studies— a stiffness study and a line thickness study— to determine the stiffness difference and the line thickness that we should render on the device.

1) Stiffness Study: To determine the just noticeable difference (JND) of stiffness value that a user could detect, a user study was performed. To do this, the method of constant stimuli was used. Randomized pairs of stiffness values where one value was consistently 20 N/m were presented to the user through the device. The stiffness differences increased in increments of 5 N/m, and the maximum stiffness difference was 40 N/m. A damping value of 0.5 Ns/m was used throughout the user study. Users were instructed to lift their hand off the device between each stiffness value change. They were not allowed to look at the device or the user interface. At the end of each round, users were asked which value they thought was stiffer.

2) Line Thickness Study: To determine what line thickness we should be rendering, another user study was performed. Three different line thicknesses (10, 20, and 30 pixels) were used in random order. For each line thickness, 5 different angles with respect to the horizontal (0, 30, 45, 60, and 90 degrees) were presented in a random order. Users were asked to guess the angle of each line, and they were not allowed to look at the device or the user interface. The user was allowed to move the mouse around the virtual environment to explore presented line.

IV. RESULTS

A. Rendering

Multiple values were tested and the maximum stiffness was determined, as listed in Table I. We noticed that as the damping value increased, the subsequent increase in stiffness value gradually decreased. Between 0.40 and 0.50 Ns/m, the increase in stiffness was only 3 N/m so we decided we were approaching the maximum stiffness value. To err on the side of caution, we denoted the maximum stiffness and damping value as 60 N/m at 0.5 Ns/m.

TABLE I: Maximum Stiffness Values

Damping Ns/m	Stiffness N/m	Damping Ns/m	Stiffness N/m	Damping Ns/m	Stiffness N/m
0.00	15	0.20	45	0.40	60
0.05	25	0.25	50	0.45	62
0.10	35	0.30	55	0.50	63
0.15	40	0.35	58	**0.50**	**60**

B. Stiffness Study

We tested with 3 users and found that the JND value was likely between 5 and 10 N/m, as shown in Table II. For our purposes, we decided to use a difference of 20 N/m so that the users could definitively feel a difference in stiffness without it being too aggressive.

TABLE II: Stiffness Difference Study

Stiffness A	Stiffness B	Difference	User 1	User 2	User 3
20	20	0	A	A	B
20	25	5	B	A	B
20	30	10	B	B	B
20	35	15	B	B	B
20	40	20	B	B	B
20	45	25	B	B	B
20	50	30	B	B	B
20	55	35	B	B	B
20	60	40	B	B	B

All stiffness and difference values are in N/m.

TABLE III: Line Thickness Study

Thickness	User 1 Guess	User 1 Error	User 2 Guess	User 2 Error	User 3 Guess	User 3 Error
10	0	0	0	0	0	0
	45	-15	45	-15	45	-15
	30	15	60	-15	30	15
	60	0	60	0	60	0
	90	0	90	0	90	0
20	0	0	0	0	0	0
	45	-15	30	0	30	0
	45	0	60	-15	30	15
	60	0	60	0	60	0
	90	0	90	0	90	0
30	0	0	0	0	0	0
	0	30	45	-15	30	0
	45	0	45	0	45	0
	60	0	60	0	90	-30
	90	0	90	0	60	30

All thickness values are in pixels and all angles (guess and error) are in degrees.

C. Line Thickness Study

We tested with 3 users and found that users struggled most lines that were 10 pixels wide, as seen in Table III. They commented afterwards that the line was too thin to be noticeable and easy to skip over. Users performed better with lines that were 30 pixels thick, however still made quite a few errors. One user commented that the line was too thick for them to perceive the difference between a line that was nearly vertical and vertical. Users performed the best on lines that were 20 pixels thick. So, that was selected as the optimal thickness for rendering.

We observed that this study was subject to training bias. Although we randomized the thickness orders, we found that as users became more experienced using the device, they began guessing angles faster and more accurately having developed better methods for exploring the line.

V. LIMITATIONS

One issue with our user studies were that we only had 3 users for each of the studies. So we do not have sufficient data to definitively say that the values we found were optimal. Furthermore, our test subjects were all sighted, which would not be the target market of this device. So these studies may not be the best for determining what is necessary for this device and further user testing would need to be done with visually impaired users.

Another issue we learned after talking with a visually impaired person is that visually impaired people don't use mice, meaning that they do not have the prior knowledge in mouse manipulation. Additionally, our device is larger than the size of a regular mouse, making it more difficult for visually impaired people to use. Therefore, either shrinking the size of our device or considering a new design is necessary in the future.

VI. FUTURE WORK

Future work would start with user testing, specifically on the visually impaired population. The amount of data collected makes it difficult to define the optimal condition for haptic feedback. Therefore, more user testings are planned to eventually determine the optimal condition. In parallel to the user testing, experimenting with various haptic feedback should be considered.

Future efforts in mechanical design will focus on refining the delta mechanism to enable more accurate force rendering and shrinking the mouse casing for improved comfort and control. We will also consider alternatives to a mouse-shape design.

On the system communication side, depending on the need for rendering more complicated objects, position and velocity information transfer will be supported. While the implementation of the interface won't be difficult, the system will no longer communicate in a toggling fashion and we need to put in effort to optimize the performance of such interface.

For the GUI, improvements in the number of geometric objects that can be rendered, the range of parameters of those objects, and the scaling of user motion and motion in the virtual environment will be improved. In addition, solid shapes, rather than outlines only, will be added.

VII. CONCLUSIONS

We have developed a device for enhancing the learning experience for the visually impaired. **Haptic Mouse** uses a delta mechanism to provide users with haptic feedback based on the position in a virtual environment containing a geometric object. We have developed the mechanical design, graphical user interface, and the communication between the mouse and the user's computer. We have tested the capabilities of the delta mechanism as well as performed user studies to learn what line thickness and stiffness difference would be best for rendering lines and shapes. These will inform the future development of the device.

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