Auto-Open Drawer

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1 Introduction

1.1 Objective

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. We will create a system that can extend and retract drawers in a dresser without input from the user beyond a command signal.

1.2 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 ageing 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.

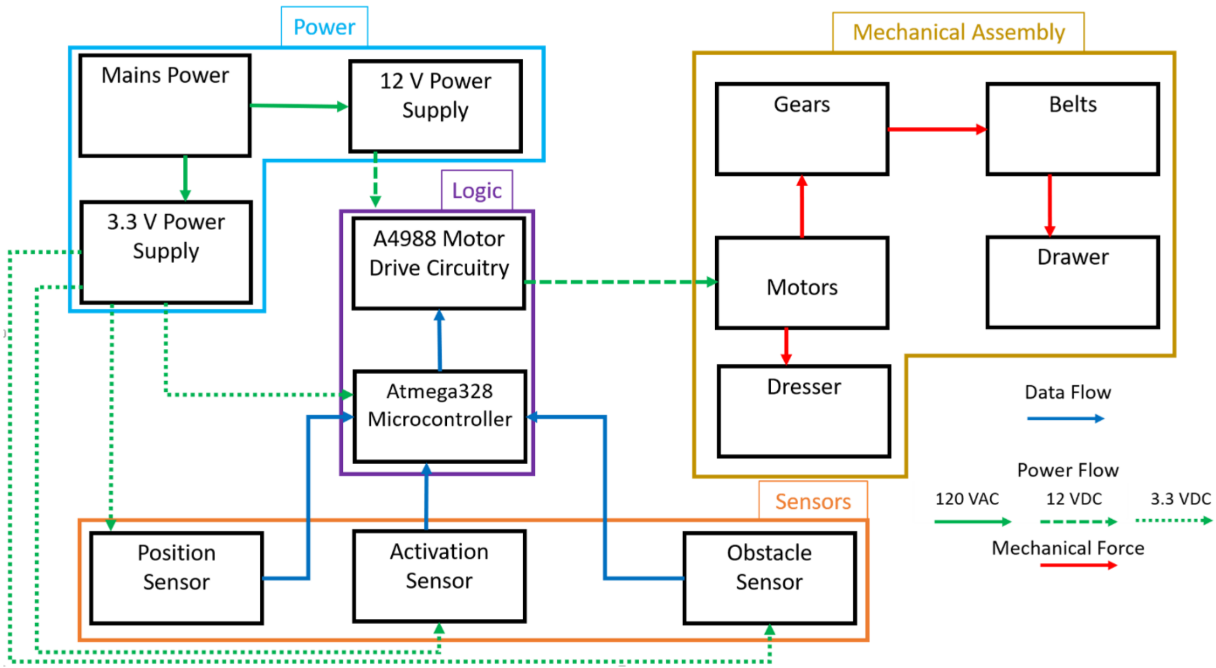
Our drawer system must be as affordable as possible because people with limited mobility invest in a variety of aid services already. The price point for an automated dresser should be at most double the cost of an equivalent, technology-less dresser [1]. IKEA has basic three-drawer dressers ranging 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 High-Level Requirements

- The drawer must extend and retract in 2±1 seconds with 10±5% kg inside.
- The drawer must detect obstacles within 50 ms of contact and reopen.
- The dresser system must be able to be powered by 120 VAC 60 Hz.

2 Design

Each drawer requires a mechanical assembly and sensor network in order to extend and retract autonomously. The activation sensor takes an input from the user to begin the movement; the position sensor halts movement once the drawer is fully extended or retracted; and the motor drives the pulleys which rotate the belt, pulling the drawer linearly. The obstacle sensor will signal the microcontroller if the closed state is obstructed, at which point the drawer would reopen for the user to address the obstacle. The power system ensures that the dresser can be continuously powered for anytime use.



2.1 Power

The power system provides the interface between the mains power, the control circuitry, and the powerful motors. This will supply electrical power to all the components, and will be able to control the motor with signaling from the microcontroller

2.1.1 Mains Power

This module will safely draw power from 120 VAC wall power outlets. It will have failsafes for reverse polarization, power surges, or shorts.

Requirements	Verification
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
Draws no power when improperly plugged in	1. Reverse polarize circuit 2. Bias with low voltage (<0.5V) 3. Check output has no power using the multimeter 4. Plug into wall 5. Check output has no power using the multimeter

2.1.2 12 V Power Supply

The 12 V Power Supply will down convert the 120 VAC to the 12 VDC necessary power input to the motor drive circuitry.

Requirements	Verification
Must be able to continuously source 6±5% Amps at 12±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 12±5% VDC

2.1.3 3.3 V Power Supply

The 3.3 V Power Supply will down convert the 120 VAC to the 3.3 VDC necessary power input to the various sensors.

