AUTO-OPEN DRWAER

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Final Report for ECE 445, Senior Design, Spring 2019

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1 May 2019

Project No. 52

Abstract

The system can extend and retract drawers in a dresser without input from the user beyond a command signal. This is executed by motors running a belt-and-pulley system that guides the drawer's motion. Our proof of concept shows that a drawer with contents inside can operate automatically with incorporated safety features and a variable activation method adaptable to the user.

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1. Introduction

A full, heavy drawer can be a laborious task to access. This is even more true for people with limited mobility who might struggle with the strength and/or range of motion necessary to open a drawer. Our goal is to bring more autonomy to people with limited mobility by augmenting the drawer opening and closing mechanics.

The design of the Auto-Open Drawer must balance functionality with safety. To that end, the motors were variable speed, adjustable by the applied potential difference. A network of sensors controlled when the drawer moves. In summary, each of these parts has been proven in this project to function correctly and reliably, though their integration requires more attention.

1.1 Background

For our target audience, "autonomy is priceless" [1]: the freedom to pick an outfit without a caretaker or the ability to easily access valuables is currently lacking. As an anecdote, one young woman with cerebral palsy has bruised knees from crawling across her floor in order to garner enough strength to pull open her dresser drawers and perform other routine tasks [1]. Muscle loss is a prevalent symptom of aging and of certain diseases [2]. Hence, our dresser is not an assistant but a complete replacement so that the user does not have to exert their strength.

Our drawer system must be as affordable as possible because people with limited mobility invest in a variety of aid services already. The price point for an automated dresser should be at most double the cost of an equivalent, technology-less dresser [1]. IKEA has basic three-drawer dressers ranging from $40 [3] to $180 [4]. Therefore, our design is allowed great flexibility in its cost and the final price of our additions will remain under $180.

1.2 Performance Requirements

The performance requirements as described in the project proposal are:

1. The drawer must extend and retract in 2±1 seconds with at least 1±0.5% kg inside or extend and retract in 6±3 seconds with at least 10±5% kg inside.
2. The drawer must detect obstacles within 50 ms of contact.
3. The dresser system must have a communication protocol with an external computer.

Requirement 1 was established broadly to allow flexibility in the choice of motor, though this range was more than adequate for the final product. The sensitivity of the sensors was the main performance factor driving Requirement 2, yet we found the sensors to be more sensitive than expected. Finally, when the hardware can communicate with an external computer, the entire spectrum of existent technology becomes available to activate the drawer, allowing a real product to be adaptable to the reason for limited mobility.

1.3 Subsystem Overview

The drawer that is extended and retracted is a part of the Mechanical Assembly. Controlling this movement is the Logic. The Sensors provide the data on which the logic processes. Powering the electronics is the Power block. This interconnection is shown in Figure 1.

While the four primary blocks did not change during the course of the semester, the detailed blocks did require adjustments. Namely, the initial design of stepper motors was changed to DC motors and the power supplies were reduced in number from three to two and those final potentials were 18 V and 5 V.

