Automated Door Opener

24262 *Mechanical Design: Methods and Applications*

12/6/2024

Team Members:

Chris Dycus - cdycus

Jaeho Sung - jaehos

Johnirv Hollingshead - jihollin

Joshua Tsang - jtsang2

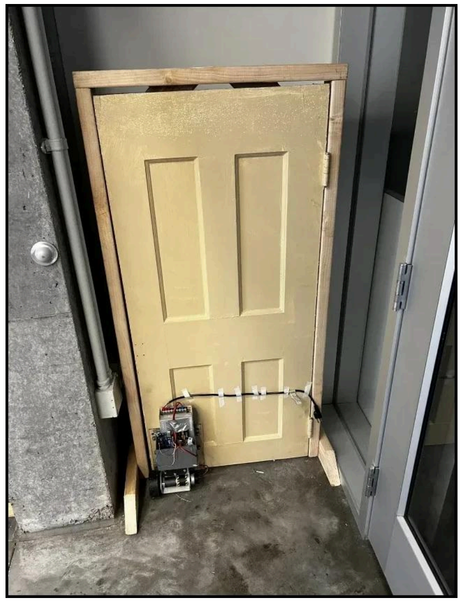
Kenji Tella - ktella

Min Seo Kim - minseoki

Table of contents

Summary

a)



b)

We selected home doors as our product to improve accessibility for individuals with limited mobility. User surveys highlighted significant frustration with manual door usage, emphasizing the need for a more accessible solution. While existing automated door systems reduce physical effort, they often fall short in terms of affordability, ease of use, and accessibility. Our goal was to design an automated door opener that bridges these gaps, offering a cost-effective and user-friendly solution to fulfill the needs of a broader audience.

c)

Key product specifications identified by our target population included affordability, reliability, ease of installation, and user-friendliness. Wheelchair users expressed frustration with the high cost and complexity of current automatic door systems, typically priced around $10,000 USD. To address these concerns, our final design incorporates a low cost motorized wheel mechanism that can be easily installed by a single person using only a power drill and a few screws. We prioritized reliability by selecting durable materials such as aluminum and rubber and incorporating high-torque, budget-friendly motors for consistent performance. These modifications ensure the product is cost-effective, low-maintenance, and accessible, meeting the critical needs of individuals with limited mobility.

d)

e)

Our Automated Door Opener empowers wheelchair users with a reliable, affordable, and user-friendly solution for home accessibility. Unlike existing products that are often prohibitively expensive and complicated to set up, our device can be installed in less than 15 minutes with minimal tools and effort. Activated via wireless remote or motion sensor, it delivers effortless operation, promoting independence and convenience in daily life.

f)

The Automated Door Opener operates using a combination of an Arduino microcontroller, a motor controller, a motor, and high-traction wheels. The Arduino microcontroller serves as the brain of the system, receiving input from either a wireless remote control to activate the motor. Upon receiving a signal, the Arduino instructs the motor controller to regulate power to the motor. Mounted on the door, the motor's high-traction wheels grip the floor, smoothly moving the door along its path to open and close.

g)

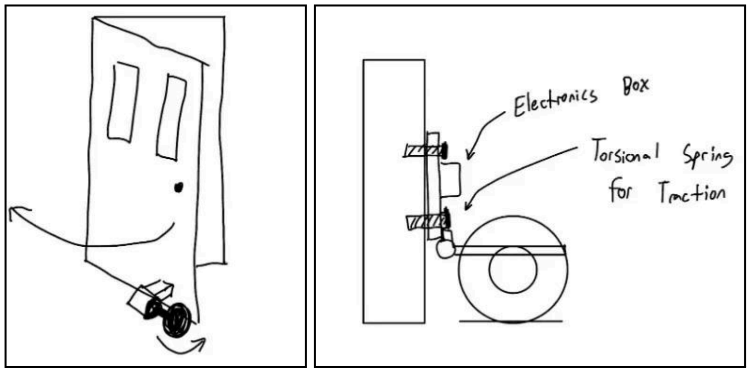
We plan to sell this product at a $200 USD price-point.

- Allows for 50% profit margins

- Still at least 3x cheaper than other market alternatives for automatic door openers.

4. Early ideation

a)



Our initial design sketches focused on creating an automated door opener that was both cost-effective and easy to install. The first design incorporated a battery-powered system for installation flexibility. However, power calculations revealed insufficient energy for prolonged use, necessitating frequent recharging or replacement. Consequently, we transitioned to a standard electrical outlet as the primary power source.

