July 10th, 2023

Dr. Michael Hegedus
School of Engineering Science
Simon Fraser University
Burnaby, BC, V5A 1S6

RE: ENSC 405W Design Specification for Roll Technology

Dear Dr. Hegedus,

Roll Technology has prepared this design specifications document for ENSC 405W/440, in regards to our product Chairable. The aim is to create a modular product that acts as an attachment to convert a generic office chair into a motorized one.

Chairable is a modular office chair attachment specifically designed with a spherical wheel mechanism to facilitate powered movement. After attachment, the user can sit and move the chair in any direction around using simple controls at low speeds. This would allow the user to enhance their workplace environment by making it more fun and accessible.

The document includes our design requirements and specifications for our mechanical, electrical, hardware and software components. Moreover, the alternative design comparisons and test plans are added to guarantee the device's safety and effectiveness. Finally, we will share specific information about the appearance and functionalities of Chairable with CAD drawings and diagrams.

Should you have any questions or require additional information please do not hesitate to contact our Chief Communication Officer, Divyam Sharma, via email (divyams@sfu.ca) or via phone (+1 236-512 4989). We will be more than happy to address any concerns or provide any clarification you may require.

Sincerely,

Kaj Grant-Mathiasen
Chief Executive Officer
Roll Technology

ENCLOSED: Design Specification for Chairable

Company #13

Design Specification:
Chairable

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Issue Date:
July 10th, 2023

Abstract

This document serves to explain the design choices in both the proof of concept and prototype phases of Chairable, an invention in development by RollTech which aims to motorize an office chair. The electronics, software and mechanical components of the design will be covered and justification for the choices will be given. Chairable allows an office chair to be controlled and motorized at low speeds in order to provide a new and enjoyable experience while navigating throughout the workplace. This device takes in user input through a joystick and communicates with a microcontroller to send PWM signals to control motors which direct and drive an omnidirectional sphere enclosed in a frame and attached to the office chair.

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Glossary

Terminology	Definition
Microcontroller	A compact computer on an integrated circuit which is dedicated to perform a specific function
Omni-Directional	The ability to move in both forward and lateral movements simultaneously
PWM	Pulse Width Modulation
I/O	Input/Output (ex. usb port)
RF	Radio Frequency
LiPo	Lithium Polymer
Bidirectional	Referencing both clockwise and counterclockwise rotation
RPM	Rotations Per Minute
Stall Torque	The maximum torque that can be applied to the shaft of a motor before it ceases to spin
Stall Current	The maximum amount of current drawn from the motor when it has reached the stall torque
Free-run	The scenario where a motor has no load applied to the shaft
6s/12s	6 Cell / 12 Cell Battery

Approvals

RollTech approved and reviewed this document that provides the design specifications of Chairable which is a product currently in development.

1 Introduction

A product for individuals seeking out a fun and accessible solution in an otherwise bland workplace environment. Chairable combines a battery powered spherical wheel system, a strategically placed footstand and an intuitive user interface into an attachment for an everyday office chair. Chairable's goal is to provide powered movement to the chair, therefore avoiding the need for physical exertion. Users will remain seated while controlling and navigating the chair's movement through a simple user interface. Chairable is built to be modular, compact and cost effective and serves as a solution to improve on the ability of existing office chairs. In addition, the added benefit of an omni wheel enables smooth navigation in tight work spaces increasing its versatility in different environments.

1.1 Scope

This document describes the design of interest decided by RollTech in developing Chairable and justifies the mechanical, electronic, software components of the chosen design with equations and diagrams. There are also two appendices at the end of the document which outlines the Design Alternative and Test plan for the device.

1.2 Challenges

The following are a list of challenges encountered while designing Chairable:

- Designing a control mechanism to easily control the device
- Finding the right type of ball, in terms of material and size, for the wheel
- Constructing a frame that is able to support the entire system
- Accurately representing Chairable using CAD
- Having sufficient torque provided by motors
- External force interfering with the function of motors

1.3 Updates on Feedback

After speaking with Dr. Mike Hegedus and Dr. Shervin Jannesar and receiving feedback from them, the following updates on the design and requirements were added:

1. Wheel system would be tested on basic flooring materials to ensure it works, but will not be tested on uncommon flooring materials.
2. The design chosen has the frame enclosing the ball so adequate pressure can spread around it because the other options presented were too difficult to implement.
3. The ball of choice to be used in the design will be a solid ball because there are concerns about the possibility of the inflatable ball deflating and impacting the design.
4. The goal is to move a person and an office chair together, but if that proves too difficult then the load will be reduced to an office chair only as suggested by Dr. Jannesar.