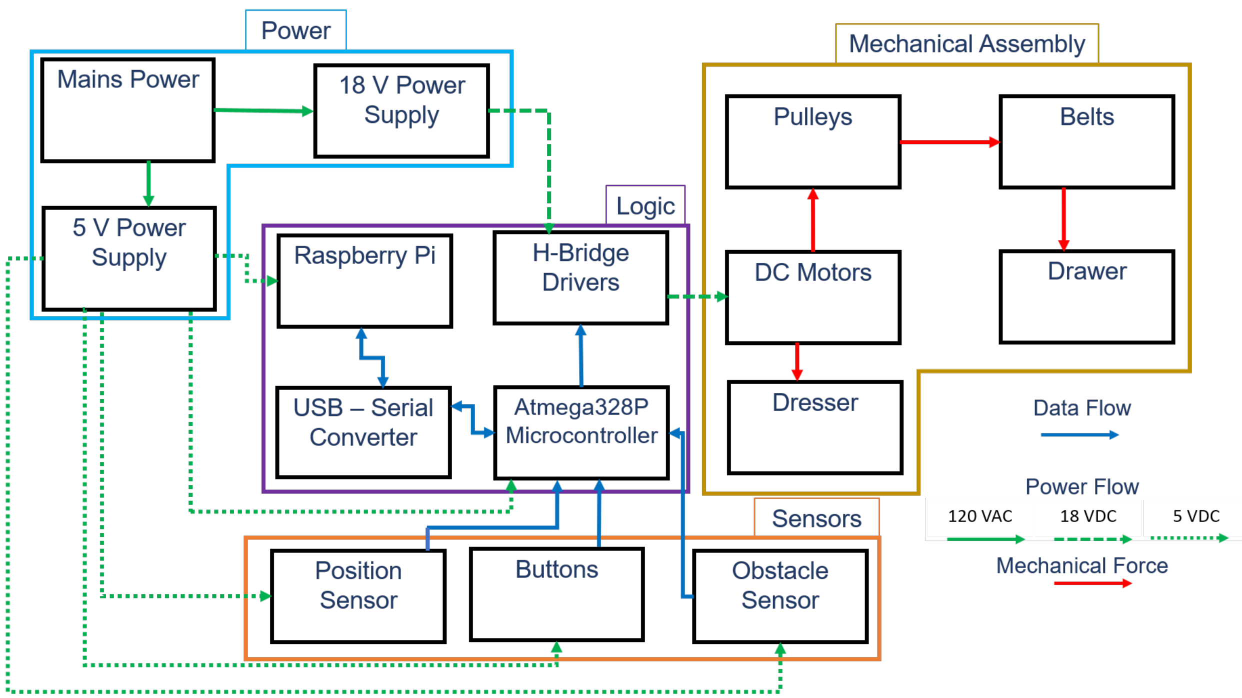

Figure 1: System block diagram of the project

2 Design

2.1 Power

As this proof of concept was designed as a dresser, the intent was for it to be plugged into a wall outlet. The power block for the auto-open drawer converted the 120 VAC from mains power to the DC voltages used for the project. Two voltages were used in the end: 5 Volts and 18 Volts.

2.1.1 Power Supply, 5 Volts

The 5 Volt power supply was used to power the microcontroller and the sensors. Because the motors were not run off of this supply, the 5 Volt power supply did not need to be able to source more than 1 Amp of current. We chose to use the 5 Volt version of the ATMEGA328P instead of the 3.3 Volt version because it not only gave us a wider range of analog voltage outputs from the Hall effect sensors and pressure sensors, but also because 5 Volt DC power supplies are quite common. In the final product, a USB cell phone charging cable was cut and stripped to access to the +5V and ground potentials, which were then soldered on the perf board.

2.1.2 Power Supply, 18 Volts

The 18 Volt power supply was used to power the motors. Even though the motors were rated up to 24 Volts, 18 Volts still gave the motor enough torque to completely extend or retract the drawer within the 2±1 seconds performance requirement. The reason we chose to use 18 Volts instead of the rated 24 Volts was to limit the complexity of the circuit. Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) with a maximum gate-to-source voltage of 20 Volts are common, whereas ones compatible with 24 Volts are much more difficult to find and therefore more costly. Rather than complicating the system with a third power supply or driving up the cost, we decided to run the motors at 18 Volts.

2.2 Mechanical Assembly

The mechanical assembly consisted of all the physical components that transmit mechanical forces to move the drawer. These included the original dresser modified by our project, belts attached to the drawers and around pulleys to guide drawer motion, pulleys that moved the belt by converting rotational motion to horizontal motion, and the motors that converted electricity to rotational energy.

2.2.1 Dresser

The dresser we chose featured three drawers stacked vertically. For our own convenience, we chose a dresser with plenty of space behind the drawers to mount our motors and electronics. It also had a small amount of space between the drawers and the walls to mount the belts.

2.2.2 Belts

The belts we used were made of timing belts made of "premium rubber" [5]. They were toothed in order to maintain a strong connection with the pulleys. They were also 6 mm wide, which allowed them to mount them in the small space next to the drawers with ease.

2.2.3 Pulleys

The pulleys we used were 5 mm diameter timing pulleys matched to the acquired timing belt. For each drawer, one pulley was placed near the front of the dresser to achieve maximum extension. It was mounted on a screw, bored through the wall of the dresser, that allowed it to rotate freely with minimal friction. Another pulley was mounted on the motor shaft behind the drawer. However, the motor shafts were 6 mm in diameter and D-shaped so the mismatch prevented connection. Assistance from the machine shop gave three pulleys a bored-out 6 mm diameter and then they mounted tightly on the motor shafts with their setting screws.

2.2.3 Motors

We chose to use standard brushed DC motors for our purpose. Initially, we planned to use stepper motors, but we ultimately changed our design to simplify our circuit and our software. Stepper motors would have required two H-bridges each to run them, and they would have required constant processing time form the microcontroller while moving. The DC motors each only required one H-bridge, and the microcontroller could toggle a single GPIO pin to start the motor and then toggle it again only once the drawer reached its desired position. This change accompanied the refinement of the position sensor when it was decided to only gather end-stop data instead of constant position data.

2.3 Logic

The logic block received input from our sensors and processed this data in order to activate the motors. We used the ATMEGA328P microcontroller to run the code that would process this data, n-channel MOSFETs to drive the motors, and a Raspberry Pi 2 to be able to expand the different activation methods and communicate with other devices.

2.3.1 Microcontroller

We chose to use the ATMEGA328P as the microcontroller for this project because there is a vast amount of documentation available about this microcontroller and its processing speed was fast enough for our second performance requirement. It also featured enough GPIO pins for all of our devices. We had three digital inputs corresponding to each of the three buttons, three analog inputs corresponding to each of the three Hall effect sensors, three more analog inputs for each of our three pressure sensors, and six pulse-width-modulated outputs, two to drive each of the motors. In the end, few pins remained unused.