Another key feature in our early design was a gear train connected to a rack and pinion mechanism to translate the motor's rotational motion into linear motion for opening and closing the door. Although this system was mechanically sound, we realized that this design setup could interfere with wheelchair wheels, potentially creating an obstruction and posing a safety hazard. To resolve this issue, we adopted a high-traction wheel system directly mounted on the motor.

Key features that we retained include the use of a motorized mechanism for door operation and the generic backboard setup including the electronics box and screw holes.

b)

Power Source Feasibility: The initial idea of using a battery system proved impractical due to power, budget, and size limitations, highlighting the advantages of a consistent and reliable power supply from an electrical outlet.

Mechanical Interference: The gear train and rack and pinion mechanism, while effective in theory, posed significant practical challenges due to potential interference with wheelchair movement, underscoring the need for a non-intrusive mechanism.

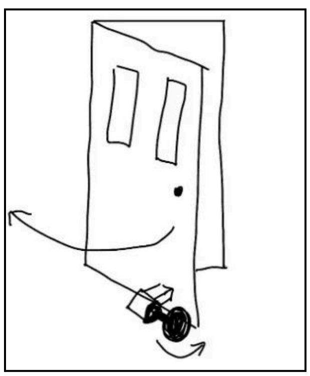
User-Centric Design: Feedback from potential users emphasized the need for an unobtrusive, easy-to-use system, steering our design towards the current configuration with a high-traction wheels system.

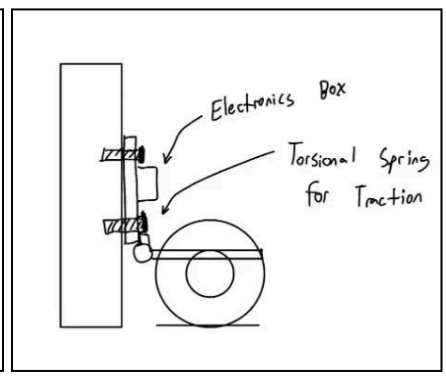
5. Developed Ideation

a)

Reflecting on our initial ideas and the ideation process, we can see significant improvements in our design approach. Initially, we were focused on integrating a battery system and a rack and pinion mechanism. However, practical challenges such as power limitations and potential interference with wheelchair movement forced us to reconsider these concepts. Through user feedback and iterative prototyping, we learned that reliability and unobtrusiveness were important. The shift to a standard electrical outlet for power ensured consistent performance, while the adoption of high-traction wheels on a track system addressed the need for smooth and unobstructed door operation. These lessons reinforced the importance of adaptability and user-centered design in our project.

b)





High-Traction Wheels: Positioned on the door, these wheels ensure smooth and reliable movement of the door, avoiding any interference with wheelchair paths.

Arduino Microcontroller: Acts as the control unit, processing inputs from the wireless remote or motion sensor and sending commands to the motor controller.

Motor Controller: Regulates the power supplied to the motor based on commands from the Arduino, ensuring precise control of door movements.

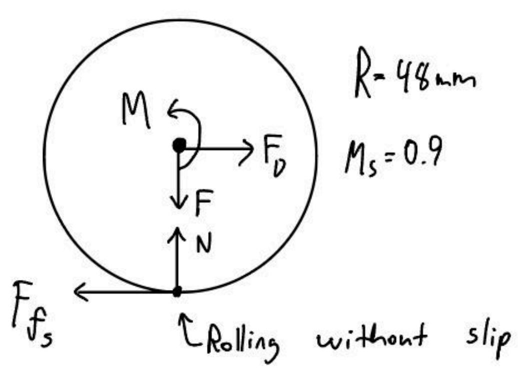
Motor: Drives the high-traction wheels to open and close the door.

Wireless Remote/Motion Sensor: Provides input to the Arduino to activate the door mechanism, offering hands-free operation for users.

Power Supply: Standard electrical outlet connection with optional battery backup for power outages.

6. Stress analysis

Wheel FBD:



$N = F$ from $\Sigma F_y = 0$

$F_{fs} = \mu_s \cdot N$

$F_D = 10\,lbs$ (force needed to open door)