1.4 Product Stage Classifications

The following table lists out the conventions used for the product stage classifications:

Encodings	Development Stages
A	Proof Of Concept
B	Engineering Prototype
C	Production Version

Table 1: *Product stage labels*

The format of the requirement ID's is shown below:

D (Document Section).(Subsection).(Requirement Number)-(Classification)

2 Chairable System Overview

Chairable is an omni-wheel based attachment designed for office chairs. This advanced movement system utilizes multiple subsystems which collaboratively interact to create a comprehensive and resilient user experience. The first subsystem is the mechanical system, which maintains continuous and efficient contact with the motors, wheels, and floor. The second subsystem is the electrical system, responsible for regulating the battery, power delivery, and control signal functionality. The final system is the software system which translates user input into responsive movement and oversees the chair's operation. Figure 1 demonstrates how the three main systems are integrated together.

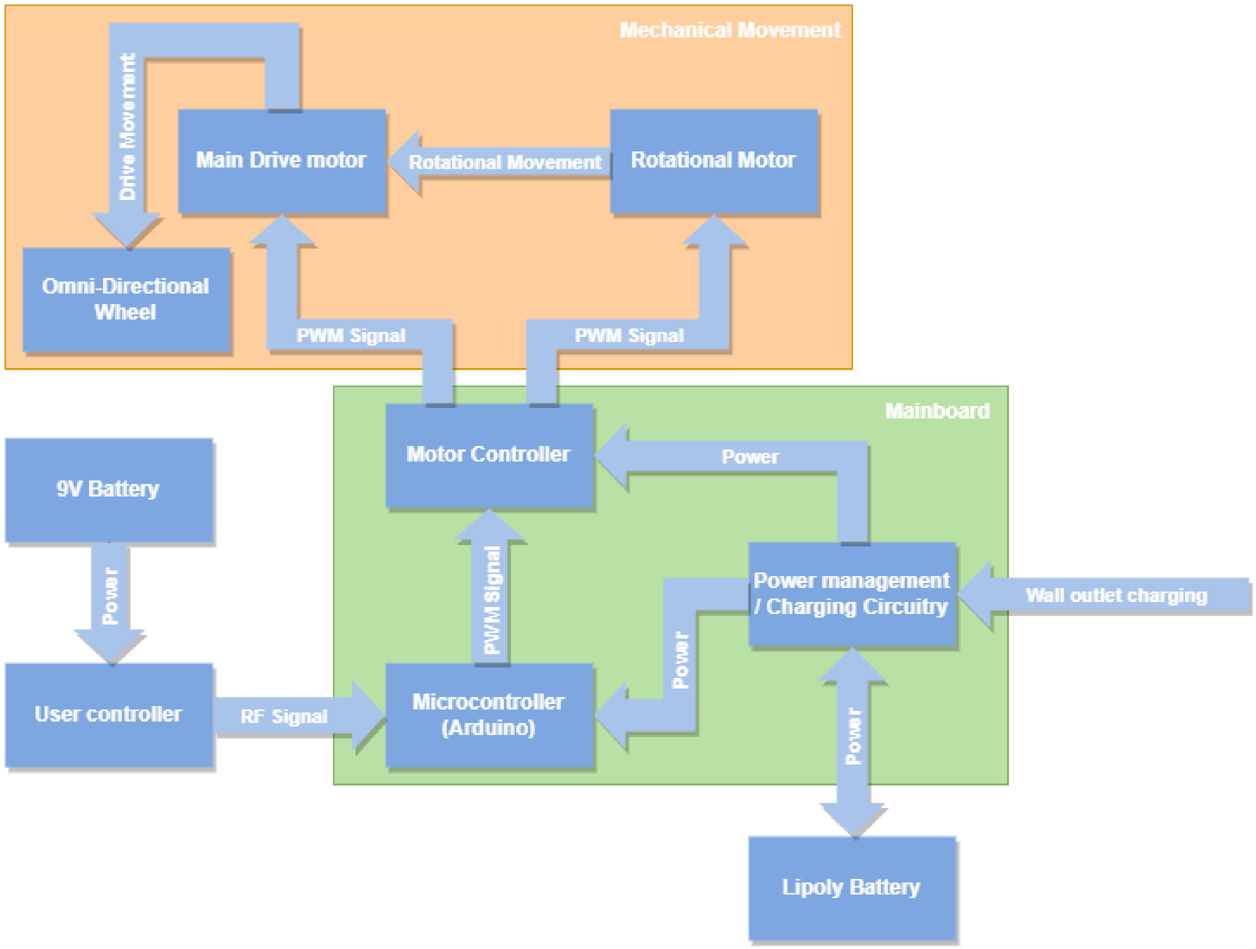

Figure 1: *Chairable system block diagram*

The Omni-Directional wheel is powered by the primary drive motor, specifically designed to handle the combined weight of the chair and user, facilitating the main chair movement. A smaller rotational motor enables turning and lateral movement. Both motors are controlled through a motor controller circuit, which manages power and adjusts speed based on signals from the microcontroller and power management circuitry.

To facilitate user control, an external user controller communicates with the internal microcontroller via an RF chip and is powered by a separate 9V battery. A custom power management and charging circuit ensures efficient power distribution to each system component and enables recharging of the internal battery.

Figure 2 demonstrates the Chairable attachment including user controller with an accompanying office chair.

Figure 2: *Overview of Chairable with controller attached to a office chair [1][2][3][4]*

Table 2 provides a comprehensive list of materials and parts required to create the initial design of Chairable along with their approximate costs.