2.3.2 Software

The software that ran on the microcontroller was specifically designed to be expandable to different pieces of furniture in which the auto-open functionality would be implemented. We implemented a class that would represent a single drawer. It included a constructor allowing the user to specify which pins on the microcontroller correspond to the activation button, Hall effect sensor, pressure sensor, and the two sides of the H-bridge. Then, the microcontroller called an “update” method repeatedly during the entire operation of the drawer. This algorithm is shown visually in Figure 2.

The update method constantly read the analog voltage from the pressure sensor. It was important that the code be able to adapt to all different shapes and sizes due to the variety of application of this product. In order to protect the user, the pressure sensors would be mounted any place where it is possible to have something caught, trapped, or pinched. This meant that the code would not simply be allowed to detect the absolute voltage, but rather a change. We implemented a complex algorithm to be able to detect obstacles pressing on foam of any size.

The first step of this algorithm is to read the voltage from the pressure sensor and average it with the past 75 values. To accomplish this, each drawer object had an array of 75 values representing the previous 75 sampled values. Additionally, it had a variable representing the index of the oldest value. Each time the voltage was read, the value at this index was replaced with the new value, and the running average added the new value and subtracted the old one. This average value helped to decrease the noise present in the data which was causing false positives before. Once this average was updated, its change since the last sample is calculated. This helped to differentiate the absolute resistance of the pressure sensor from a sharp change in resistance due to a collision. Then, to make sure this change is not just between noise, this change value was added to a time-moving average that gave the most weight to the newest value, with less weight given to older values by an exponential decay factor.

Once this value was calculated, the code read the button pin to see if the user had activated the drawer. If they had, the current state of the drawer was used to determine which way to spool the motor. If the drawer was closed or closing, the motor was activated to extend. Then, the Hall effect sensor voltage was read to determine if the drawer had extended fully. Once it read a low enough value, representing a north magnetic field (placed at the rear of the drawer), the motor was deactivated. If the drawer was open or opening when the user activated the drawer, the motor was spooled in the reverse direction. In this case, the microcontroller continuously read the Hall effect sensor to look for a south magnetic field (placed at the front of the drawer) and analyzed the pressure sensor data. If an obstacle was detected before the magnet, the drawer opened back up. If the magnet was detected first, the motor stopped.