At moment when 10lb threshold is reached $a = 0$ Forces in equilibrium

$\Sigma F_x = 0 \Rightarrow F_D = F_{fs} = 10lb \quad \mu_s N = 10lb$

$\Sigma M = 0 \Rightarrow M = F_{fs} \cdot R \qquad N = \dfrac{10lb}{\mu_s} = F$

$M = 10lb \cdot R$

Downforce needed: $F = \dfrac{10lb}{\mu_s} = 11.11\,lb \approx \boxed{50N = F}$

Motor Torque needed: $M = 10lb \cdot 48mm = 44.5N \cdot 0.048m$

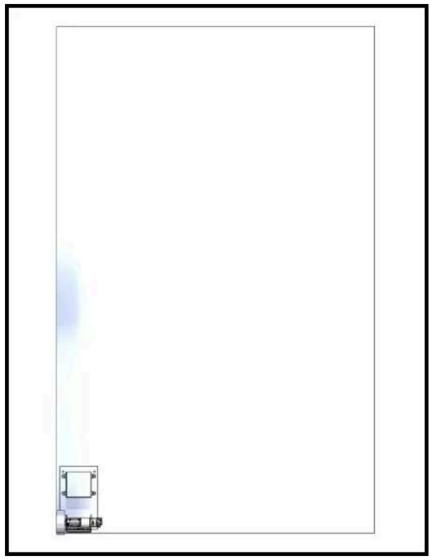
$\boxed{M = 2.136\,Nm}$

7. Prototype in CAD

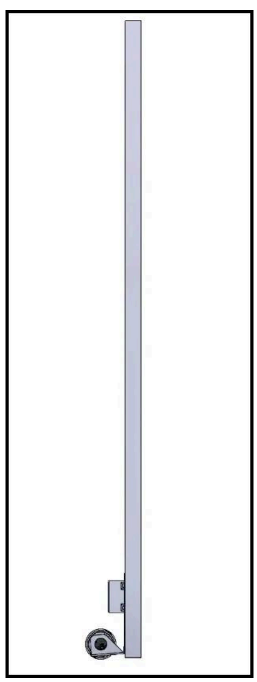
Modified Product:

a)

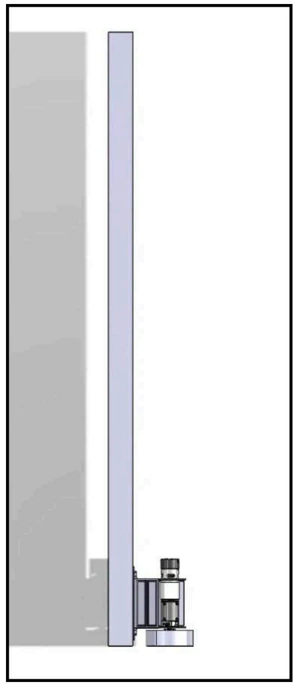
Front:



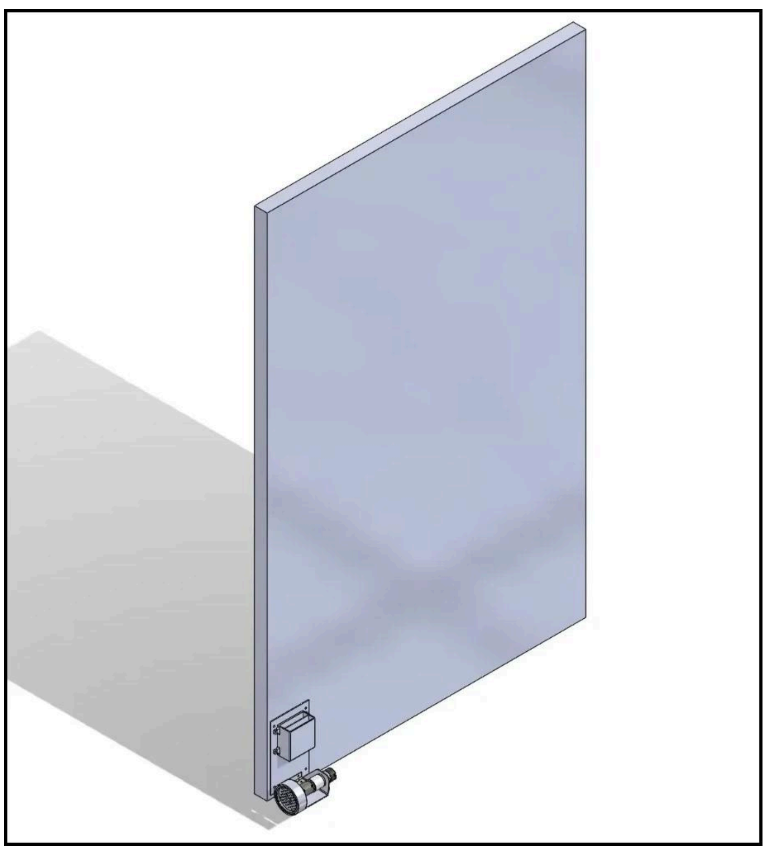
Right:



Top:



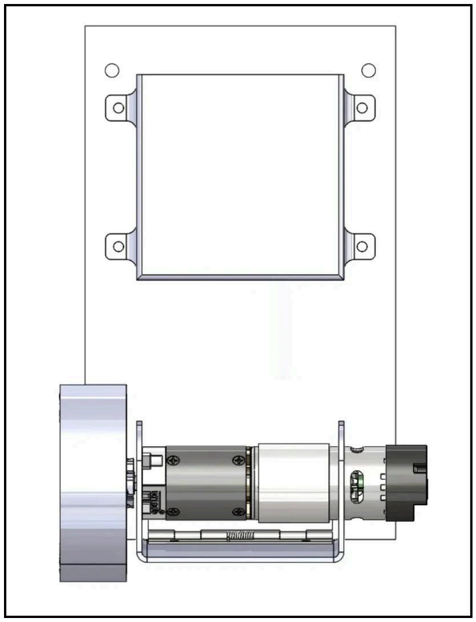
Isometric:



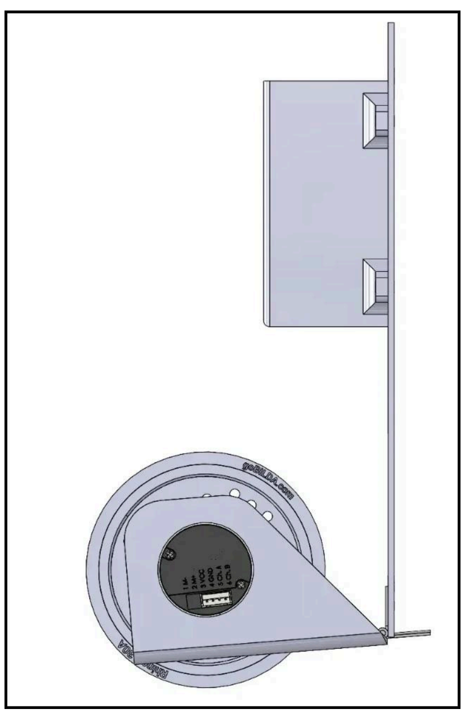
Subassembly (our product):

b)

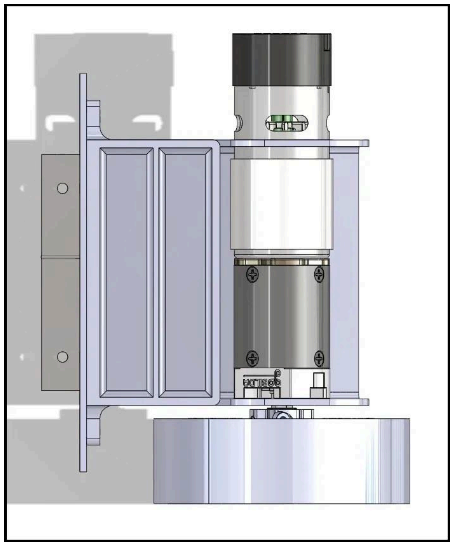
Front:



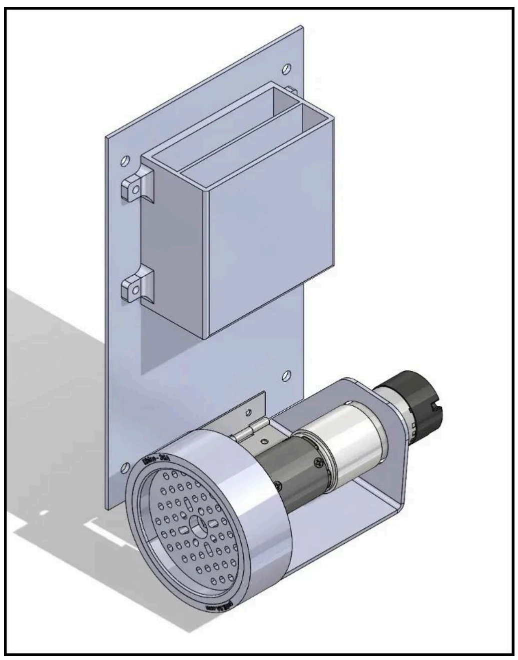
Right:



Top:



Isometric:



c)

How the product works:
There is an electrical connection from a wall outlet to the device. This connection will go directly into the power supply which powers the motor controller at a stepped down 12V. This motor controller is also connected to the Arduino, which receives inputs from an IR remote controller. When in use, the arduino will send signals to the motor controller, which will power the motor. The motor will then turn the wheel of the mechanism and by doing so open the door. After 10