Materials	Individual Cost ($)	Quantity	Total Cost ($)
Main Driver Motor (SK3 - 6364-190KV) [1]	$120.70	1	$120.70
Rotational Motor (JGB37-545) [2]	$20.00	1	$20.00
5000mAh LiPo Battery [3]	$88.15	1	$88.15
6 Cell LiPo Charger [4]	$50.17	1	$50.17
Arduino Uno Microcontroller [5]	$30.00	2	$60.00
DC-DC Step Down Converter (LM2596) [6]	$5.00	2	$10.00

DC Motor Controller (L298N) [7]	$5.00	2	$10.00
6S Bidirectional ESC [8]	$30.00	1	$30.00
RF Module (nRF24L01) [9]	$2.50	2	$5.00
Emergency off switch [10]	$20.00	1	$20.00
RGB LEDs [11]	$0.50	2	$1.00
30A Fuse with case [12]	$12.00	1	$12.00
PS2 Joystick Module [13]	$1.00	1	$1.00
9V Alkaline Battery [14]	$3.00	1	$3.00
Controller on/off switch [15]	$0.50	1	$0.50
Plastic Ball (Wheel) [16]	$21.00	1	$21.00
Rubber Wheel [17]	$8.29	1	$8.29

Table 2: *Estimated bill of materials*

3 Chairable Design

This section describes the detailed design requirements for Chairable and is organized by respective subsystems: Mechanical, Electrical, Circuitry, and Software.

3.1 Mechanical Design Specifications

Table 3 provides a list of the mechanical and structural components essential to the design of Chairable.

Design Requirement ID	Description	Expected Changes for future Designs	Related Requirement Specifications
3.1.1	Structural frame constructed of aluminum in order to remain lightweight and structurally sound	Potentially change certain components to steel if aluminum is not sturdy enough (ex. L-Bar)	3.1.10 B 3.2.3 B
3.1.2	Driving wheel of 2 inch diameter made of rubber for high grip on omnidirectional ball		3.2.2 A
3.1.3	6” diameter Jolly Pet Push’n’Play ball selected as omnidirectional ball for sturdiness		3.1.7 B 3.1.8 B
3.1.4	1” Diameter plastic balls used as ball bearings to allow for lateral movement of system	Potentially change to metal bearings if plastic insufficient	3.2.2 A 3.2.3 B
3.1.5	Supporting L-Bar to be made of aluminum strong enough to withstand applied force as well as remain stable if system is impacted	Create component out of steel if aluminum component insufficiently strong	3.2.3 B
3.1.6	Lower supportive disk to be extremely smooth to allow 360 degree movement of driving motor	Create rail or thrust bearing system to better allow rotational movement	3.2.3 B 3.3.5 B