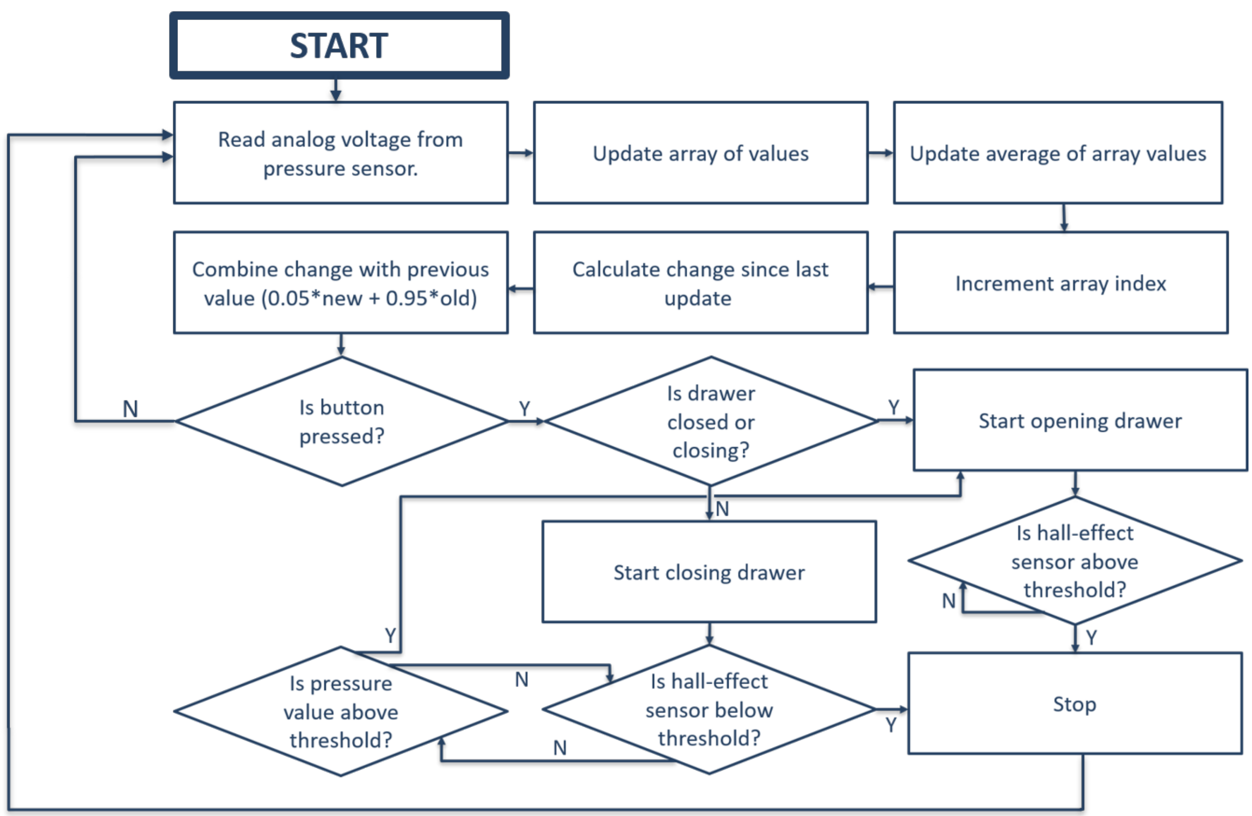

Figure 2: Flowchart of the logic

2.3.3 Motor Drivers

The motors were each controlled using four MOSFETs as seen in Figure 3. Each lead coming from the motor was connected to the source of one transistor and the drain of another. The free drain of the MOSFET was connected to +18V, while the free source was connected to Ground. The gates of these MOSFETs were then connected to the IRS2183 driver IC. These ICs took the 5 Volt control signals from the microcontroller and activated one of the two MOSFETs accordingly. These ICs featured a dead time, which ensured that the on MOSFET was turned off before the off MOSFET was turned on.

Not having the dead time feature was what plagued our initial H-bridge design. Originally, our design used p-channel MOSFETS for the high side. The gates were tied together so that a high voltage turned on the n-channel MOSFET and turned off the p-channel MOSFET, and a low voltage did the opposite. This was a far simpler design than the one we ended up using. However, during the transition from high to low, there was a split second during which the gates were part way between +18V and 0V, shorting the power supply through the two MOSFETs, straight to Ground.

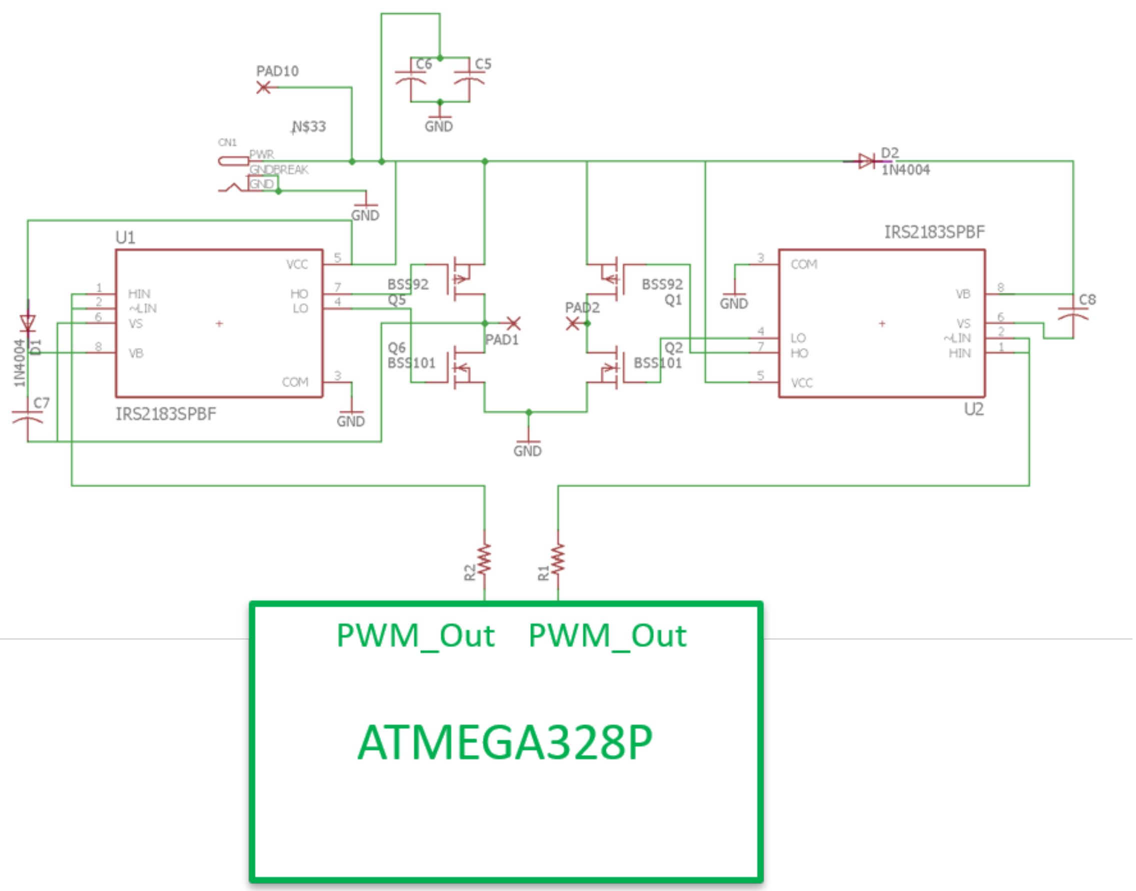

Figure 3: Output schematic

2.4 Sensors

There were three data for the microcontroller to sense. We first needed a way to take direct input from the user to activate the drawer. We used large, bright, momentary buttons for this purpose. We further needed a way to detect when the drawer reached the end of its travel. For this purpose, we used a Hall effect sensor mounted at the front end of the dresser and two magnets mounted at each end of the drawer. Finally, we needed a way to detect obstacles that would prevent the drawer from closing and possibly trap and injure a body part. A schematic of these data inputs is shown in Figure 4.