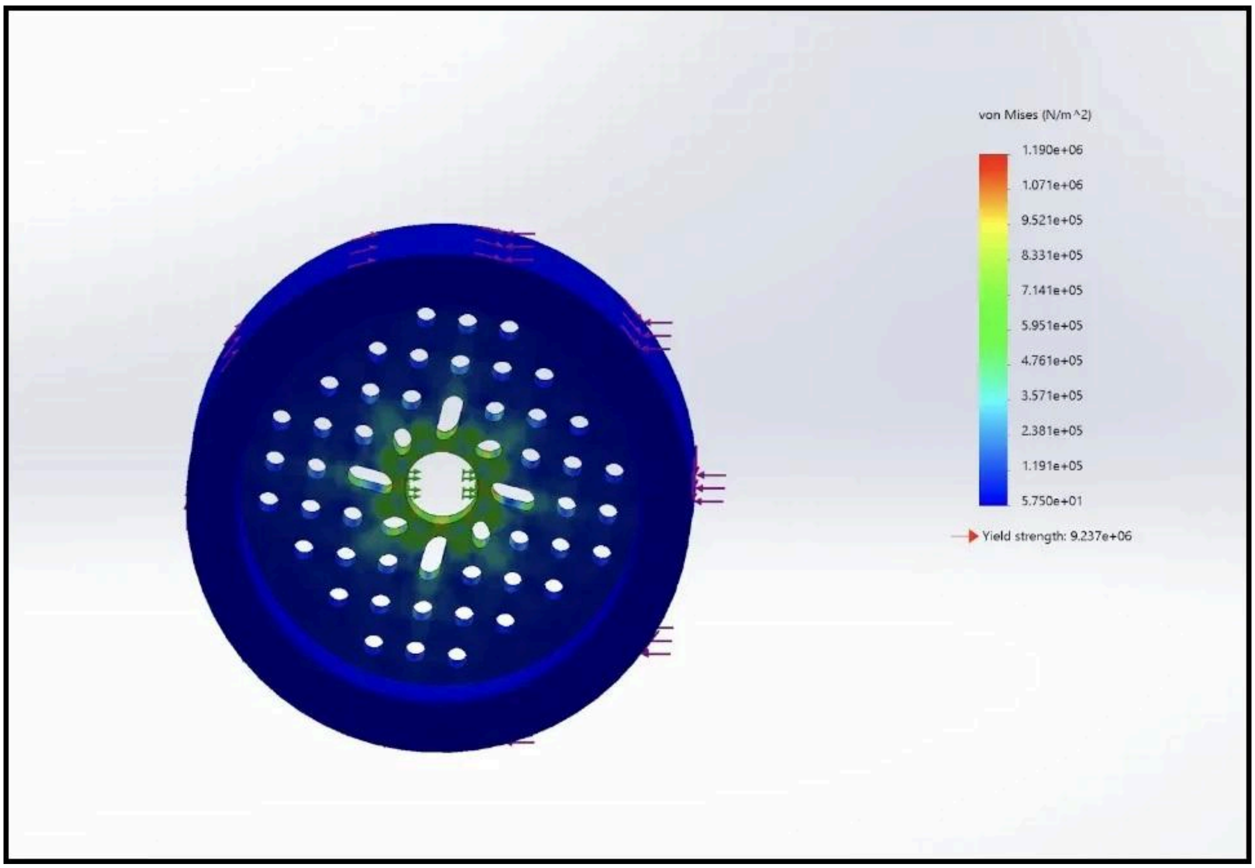
seconds (or any user set value), the arduino will automatically send another signal to the motor to close the door.

8. Testing with FEA

a)

It is not possible to display what specific orientation in which the wheel will most likely fail first, as it is completely symmetrical. However, as the wheel is only connected with four bolts to the hubs, if failure were to occur, it would happen near the 4 hub mounting points. As there isn't 1 explicit worst case loading condition, we did FEA in the orientation in which the cross section of the wheel is smallest, which we believed to be worst case.

b)



c)

We chose the loading condition of a 11.1 lbf force because that is the design requirement that we have calculated. We also applied a torque of 18.9 lb-in from our planetary gearset motor which will react the friction force that will move the wheel.

d)

In order to perform the FEA (Finite Element Analysis) simulation, we used the values obtained from our hand calculations as the loading conditions, ensuring consistency between both methods. The primary similarity lies in the applied forces: the hand-calculated downforce of 50N and torque of 18.9 lb-in were directly incorporated into the simulation. These values were used to evaluate the stress distribution across the wheel.

There were no notable discrepancies between the hand calculations and the FEA results because the wheel was assumed to withstand the applied forces without failure. The FEA provided confirmation of this assumption as the wheel's maximum stress ($\sim 7.141 \times 10^5$ N/m^2) was far below its yield strength (9.237×10^6 N/m^2) in the simulation.