Table 3: *Mechanical design specifications*

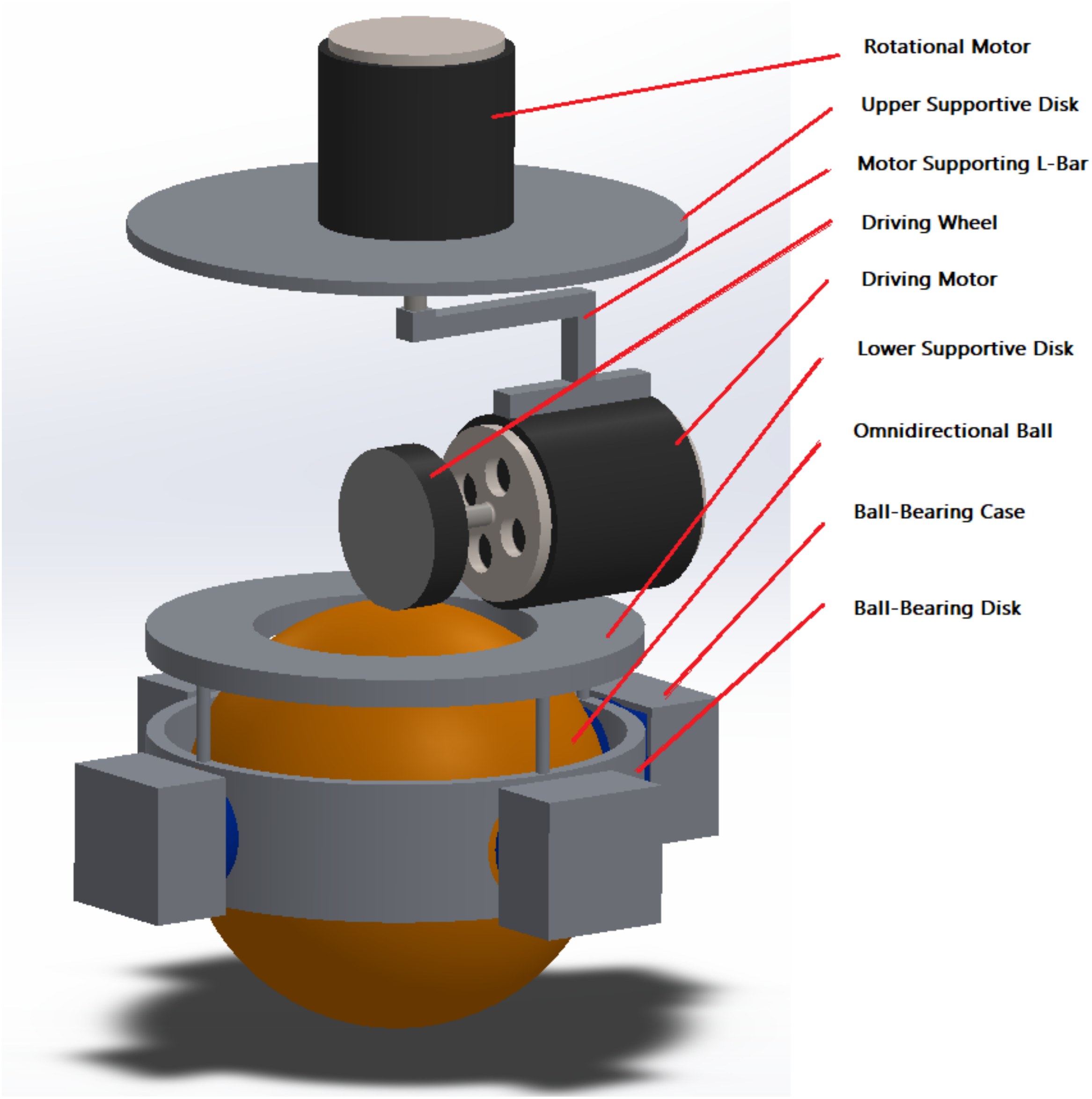

Figure 3: *Internal workings of the motor and ball unit*

The designed mechanical system of the omnidirectional ball motor apparatus is centered around the 6 inch diameter omnidirectional ball and the infrastructure surrounding it to drive movement. Circling the ball at its midsection, an aluminum disk referenced above as the ball-bearing disk has 4 metal ball-bearing cases attached to it. Encased within each ball-bearing case is a 1 inch diameter ball to allow for lateral force transfer without toppling the mechanism. Attached above through the use of small aluminum rods is the lower supportive disk, which adds stability to the driving motor by acting as a brace for any shock to the system to prevent damage in case of impact. The driving wheel is the main driving force behind the movement of the system, rotating while held against the omnidirectional ball to roll the ball. High friction is needed between the ball and the driving wheel, so a 2 inch diameter rubber wheel was chosen for this part.

The driving motor is connected to the rotational motor through what has been titled the motor supporting L bar. The supporting L bar allows for the driving motor to be spun around in accordance with the direction of the rotational motor. The supporting L bar is connected to both the main casing of the driving motor as well as the axle of the rotational motor. Finally, the upper supportive disk is bolted to the casing of the rotational motor and is also connected to the outside frame.