2.4.1 Buttons

The buttons were simple to implement. They were connected between their designated input pin and Ground. Then, the internal pullup resistors in the microcontroller were connected in software. In this configuration, a low potential represented a pressed button, and a high potential represented no press.

2.4.2 Hall Effect Sensors

The Hall effect sensors each had three pins. One connected to +5V, one connected to ground, and the third connected through a resistor to an analog input of the microcontroller. With no magnetic field, the sensor output approximately 3 Volts. In the presence of a magnetic north field, the voltage drops to slightly under 2 Volts, and increases to just over 4 Volts in the presence of a magnetic south field.

2.4.3 Pressure Sensors

The pressure sensors were implemented with static-dissipative foam. This black material dissipates static charge, typically from integrated circuits after use. We chose this material because it is inexpensive, readily available, easy to cut into any shape or size, and displays variable resistance when compressed. We connected a piece of foam in a voltage divider with a known resistor. Initially, we had the wired connected to each end of the foam. However, in this configuration, the foam had a resistance on the order of megaohms that did not change much under pressure. So instead, we coated each side of the foam in aluminum tape, a strong conductor. This configuration reduced the resistance to the order of tens of kilohms that changed much more when compressed.

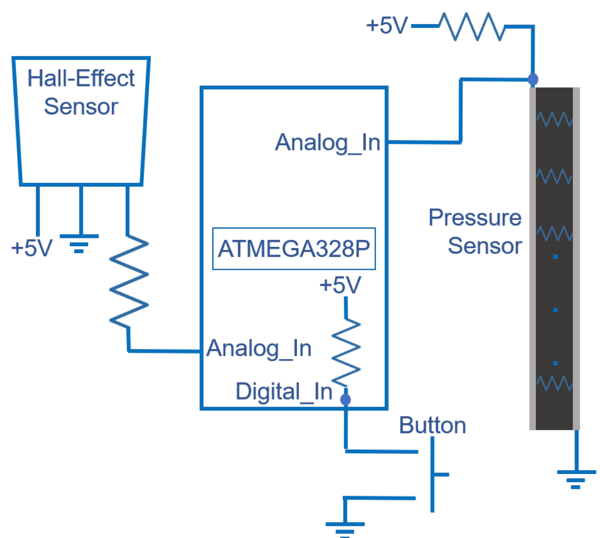

Figure 4: Sensor schematic

3. Verification

3.1 Position sensor

We oriented the front and rear magnets such that the Hall effect sensor's output voltage increased when the drawer was extended and decreased when the drawer was retracted. To test the magnitude of these changes, the poles were held in front of the Hall effect sensor and moved away laterally in increments of 1 mm. The voltage output by the senor was recorded. As seen in Figure 5, the change in voltage is approximately 0.3 Volts and this occurs approximately 15 mm away from the Hall effect sensor.

3.2 Obstacle sensor

With the capacitive metal tape covering the static-dissipative foam, the obstacle sensor became much more sensitive than we had expected. Furthermore, it could not practically be pressed all the way in. We measured the resistance with a multimeter and compressed the foam with four fingers at approximate intervals of 0.01 in. The data in Figure 6 is extrapolated to a zero output value from the compression that could be applied.