Requirements	Verification
Must be able to continuously source 2±5% Amps at 3.3±5% VDC	1. Power supply will be connected to a 1.65±5% Ohm synthetic load 2. Use oscilloscope to ensure steady voltage signal

2.2 Mechanical Assembly

This is the physical effect of the project. We aim for it to be aesthetically pleasing and as robust as the various furniture that might use this drawer system. It will have motors mounted behind the drawers that turn a pulley system that moves the drawer in and out.

2.2.1 Pulleys

A timing belt pulley will be mounted to the shaft of the motor. There will also be a corresponding pulley, left free to rotate, mounted near the front of the dresser.

Requirements	Verification
Must mesh with belt teeth 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. Monitor the belt while the scale reads 150±5% N 3. Ensure that the belt does not skip
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

2.2.2 Belt

The belt will be a rubber timing belt with teeth that match the pitch of the timing belt pulleys. It will be held taut by the separation of the pulleys, and it will be able to keep the motor-mounted pulley rotating synchronously with the free pulley. There will be a point on this belt fixed to the rear of the drawer that will move forward and backward as the pulleys rotate.

Requirements	Verification
Must mesh with pulley teeth and avoid skipping against 150±5% N of force	1. A spring-scale will be used 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.

2.2.3 DC Motors

These motors will be housed in the dresser behind the drawers. They will be responsible for rotating the pulley system to ultimately slide the drawer. The one motor per drawer will have both forward and backward modes.

Requirements	Verification
Must be able to extend and retract the drawer in 2±1 s while loaded with 10±5% kg of material	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.

2.2.4 Drawer

This will be the actual container that slides in and out of the dresser. It will be connected to a fixed point on the belt which will move back and forth between the two pulleys as the motor rotates.

Requirements	Verification
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 linkage remains intact once the scale reads 150±5% N, this requirement will be verified.

2.2.5 Dresser

This is the housing for the whole system. This will be visible to the user during normal operation. The drawers will be able to glide easily relative to the dresser on bearing slides.

Requirements	Verification
Must remain in a 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. Ensure the dresser has remained upright for all these tests

2.3 Logic

This will be what processes the information coming from the sensors and decides what to command the motor to do.

2.3.1 Motor Drive Circuitry

This will be the hardware between the motors and the microcontroller. It will be connected to the 3.3 V of the microcontroller as well as the 12 V for the motors. The microcontroller will send logic-level “activation” signals to the motor to tell it to rotate. The polarity of the “direction” pin will control the direction of the rotation.

Requirements	Verification
Must be able to clamp inductive spiking from motors at 14±5% V	1. Connect the voltage across the motor coils.

	2. The voltage will be continuously monitored as the controller abruptly cuts power.

2.3.2 ATmega 328P Microcontroller

This will be the microcontroller that controls the whole system. Inputs will come directly from the buttons, position sensors, and obstacle sensors. For the latter two, data will be analog values. For the buttons, data will be a digital value.

Requirements	Verification
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

2.4 Sensors

This is the interface between the user and the microcontroller. When deciding what to do, the microcontroller will take into account the current position of the drawer, the button inputs from the user, and data from the obstacle sensor.

2.4.1 Obstacle Sensor

This will consist of an array of static-dissipative foam around the perimeter of the drawer. Each piece of foam will be an impedance between a positive voltage and a known resistance to ground. When the foam bumps into an obstacle, it will deform, causing the impedance of the foam to change. The Atmega328P will detect a change in voltage at the point between the foam and the shunt resistor.

Requirements	Verification
Must have a change of impedance of at least 10±5% Ohm when compressed with 5±5% N	1. Connect the pressure sensor to a multimeter set to impedance measurement 2. Record the uncompressed impedance of the pressure sensor 3. Pressure the sensor with 5±5% N and monitor the deformed impedance 4. Ensure that there is minimum of 10±5% Ohm difference

2.4.2 Activation sensor

This will be the primary way for the user to activate the drawers. These large buttons will be easy to see and press. They will be normally open and be held logic-HIGH by pullup resistors. Pressing them will short the given input pin to logic-LOW.