The FEA simulation better represents a physical prototype because it provides a more detailed and accurate representation of the wheel's behavior under load, as it accounts for the distribution of forces across the wheel and evaluates areas of localized stress concentration. While our hand calculations are essential for configuring the loading forces and understanding the system, they simplify assumptions (e.g., uniform stress distribution) and do not account for real-world complexities, such as material imperfections or variable loading, which is why we used FEA to validate our assumptions that our wheel could withstand the given loading forces.

9.Manufacturing and Drawing

a)

Wheels

Material Selection:

- We chose to use rubber due to its high friction coefficient and availability on the market. According to our calculations, we needed a friction coefficient of at least 0.9, so rubber was the best and most sensible option.

Manufacturing Method:

- Due to the difficulty of self-manufacturing wheels and the abundant availability of rubber wheels on the market, we decided to acquire our wheels from a third-party. The cost of these wheels are $8.99.
- **Per unit:** $8.99
- **Assembly:** For assembly it is straightforward and requires minimal effort. We simply insert the motor shaft into the wheel and secure it in place using four screws. Assuming that we can assemble this component in 1 minute, at $18/hr, 1 unit costs 30 cents to assemble.

- **Year:** If we expect to sell 1000 units a year, we can estimate the cost of wheels to be around $9290.

Electronics Box

Material Selection:

- We chose PLA so we can use the 3D-printer to print our electronics box. Due to the time constraints and ease of prototyping using the 3D-printer for customized parts was our best option. Also, PLA is a very cost-effective material only costing about $15 per kg.

Manufacturing Method:

- For our initial prototype for this project we used the 3D-printer due to its ease of access and prototyping. However, if we are trying to mass produce our product we will have to use a more time-efficient manufacturing method such as injection molding.
- **Per unit:** If PLA costs $15 per kilogram and the box weighs approximately 100g, the material cost comes to $1.50. With an electricity rate of $0.10 per kWh and a 5-hour print time, the energy cost adds up to $0.50. This brings the total cost of printing one box to $2.00, combining material and electricity expenses.
- **Assembly:** Similar to the wheels, for assembly it is straightforward and requires minimal effort. We simply screw the box onto the door using 4 screws. However, the assembly for the electronics box wouldn't cost us anything because the user will have to screw it onto their own doors.
- **Year:** If we expect to sell 1000 units a year, we can estimate the cost of the electronics box to be around $2000. (This cost would drop significantly if we change our manufacturing method to injection molding)

Motor Mount

Material Selection:

- We chose 5052 H-32 Aluminum because it is lightweight, corrosion resistant, easy to manufacture, and has a high strength to weight ratio. Specifically, the alloy 5052 is very easily bendable, which will decrease the cost of manufacturing. The price of aluminum is around $3 per kg.

Manufacturing Method:

- For our initial prototype we did not have all the equipment (limited equipment in TechSpark) to manufacture so we had to send our design to a 3rd party manufacturer. The manufacturing method used is one off metal sheet bending. If we consider mass-production our best time/cost effective option would be a combination of stamping and press braking.

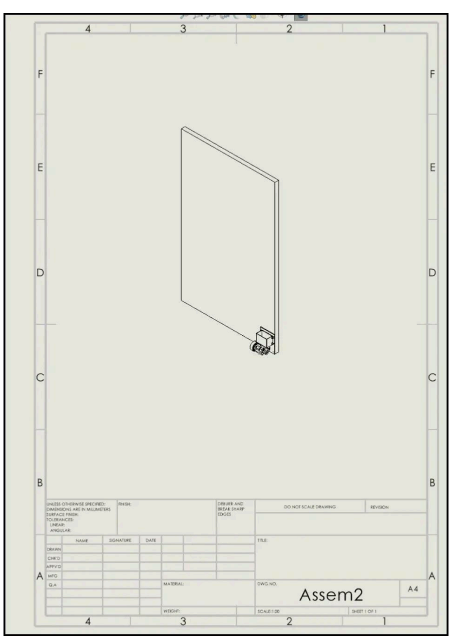
- **Per unit:** The cost of a single motor mount for a retail order is $22. However, we believe we can significantly reduce this cost by either manufacturing the motor mount in-house or ordering in bulk to take advantage of wholesale pricing. This would allow us to lower production costs and improve overall profit.
- **Assembly:** The assembly process is straightforward and requires minimal effort. We simply insert the motor into the mount, secure it with four screws, and then attach the mount to the acrylic backboard using four additional screws. Assuming the assembly time is 2 minutes per unit, and at a labor rate of $18 per hour, the cost to assemble one unit is 60 cents.
- **Year:** If we expect to sell 1000 units a year, we can estimate the cost of the motor mount to be around $22,600. (This cost would drop significantly if we manufacture in-house or order in bulk)