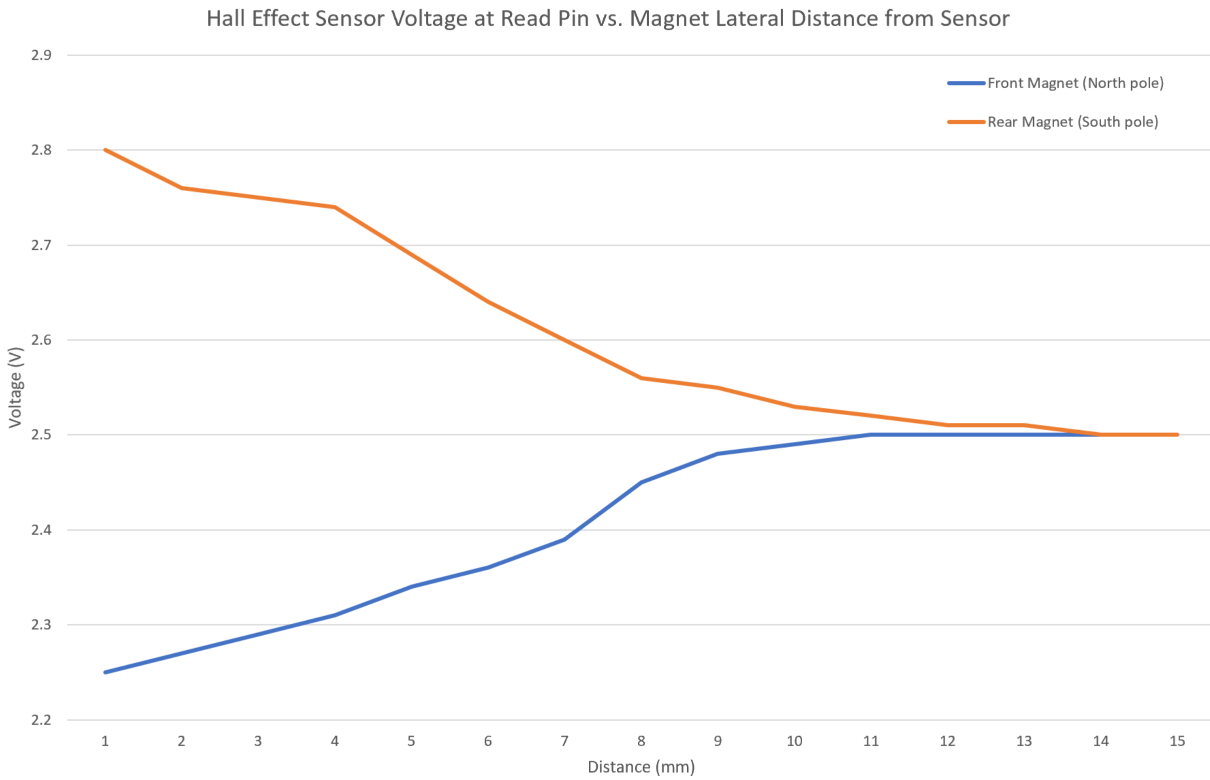

Figure 5: Hall effect position sensor data

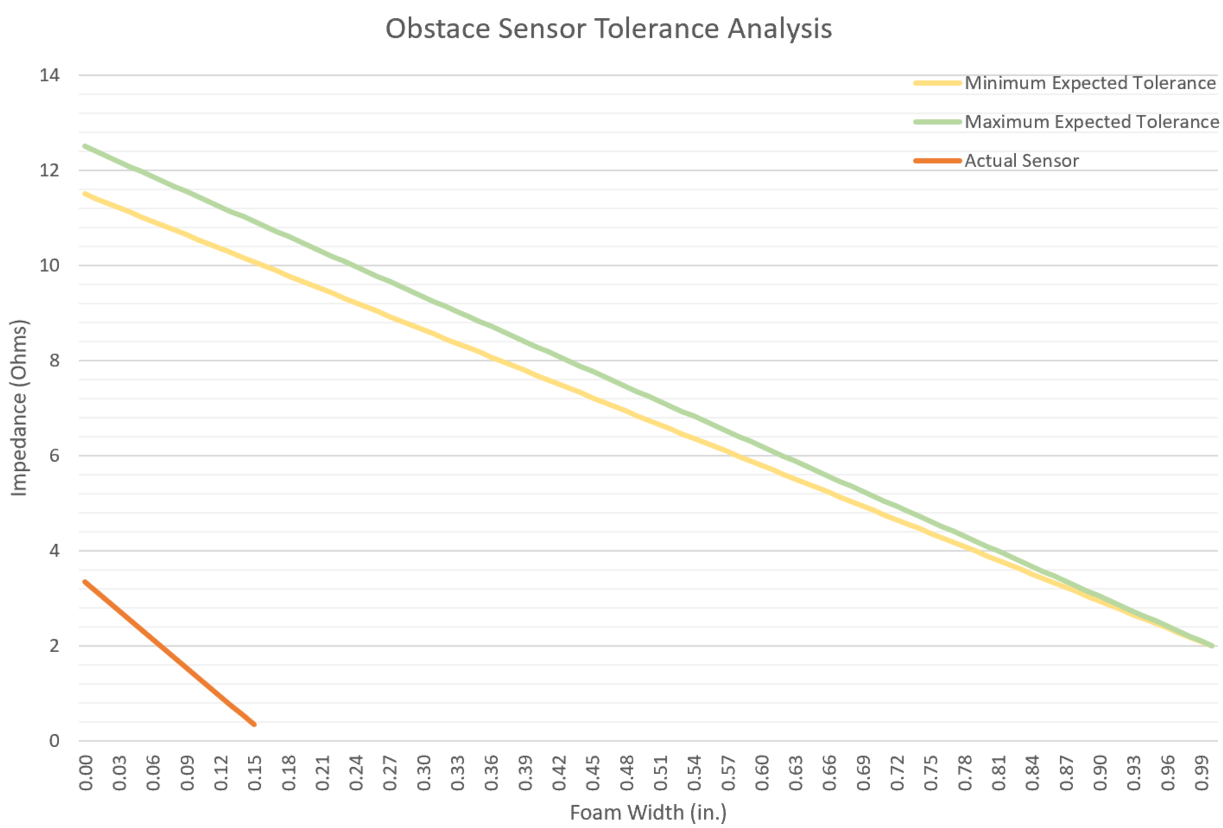

Figure 6: Static-dissipative foam obstacle sensor data

4. Costs

4.1 Parts

Assuming this proof of concept would be manufacturable, it is prudent to consider its production cost. For the Actual Cost column in Table 1, we used the Bulk Purchase Cost for each Quantity of the Part.