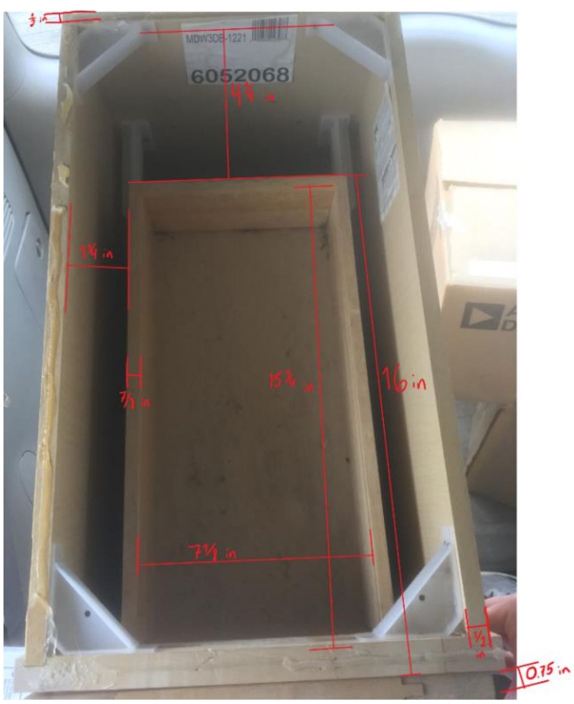
Requirements	Verification
The physical buttons must have a diameter larger than 3.5±1.5 cm for our specific audience	1. Use a ruler to measure the diameter

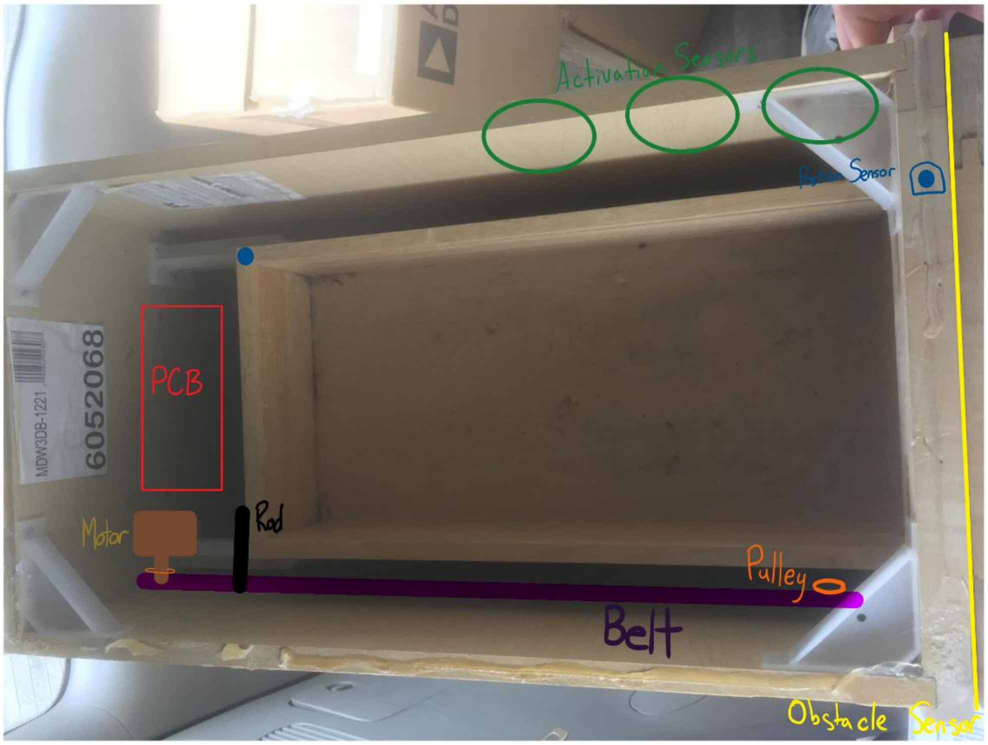
2.4.3 Position Sensor

A Hall Effect sensor will be installed in the face of the dresser, above each drawer. Two rare earth magnets will be installed inside the wall of each drawer with their south pole facing the Hall Effect sensor. One magnet will be underneath the sensor when the drawer is closed and the other will be placed so as to be underneath the sensor when the drawer is at its fully extended position.

Requirements	Verification
Must have a change of output voltage of at least 6±5% Volt when it is in the middle of travel versus when it has reached the end	1. Connect the Hall Effect sensor with a 10±5% kOhm pull-up resistor 2. Power the Hall Effect sensor with 12±5% VDC power 3. Connect the pull-up resistor/output pin node to a multimeter set to voltage measurement 4. Record the output voltage with no magnet nearby 5. Hold the magnet over the Hall Effect sensor with the south pole facing the sensor. Record the output voltage. 6. Repeat to ensure there is a reliable 6±5% Volt difference between the no-magnet and magnet cases

2.5 Physical Design





We have acquired the above dresser from Habitat for Humanity ReStore. We chose it because it has ample space behind and around the drawers for motor, belt, power, and PCB installation. The timing belt (purple) will extend from the pulley (orange) around the motor shaft to the pulley near the front of the dresser for maximum extension. The motor (brown) will be mounted on the back wall, as will the PCB and power supply (red). The position sensor (blue) will be in the face of the dresser above the drawer; the magnets will be set into the wall of the drawer. The activation sensors (green) will be on a panel that can align with the currently-absent top surface of the dresser. The obstacle sensor (yellow) will be in between the exterior of the dresser and the interior of the drawer's face.