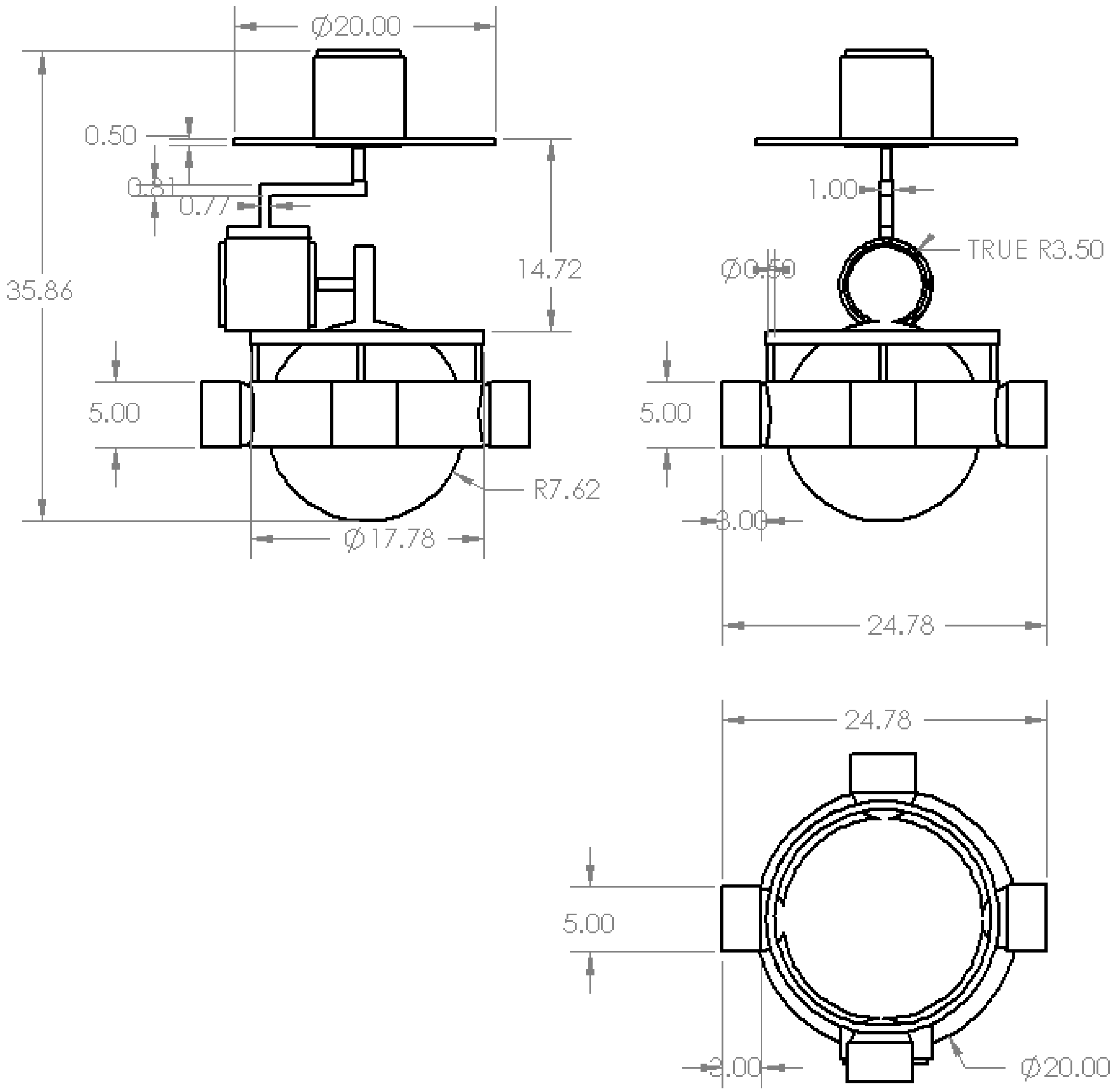

Figure 4: *Dimensions of main motor system internals (centimeters*)