Table 1: Parts cost

Part	Quantity	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Hall effect sensors (A1308UA)	3	Allegro	2.17	N/A	2.17
USB connection 2.0 Type B	1	Amphenol ICC	0.93	N/A	0.93
Magnets	6	Radial Magnet Inc.	0.41	0.38	2.28
Static Dissipative Foam	1	Protektive Pak	6.14	N/A	6.14
Buttons	3	Omron	0.40	N/A	1.20
IRF510 MOSFETs	12	Vishay	1.57	N/A	18.84
IRS2183 MOSFET Drivers	6	Infineon	3.67	N/A	22.02
1N34A Diodes	6	NTE	2.03	N/A	12.18
47 µF Ceramic Capacitors	12	Jameco	0.31	0.22	2.64
0.22 µF Mylar Capacitors	12	Jameco	0.47	0.33	3.96
1 kΩ Resistors	30	Jameco	0.01	N/A	0.30
ATMEGA328P	1	ATMEL	1.87	N/A	1.87
PCB	1	PCBway	0.80	0.30	0.80
Dresser	1	Habitat for Humanity ReStore	5.00	20.00	20.00
Screws	9	Home Depot	0.20	0.20	1.80
Timing Belt and Pulleys	1	Amazon	12.69	12.69	12.69
Total					**109.82**

4.2 Labor

Our fixed development costs are estimated to be $67,000/year for an ECE Illinois Undergrad [1]. The three of us worked approximately 10 hours per week over the 16-week semester.

$$\frac{\$67{,}000}{year} \times \frac{1\ year}{50\ weeks} \times \frac{1\ week}{40\ hours} \times \frac{10\ hours}{week} \times 16\ weeks\ \times 3\ \times 2.5 = 40{,}200 \quad (1)$$

5. Conclusion

While each individual aspect of the project functions as desired, we were not able to assemble everything into a combined product. We have proven that the modules of this project are viable, but we require additional time, testing, and fine-tuning to fully realize the goal of an automatic drawer that can extend and retract from a single activation input from the user.

5.1 Accomplishments

We achieved each individual aspect of the Auto-Open Drawer functioning properly. Namely,

1. Each button activates its proper drawer.
2. The drawer extends fully, then stops.
3. The drawer rolls back out if the obstacle sensor is compressed.
4. Through Raspberry Pi GPIO, signals from a remote activation method are received.
5. By adjusting the location of the magnets, the drawer retracts with weight inside.

5.2 Uncertainties

Since we bought a fully made dresser, the dimensions of the dresser made it difficult to install the motor and the belt. As a result, the belt was loose, so we had to adjust the tension through a clip. Also, the motor was tilted, so we had to put a paper buffer between it and the wall to align the pulley on its shaft with the front pulley. Initially, we designed the system to have 3 H-bridges for the motors, but only top dresser's H-bridge worked. After multiple verifications by each team member and attempts to duplicate the circuit, we were not able to find a reportable error for the H-bridges on other motors. Also, serial communication worked independently but when it was connected to the system it did not respond and we still do not know what caused the problem.

5.3 Ethical Considerations

Since the objective of this project is to bring more autonomy to people with limited mobility, we must carefully adhere to the IEEE Code of Ethics #8 by avoiding terms that could be discriminatory [6]. So, throughout the project, we will be using the term "people with limited mobility" for the people who can benefit from this technology the most. However, this does not mean that people with limited mobility need this technology nor that others cannot benefit from this product.

5.4 Future work

The design herein has a plethora of applications. For people of limited mobility, a dresser can be ergonomically designed to adapt to their situation. High-end furniture sales would desire quieter transitions, guiding the choice of motor and the possible installation of mufflers or other noise masking techniques. A "smart storage" system could take a request (e.g. verbal with Amazon Alexa) and extend the drawer containing that item (socks, pencils, etc.) without the user having to remember the location.

Additionally, there is more that could be prototyped on this proof of concept. The obstacle sensor could be set up to surround the drawer, though that would require many more analog inputs, leading to possibly another integrated chip. With a larger budget, we would have liked an external obstacle sensor as well to prevent the drawer from opening into the user. Finally, implementing variable speed for users to choose based on their use case is recommended.