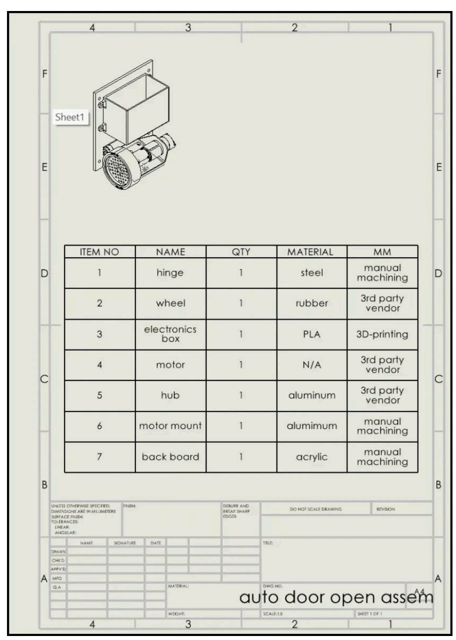
b)

Component	**Material**	**Manufacturing Method**	**Units per Assembly**	**Cost per Assembly**	**Units per Year**	**Cost per Year**
Wheels	rubber	Acquired from third-party vendor	x1	$9.29	x1000	$9290
Electronics Box	PLA (plastic)	3D-printing	x1	$2.00	x1000	$2000
Motor Mount	Aluminum	Manual Machining	x1	$22.60	x1000	$22600

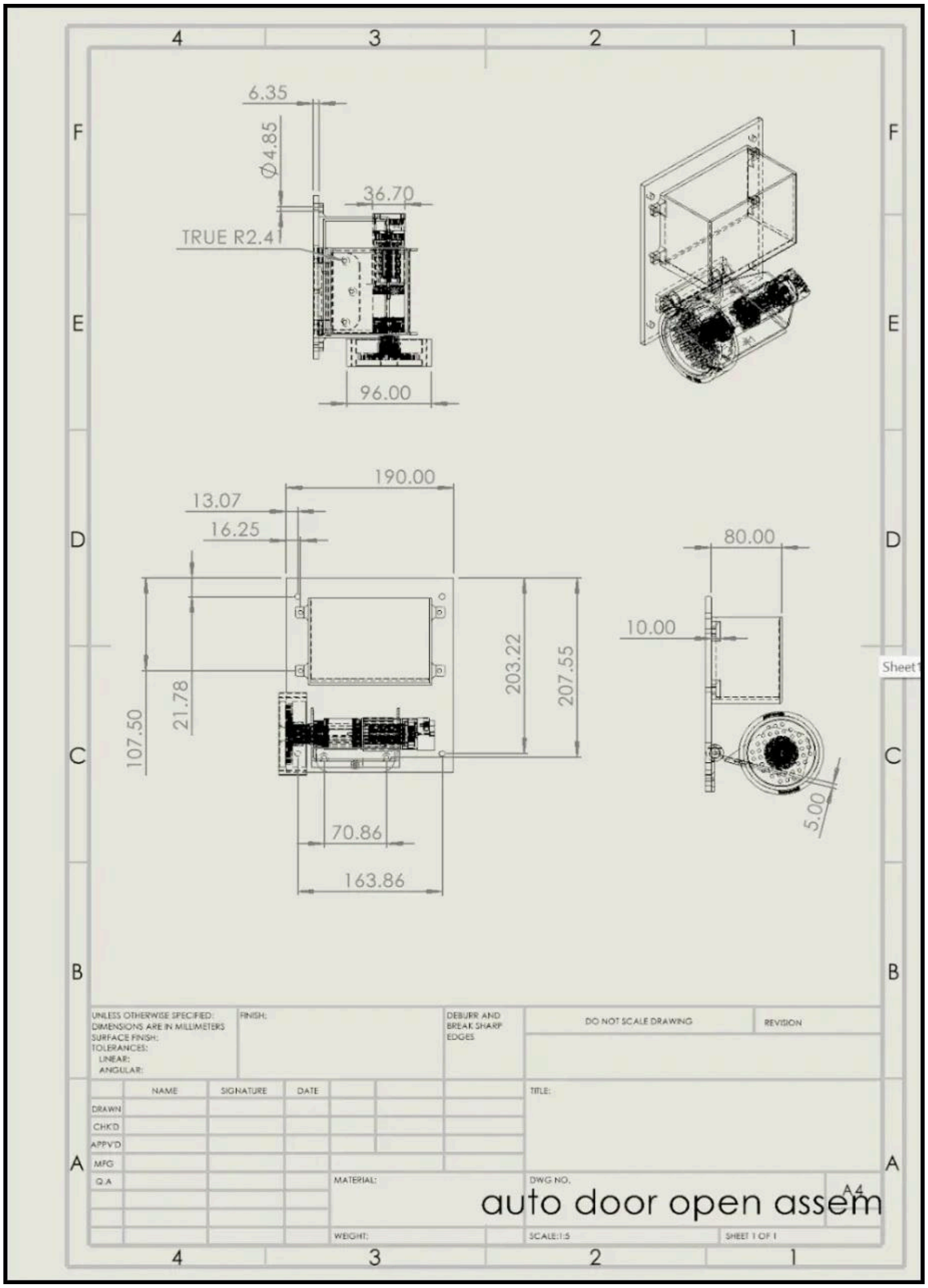
(all prices listed in USD)