2.6 Tolerance Analysis

The most significant risk to full completion of this proposal is the sensor network. Most reach goals involve including additional sensors for added functionality, though for concrete purposes we will discuss the obstacle sensor. We hope to have rapid and reliable obstacle detection, especially because this is a failsafe to protect injury to body parts, so we have chosen apt requirements. The successful fulfillment of these requirements will be driven by the sensors we chose, the type of communication to the controller, and the speed of our logic and motor response. There is a danger that, to achieve the sensitivity we desire, the necessary systems will drive up the cost of our project as well as require repetitive and thorough characterization and testing. We can ensure that the project as a whole is not compromised by the obstacle detector or any other sensor by keeping each sensor modular.

3.1 Cost

Our fixed development costs are estimated to be $67,000/year for an ECE Illinois Undergrad [15]. The three of us expect to work 10 hours per week over the 16-week semester.

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

Part	Cost
ATmega328P (Digikey)	$5
DC Motors (Robotshop)	2 for $13 each
A4988 Drivers + Heatsinks (FilamentOne.com)	3 for $10
Passive Components (Amazon)	$10
Static dissipative foam (Solarbotics)	$4.95
Hall Effect sensor (Digikey)	3 for $1.15 each
Hall Effect magnet (Digikey)	6 for $0.23 each
Physical Buttons (Amazon)	5 for $13
Ball Bearing Drawer Slides (Ebay)	$22.49 for 5
Rubber belts and Drive gears (Amazon)	$13.89

We plan to have three drawers mechanized, run by one PCB and microcontroller. Therefore, the sum total of the development cost is $40,317.

3.2 Schedule

Week	David	Levi	Jay
2/11	Work on Design Document	Work on Design Document	Work on Design Document
2/18	Research & Choose ball bearing drawer slides	Research & Order Parts for **Power** and **Logic**	Research & Get all sensors for drawer
2/25	Research & order belt & gears	Be able to connect motors and logic to power	Order other necessary parts for the sensors system
3/4	Assist sensor creation Assist motor control Confirm power installation design	Be able to control motors through atmega328 via drivers	Have the physical buttons ready for the control system
3/11	Characterize motors	Verify motor command delay/timing with button activation	Have the pressure sensor ready to be tested
3/18	Create & order PCB	Interface with obstacle sensor and start tuning	Have the position sensor ready to be tested
3/25	Install & Test motor/gear/belt system	Finish tuning so atmega328 can detect obstacles	Connect the sensors with other system
4/1	Install sensors & PCB	Experiment/look into smart activation methods	Continue working on installing the sensors
4/8	Test integrated system & address errors	*Extra time for complications*	Install and test the sensors with the motors
4/15	Address errors	*Extra time for complications*	Conduct testing and fix any errors
4/22	Prepare for final presentation	Prepare for final presentation	Prepare for final presentation
4/29	Work on final report	Work on final report	Work on final report

4 Safety and Ethics

4.1 Safety concern – Stop motion

There are some potential safety concerns with this project. Since we will design a drawer that extends and retracts autonomously, it is important that the motion stops when the drawer detects an obstacle such as a hand. In order to prevent the hands from jamming, we will be implementing a pressure sensor that stops the motor from continuously closing if an obstacle is detected.

Also, the sensor of the drawer that stops the motor when an obstacle is detected could malfunction due to dirt on the sensor or a faulty sensor itself [5]. To avoid this possible malfunctioning, we will wipe the sensor clean and perform as many trials as possible during the final stage of the project.

4.2 Safety concern – Speed

It is important to adjust the speed of the drawer extending and retracting because if it is too fast the drawer can potentially harm the surroundings by knocking out an object or a person. On the other hand, if it is too slow it will go against the ACM code of ethics 2.1 of striving to achieve the high quality of work and the product will be somewhat impractical [6].

In order to adjust the speed of the drawer, we will be using a high-power motor to move the drawer at an adequate speed. Furthermore, we will be programming a feedback loop which will control the position of the drawer and consequently its speed.

4.3 Ethics

Since the objective of this project is to bring more autonomy to people with limited mobility, we need to be careful to adhere to the IEEE Code of Ethics #8 by avoiding terms that could be discriminatory [7]. 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.

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