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Appendix A: Requirement and Verification Table

Table 2: System Requirements and Verifications

Requirements	Verification	Verification Status (Y or N)
	I. Power	
The system draws 120 VAC from wall when properly plugged in	1. Properly polarize circuit 2. Bias with low voltage (<0.5V) 3. Check output using the multimeter 4. Plug into wall 5. Check output using the multimeter	Y
The power supply must be able to continuously source 6±5% Amps at 18.5±5% VDC	1. Power supply will be connected to a 2±5% Ohm synthetic load 2. Connect the power supply with the motor 3. Use multimeter to check the continuous source 6±5% Amps at 18.5±5% VDC	Y
The power supply must be able to continuously source 2±5% Amps at 5.0±5% VDC	1. Power supply will be connected to a 1.65±5% Ohm synthetic load 2. Use oscilloscope to ensure steady voltage signal	Y
	II. Mechanical Assembly	
The belt must not slip against the pulley and avoid skipping against 150±5% N of force	1. Use a spring-scale to pull the drawer out while the pulley is held in place 2. If the belt does not skip once the scale reads 150±5% N, this requirement will be verified	Y
The belt's azimuthal angle must ensure a level, linear transition for the drawer	1. Carefully measure the axes to be on the same horizontal plane 2. Drill pilot holes and insert small pin 3. Use a level to confirm that the axle installations are level	Y
The drawer must be able to extend and retract in 2±1 s while loaded with at least 1±0.5% kg inside	1. Calculate the rotation speed necessary to achieve drawer extension in 2±1 s 2. Load the drawer with 10±5% kg of material. Extend the drawer manually with a spring scale and record the force required 3. Attach the spring scale to measure the linear force the motor applies 4. Increase the motor rotation in 10 equal steps, for 6±1 s each, from 0 to the speed calculated in (1) 5. If the final speed applies equal to or more than the force recorded in (2) for 6±1 s, this requirement is verified	Y
All device mountings must remain mechanically linked under the full force of the motor	1. A spring-scale will be used to pull the drawer out while the gear is held in place 2. If the mountings remain intact once the scale reads 150±5% N, this requirement will be verified	Y

The dresser must remain in gravitational equilibrium after the installation of this project	1. Set the dresser upright with drawers closed 2. Observe for three minutes 3. Stabilize the dresser and let the drawers extend 4. Observe for three minutes 5. Run the retraction and extension processes without human interference 6. Verify that the dresser has remained upright for all these tests	Y
III. Logic		
The system must be able to rout input signals to their functions in 0.5±0.25 seconds	1. Record delay between activation signal and output to motor drive circuitry 2. Repeat for position sensor and obstacle sensor 3. Confirm all are within tolerance	Y
The system must be able to communicate with all sensors, namely in a 2±2 meter radius from the PCB	1. Cut wires long enough (<2 meters) that the obstacle and position sensors can be directly wired to the PCB 2. Repeat (1) for the activation sensor buttons 3. In addition to (2), install serial/USB equipment on the PCB to work as the activation sensor. Connect this port to a Raspberry Pi 4. Bring the activation sensor away from the Raspberry Pi in 0.2 meter steps (uninhibited by obstacles in the room) until the signal is no longer received. If the last step that works is 2±2 meters from the chip, this requirement is verified 5. Optional: Test through walls and with obstacles. The distance requirement may be relaxed if this step is tested	Y
IV. Sensor Network		
The obstacle sensor must have a change of impedance of at least 1±5% MΩ per inch when compressed	1. Connect the pressure sensor to a multimeter set to impedance measurement 2. Record the uncompressed impedance of the pressure sensor 3. Compress the sensor with a clamp in intervals of 1/10 inch and monitor the deformed impedance 4. Ensure that there is minimum of 1±5% MΩ difference per inch	Y
The activation sensor buttons must have a diameter larger than 3.5±1.5 cm and be	1. Use a ruler to measure the diameter of the buttons 2. Use a ruler to measure the minimum separation between buttons	Y

separated from each other by 3.5±1.5 cm		
The position sensor must have a change of output voltage of at least 0.05±.5% Volt when it is in the middle of travel versus when it has reached the end	1. Set up the Hall Effect sensor using a 10±5% kOhm pull-up resistor 2. Connect the pull-up resistor/output pin node to a multimeter set to voltage measurement 3. Record the output voltage with no magnet nearby 4. Hold the magnet over the Hall Effect sensor with the south pole facing the sensor. Record the output voltage 5. Repeat (5) with the north pole facing the sensor 6. Repeat with no magnet. Verify there is a reliable 6±5% Volt difference between the no-magnet and each magnet cases	Y
The wireless activation sensor must operate through the Raspberry Pi and activate the drawer under the same protocol as the buttons, but independently of them	1. Use the wireless sensor to extend and the buttons to retract 2. Use the buttons to extend and the wireless sensor to retract 3. Press the buttons while the drawer is extending/retracting due to the wireless sensor; verify no change 4. Press the wireless sensor while the drawer is extending/retracting due to the buttons; verify no change	N