c)





d)


6.35
Ø4.85
36.70
TRUE R2.41
96.00
190.00
13.07
16.25
80.00
10.00
203.22
207.55
107.50
21.78
70.86
163.86
5.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
DWG NO.
auto door open assem
A4
SCALE:1:5
SHEET 1 OF 1

e)

We estimate that our product should retail for $200 USD. This pricing is justified by a manufacturing cost of approximately $100 USD, which is based on components sourced at retail prices. Despite these costs, we achieve a margin of about 50%, which is expected to increase with scaled production and bulk sourcing of components at lower prices. Specifically, the motor assemblies and controllers at bulk will reduce their price from $70 to around $35. At $200, our product is significantly more affordable than comparable solutions on the market, which typically range from $500 to $700, and is far less expensive than installing an electronic opening door, which can start at $1,500. This price point makes our product accessible to most American families while offering a competitive, cost-effective alternative to current options.

10. Continuous improvement

a)

One component that should be kept in its current form is the high-traction rubber wheel and motor mechanism. Using a wheel provides a cost-effective and efficient mechanism for opening doors without requiring complex or expensive systems like gear trains or hydraulic actuators. The high-traction rubber material ensures reliable grip on various floor surfaces, enabling smooth and consistent door movement. Additionally, its configuration with the motor and electronics box is very compact, making it very easy to install without the need of professional assistance.

b)

One area that could benefit from minor adjustments is the electronics box. Currently, it is loosely designed to allow quick access for inserting or removing the Arduino and other electrical components during development. For the finished product, the electronics box should be more organized and secure by incorporating dedicated compartments for each component, and utilizing better cable-management. Built-in channels or thermal cable tubes would keep wiring neat and reduce the risk of accidental disconnections.

c)

One area that could benefit from major adjustment is the remote control functionality. Currently, the remote must be positioned close to and level with the Arduino to activate the door, which could pose challenges for individuals in wheelchairs or using crutches. Additionally, instead of pressing a button that opens the door and closes it after a short delay, it would be helpful to reprogram the system so that the remote control can be pressed to both open and close the door.

11. Budget

Item	Vendor	Description	Link	Quantity	Unit Price	Shipping	Subtotal
Hub	goBILDA	High-strength hub, 8mm bore	here	x1	$7.99	$0.00	$7.99
Motor Controller	goBILDA	Motor controller supporting 15A for speed control	here	x1	$39.99	$0.00	$39.99
Tire	goBILDA	High-grip rubber tire	here	x1	$8.99	$0.00	$8.99
Motor	goBILDA	20V gear motor with 8mm output shaft	here	x1	$57.99	$0.00	$57.99
Hinge	McMaster-Carr	Hinge for motor	here	x1	$24.67	$4.46	$29.13
Motor Mount	SendCutSend	Aluminum mount to hold motor	here	x1	$37.21	$14.45	$51.66
Electronics Box	3D Printed	3D printed box made of PLA	N/A	x1	$2.00	$0.00	$4.00
Acrylic Backboard	McMaster-Carr	Backboard holding components together	here	x1	$13.56	$4.46	$18.02
Power Supply	Amazon	24V 15A power supply	here	x1	$23.99	$0.00	$23.99
Arduino Harness	Amazon	9V battery connector	here	x1	$3.59	$0.00	$3.59
Fork Connectors	Amazon	Fork connectors for power supply	here	x1	$8.99	$0.00	$8.99
18AWG wire	Amazon	12V/24V DC cable	here	x1	$9.99	$0.00	$9.99
XT30 Harness	goBILDA	MH-FC, 300mm	here	x1	$1.99	$0.00	$1.99
Remote	Amazon	Remote Control IFR Sensor Module	here	x1	$7.99	$0.00	$7.99
GRAND TOTAL:							$274.31

(all prices listed in USD)