Evaluation and Construction of the Spiderbot

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ABSTRACT

Link to the video: https://youtu.be/8unQgWh_Z5s

INTRODUCTION

The Spiderbot is a mobile motion-controlled robot. Its primary function is to serve as a toy. Each leg of the Spiderbot is attached to a marker, so the movements of the user's hands create line art compositions.

Our intent in the design interaction is for the robot's motions to be a seamless extension of those of the user. Two general responses to the visual feedback are expected:

1. Users may be encouraged to move more creatively and explore the possible shape and color configurations the robot can produce
2. Users might control their movements to produce a more intentional drawing.

Either way, the interaction with Spiderbot is intended to establish a connection between the user's bodily movements and the art produced.

The main control box has motion sensors which the user interacts with by moving their hands--this module wirelessly informs the motions of the robot.

The control box and the robot (Figures 1 and 2) are physically separated. The control box is nondescript except for an etching of a spider on the top and holes cut out to expose the sensors (Figure 2). The box screws onto a tripod stand of adjustable height so the user can customize the box to sit just above their waist level.

There are two kinds of motion that the Spiderbot is capable of. The first is the mobility of the robot itself, which is executed by wheels controlled by a stepper motor. The second is the movement of the legs, which sit atop the robot. Each leg is connected to a servo motor which lowers or raises the leg, allowing the markers attached to the legs to draw on the surface. The servo motors and the stepper motors are controlled by a Redbear Duo microcontroller, which communicates wirelessly with another Redbear in the control box.

Our goal is to create a toy with a contactless interface which translates bodily motion in space to visual output. There already exist many variations on remote-control toys and even contactless digital video games (for example, the Xbox Kinect) but there seems to be a lack of contactless physical toys with a solely creative (as opposed to goal-based) intent--this is what the Spiderbot aspires to be.

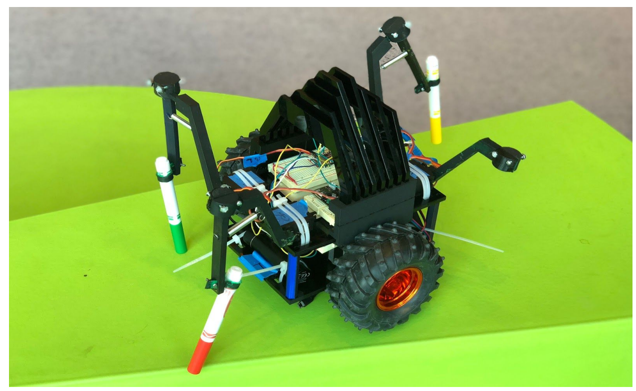

Figure 1. The robot

Figure 2. The control box

RELATED WORK

The initial inspiration for the design of the Spiderbot's user-facing interaction was the theremin, an early electronic instrument controlled by motion instead of physical contact [1]. The vertical hand motions required to play the theremin and the boxy shape of the instrument's body are paralleled by the Spiderbot's control box, which affords a similar vertical motion in interaction.

An inspiration for the interaction design of the robot's body was the Musical Melodyian, a MIDI controlled robot [2]. The Melodyian has Bluetooth capabilities, so it can be controlled wirelessly by a MIDI device. In the initial iteration of the robot's design as a musical device instead of a visual one, the movement of the robot would be controlled by MIDI commands from the control box.

Our design was also inspired by two interactive art exhibits--Lines and Forest. Lines is an installation by composer Anders Lind; lines hanging from the ceiling, floor, and walls are electronic instruments that produce sound when touched [3].

Sound Forest is an installation of "tactual sound devices"--within the installation, users can feel sounds through acoustic and haptic feedback, which informs how they interact with the space [4].

DESIGN

We created our design to give distinctive character to each part of the system. The control box is a simple, touchless interface in a wooden case, with a stand that allows the user to customize the height for comfortable use. The control box is the user-facing interface.

The robot is small--approximately one cubic foot--to accommodate the overarching design goal of the Spiderbot being a usable toy. The robot was designed to evoke the image of a spider--the movements of the legs mimic the motion of real spider legs. The robot also has a shell which sits atop the body to protect the user from stray wires and to give the robot a rounder look.