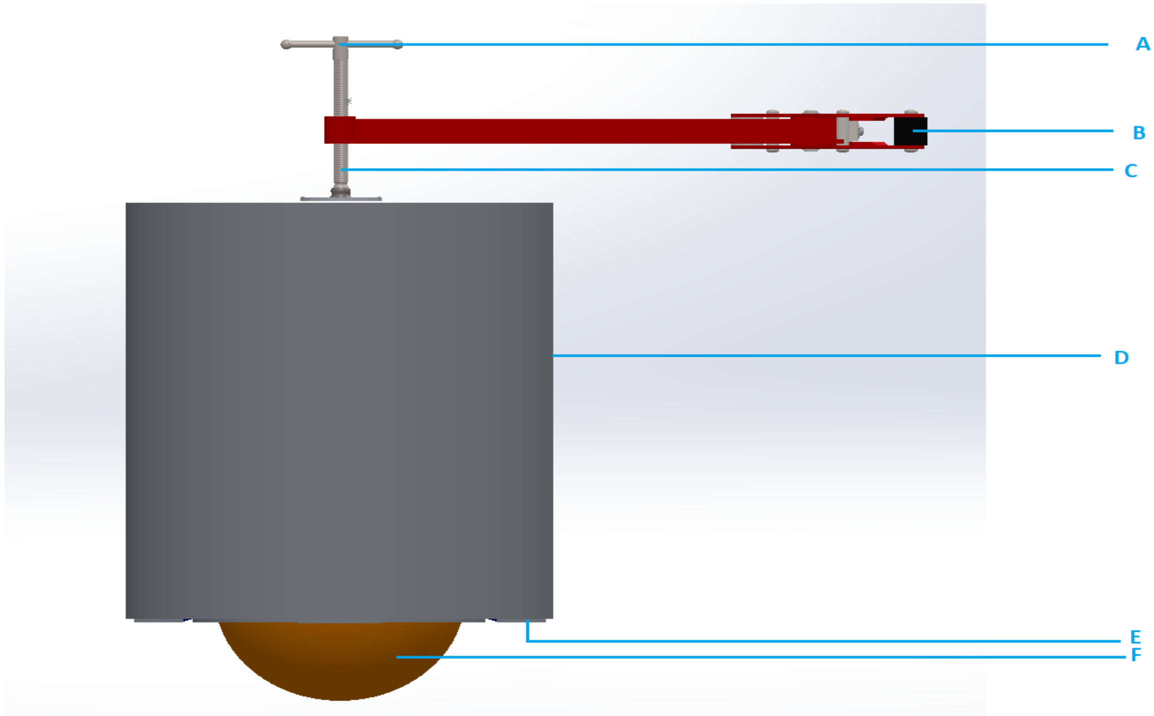

Figure 5: *External mechanical design of the attachment with clamps (front view) [2][3][4]*