This section will first outline the design and implementation process of the control box, then those of the robot.

Control Box

The control box houses a breadboard with a Redbear Duo microcontroller, two HC - SR04 ultrasonic sensors and an Anker rechargeable powermax battery. The case was laser cut from wood; four holes were cut in the top to host the ultrasonic sensors and a hole was cut in the bottom to attach a stand to the case. We were fortunate to not have any difficulties with the case once it was made.

The control box had the following design goals:

1. Relay an intuitive mental model of motion control which the user can quickly understand
2. Wirelessly communicate with the robot

Initial Implementation

The first iteration of the control box was in a repurposed cardboard box and a single microcontroller governed all of the mechanisms of the robot. This version was not wireless. Some problems we encountered were:

1. The mobility of the body was constricted by wires
2. The servos were unable to move due to an Arduino library being incompatible with the microcontroller we initially used

Both problems were resolved through the process of making the Spiderbot wireless in the modified design.

Modified Design and Integration

To make the Spiderbot mostly wireless, we integrated another microcontroller--the first housed in the control box and the second housed on the robot. Rather than incorporate additional bluetooth hardware, we used the Redbear Duo's built-in wifi and cloud capabilities.

When we initially separated the control box from the robot we encountered the following problems:

1. The ultrasonic sensors were not secured in the box and would frequently move mid-use
2. The built-in Particle publish and subscribe commands interfered with the execution of the robot's movement commands and altered the timing of the robot's motion

These problems were solved in the final implementation.

Final Implementation

To secure the ultrasonic sensors, we glued them to the holes cut into the top of the control box. In addition, we replaced the Particle commands with Transmission Control Protocol/Internet Protocol (TCP/IP). To do so, we established a wireless server/client relationship between the robot and the control box (with the control box being the server) so the timing of the transmission of motion commands would be in-sync with the robot's execution of motions.

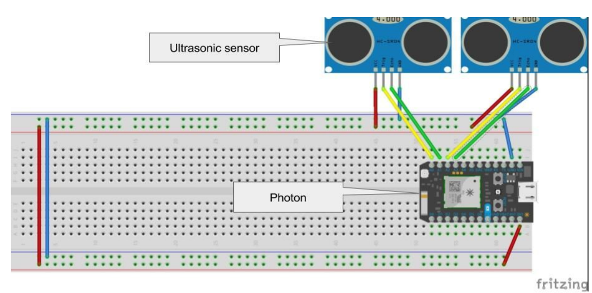

Figure 3: Fritzing diagram of the control box

Five hand motions controlled movement (Figure 4):

1. Forward (Condition 1): both hands within 20 cm of the sensors
2. Backward (Condition 2): both hands over 30 cm away from the sensors
3. Right turn (Condition 3): right hand under 20 cm and the left hand over 30 cm from the sensors
4. Left turn (Condition 4): left hand under 20 cm and the right hand over 30 cm away from the sensors
5. Stop (Condition 5): both hands between 20 and 30 cm of the sensors.

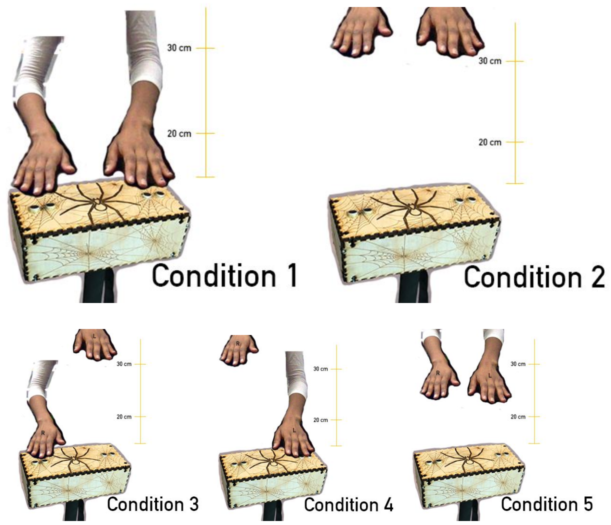

Figure 4: Diagram of the control conditions

The Spiderbot

The main module of the Spiderbot is the robot itself. The body of the robot has two vertical layers which were laser cut from ¼ inch thick black acrylic. These layers are separated by 3D-printed support columns. The body was designed to carry two Nema-17 stepper motors, four servos, four half-sized breadboards, and two 9-volt batteries.

The top level was covered by a shell with a slotted 3D printed base and laser cut acrylic panels. The bottom level has two powerless roller wheels attached - one at the front and one at the back - which maintain balance of the robot.

The main outputs of the Spiderbot can be divided into two key features:

1. Mobility (how the robot itself moves around, which includes the wheels and the stepper motors that control them)
2. Visual Output (the drawing the robot produces, which include the legs of the robot and the servos that control them)

This section will first outline the implementations of the two key features (mobility and visual output) and then discuss the integration of the two for the final prototype.

Mobility

Movement is accomplished by two large toy truck wheels mounted on two NEMA-17 stepper motors. This is the feature which achieves the overarching design goal of the Spiderbot having the feel of a toy, as it evokes remote-control cars and other motion-controlled toys. In addition, without movement, the overall possible scope of art produced would be greatly reduced.

Initial Implementation

The NEMA 17 motors were first attached to laser cut panels that were screwed to the back of the steppers. Edges on the panels allowed them to be inserted into slots on the acrylic base (Figure 5). Adapters were 3D printed that allowed the wheels to be mounted on the stepper motors (Figure 6). Some problems we encountered were:

1. The power plug to the isolator was insufficient to power both steppers enough to move the robot.
2. The wheels would occasionally slide off of the steppers.

Addressing the power deficiency was our main focus for improving mobility. The wheels were mounted on the lower level using panels similar to the ones used in the first prototype. Both the servos and the steppers were powered by a 12-volt power pack filled with 8 AA batteries.

Figure 5: Panels to mount stepper motors to body

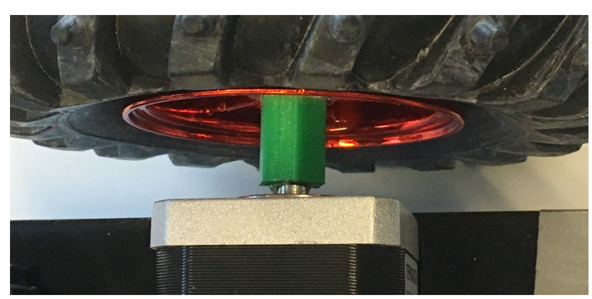

Figure 6: 3D printed adapters connecting wheels to steppers

Modified Design and Integration

Finding the appropriate power source for the steppers resulted in several reorganizations of the components on the robot body. It was determined that the 12-volt power pack was too much power for the steppers and servos so the components were installed on separate breadboards with separate power supplies. A 5-volt Anker rechargeable battery with a 5-volt to 9-volt converter cable was used to power both steppers through an isolator.

Originally the breadboards devoted to the steppers were mounted upside down on the bottom of the upper level to allow space for the 12-volt powerpack. After the powerpack was removed from the design, the breadboards were moved to the rear to allow easier access.

Another concern associated with mobility was maintaining the balance of the robot. Initially a roller wheel was mounted on bottom of the lower level on the back end of the robot to assist with balance. When this proved insufficient, another roller wheel was installed in the front, mirroring the rear wheel. Both wheels were glued onto the steppers.

Final Implementation

We frequently encountered difficulty in implementing the steppers. Before putting the steppers on a dedicated power supply we were forced to replace our drivers due to burnout. After changing the power input to the steppers we were able to move the robot in the way we desired using A4988 drivers instead of the DRV-8825 drivers provided. These drivers were later replaced again with DRV-8825 drivers and stepper functionality was returned. Prior to this replacement an electrical short destroyed two microcontrollers and may have damaged the steppers. The short was eliminated by completely rewiring the circuit and replacing the drivers as previously mentioned. The steppers were powered with a 12-volt plug in power supply.

Before the electrical short, movement was smooth and responded quickly to the control box. After, the steppers were a little wobbly, but overall movement was not greatly impacted.

The wheels started to sag. We believe this was due to combination of downward pressure from the upper layer, and improper gluing of the wheels to the steppers.

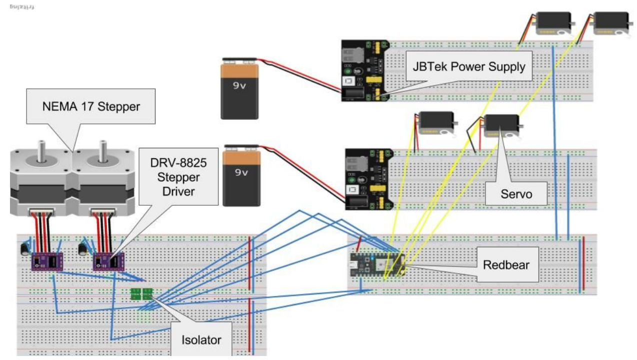

Figure 7: Wiring of mobility and visual output mechanisms

Visual Output

The visual output (drawing) is accomplished by the four legs of the spider. Each leg is controlled by a servo motor at the base and attached to a marker at the end. The drawing occurs when the servos lower a marker to the surface underneath the robot while the robot is moving. The main goal is the successful lowering and raising of the legs on command; the secondary goal is for the marker to not break contact with the paper (to produce continuous lines).

Figure 8: Example of visual output

Initial Implementation

Initially, servos supported a laser cut base with loosely attached laser cut legs (Figure 8). The servos could move up and down or side to side. These movements would haphazardly toss the legs around the paper. There was very little control over when markers would make contact with the paper, and no control over which markers would touch the paper. Additionally, the servos could only be manipulated manually as we were not able to reconcile its software with arduino and anticipated having more difficulty controlling the mechanism with a redbear microcontroller. The initial legs were not connected to markers and were attached to the servos through a Lego attachment.

Figure 9: The initial prototype's legs

To address these concerns, the decision was made to instead have one servo controlling each leg. This would allow for more color control (for example, multiple colors at once).

Modified Design and Integration

The servos were positioned to hang over the corners of the top layer of the robot. Legs were 3D printed and assembled from different parts--a ball joint, to allow the leg some flexibility of movement; a clasp to hold a crayola marker; a hole for a spring to allow for more complex micro-movements when the pen dragged on the surface (Figure 10).

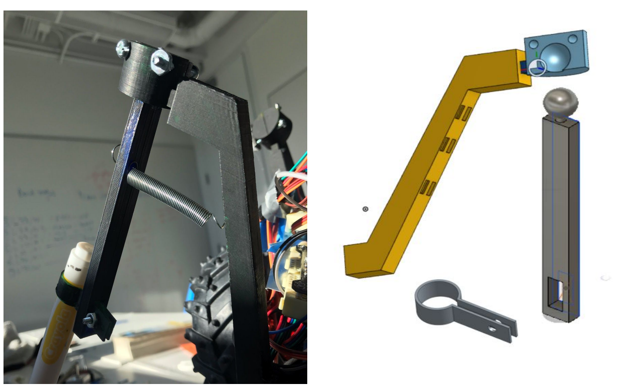

Figure 10: Photo and diagrams of 3D printed leg

The legs were designed so that markers could be clasped at various positions allowing the legs to have a variable length.

The main integration problem we faced was properly powering each of the servos. Initially the servos and steppers were fed from the same power source. When this impaired functionality the servos were connected to a separate dedicated power source--the JBtek breadboard power supply from our sensor kits. This power supply was configured to provide 5-volt of power to the four servos from a 9-volt battery.

Final Implementation

Some issues encountered in the final implementation of the legs are:

1. Inadequate power supply for servos
2. Incorrect motion

It was quickly discovered that one power supply provided insufficient power for all four servos. The circuit was reconfigured so three servos would receive power from the power supply and the fourth would receive power directly from the redbear.

Powering the servo from the redbear microcontroller caused the microcontroller to shut down, so the circuit was changed again so that two servos were powered by JBtek power supply resulting in two power supplies for the servos both powered by 9-volt batteries.

Movement issues with servos surfaced--some servos would swing much further than expected, but this was corrected by replacing the servo.

Final Integration of Features

Our goal for the body was to effectively house all components, including power supplies, and remain light weight enough for the robot to move. The goal for the outer shell was to conceal the the wiring of the breadboards yet allow access to the wiring and components.

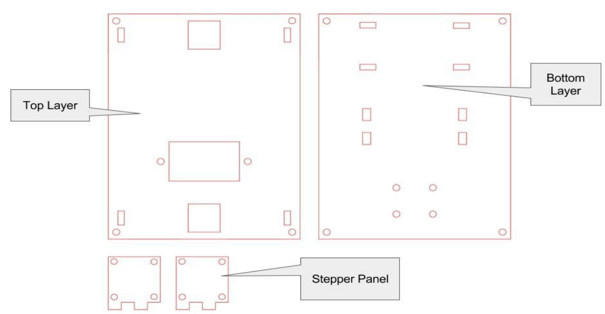

Figure 11: Diagram of layers and panels laser cut for Spiderbot body

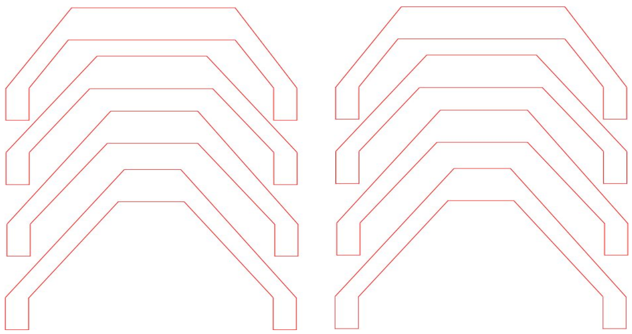

Figure 12: Laser cut diagram of Spiderbot shell

The main challenge of the body layers was to effectively house all of the components while leaving the components accessible for repairs and upgrades. As we experienced challenges with the implementation of the features many components would require relocation and reorganization. The design of the body layers was robust enough that the only modification required was the attachment of an additional roller wheel on the base. This modification was also mentioned in the section on mobility.

Initial problem:

1. Accessing all components once the robot was fully assembled.

To allow all components to fit comfortably, we laser cut a second layer for the body and 3D printed hexagonal columns to support the second layer. On the first layer the microcontroller and servos were mounted. The second layer housed the steppers, drivers, and batteries. As power issues were encountered many components would be relocated. Prior to the removal of the top layer, the breadboards with the stepper drivers were moved to the back of the back of robot for easy access.

Final Implementation

Ultimately, we found that two layers created too much weight for the steppers so the top layer and supports were removed. All breadboards were stacked on the bottom layer, now the main layer.

There were no problems with the outer shell and it did not need to be modified, but it could not be included without the presence of the second layer.

FUTURE WORK

As a final product, Spiderbot would be slightly smaller and more compact. In addition, the ideal color change mechanism in the legs would be slightly more complex. Drawing from an early design element which ultimately did not make it to the final product, leg would have the ability to switch between multiple colors with a mechanism modeled on a generic multi-colored pen; the physical mechanism for the color change would be triggered by different hand motions, or even a certain sequence of hand motions. This would allow for more complex visual output—for example, color change on a continuous line, or multiple lines of the same color.

The body would be constructed to create separate pathways for groups of wires to reduce visual ambiguity for more efficient troubleshooting. In addition, the power issues would be resolved and the toy would be powered with rechargeable batteries and consolidated power supplies.

CONCLUSION

Our goal was to create a motion controlled robot with drawing capabilities and despite setbacks we were successful in this endeavor. The created parts functioned as expected; our main challenge was properly handling power concerns. Future iterations of our robot will be smaller, lighter weight, and have greater color change capacity.

VIDEO LINK

https://youtu.be/8unQgWh_Z5s

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