Label	Specification	Use
A	Compressed Screw Clamp Tightener	This is for the user to tighten and ensure the attachment is having enough contact with the ground
B	Super Clamp (10 mm to 50mm)	A variable clamp that can attach to the center cylindrical rod of an office chair. The clamp is user adjustable within a range so it can fit various sized rod on office chairs
C	Compressed Screw Clamp Screw	This is a mechanism that ensures that only the clamp screw rotates and creates a downward force on the attachment rather than the entire attachment
D	Aluminum Casing for Attachment	This ensures that the entire omni wheel system cannot be tampered with and stays contained
E	Ball Bearing	The ball bearings around the solid ball(F) allowing for it to rotate in any direction in position
F	Solid Ball	This is the ball the entire attachment rotates on

Table 4: *Labels from figure 5*

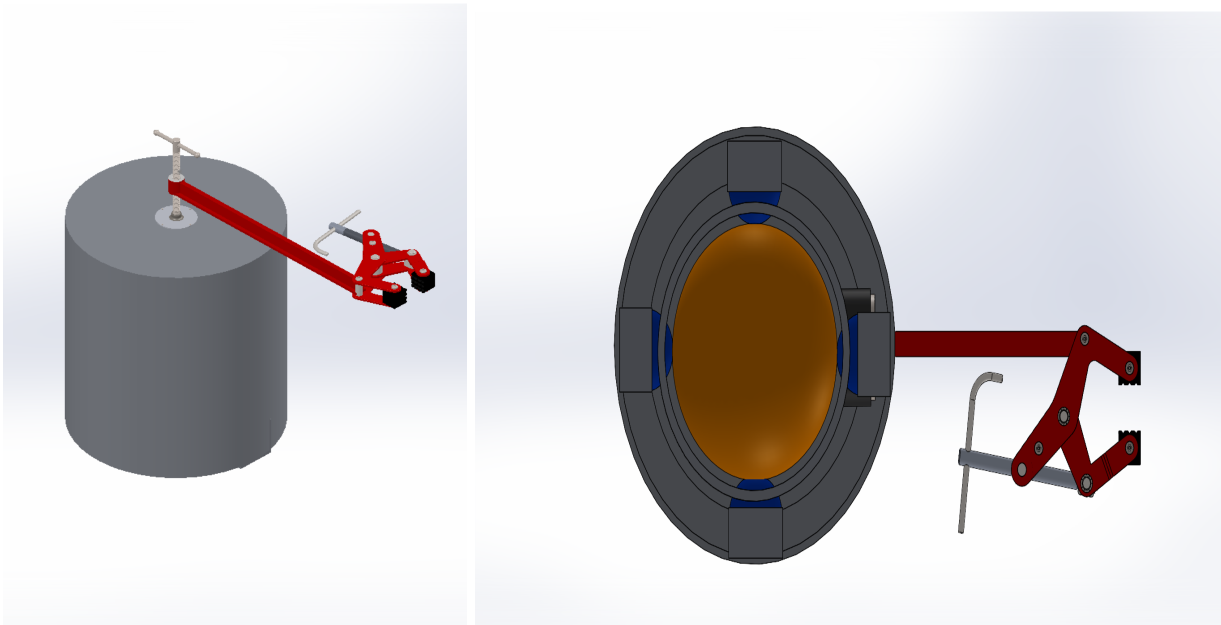

Figure 6: *External mechanical design of attachment (isometric view, bottom view)[2][3][4]*

The external casing covers the internal omnidirectional wheel system and is connected to the internal system through the ball bearing cases. As shown in figure 5, the casing covers half of the solid ball. This allows for the entire attachment to come in a shielded system which protects parts from damage as well as looks aesthetically pleasing. The frame, like most other metal components, is also to be constructed of aluminum due to its low weight and sturdiness.

There are 2 clamps on the external system as noted in figure 6 (isometric view). The clamp on top of the system is a Compressed Screw Clamp. It allows for the user to add downward force such that the ball and the attachment have good amount of contact with the ground. Not only that, it ensures the motor can easily drive the ball. The second clamp allows for the user to connect the system to the main central pillar of the office chair. The rod can vary its length by 1-5 cm to ensure fitting to multiple roller chair types.

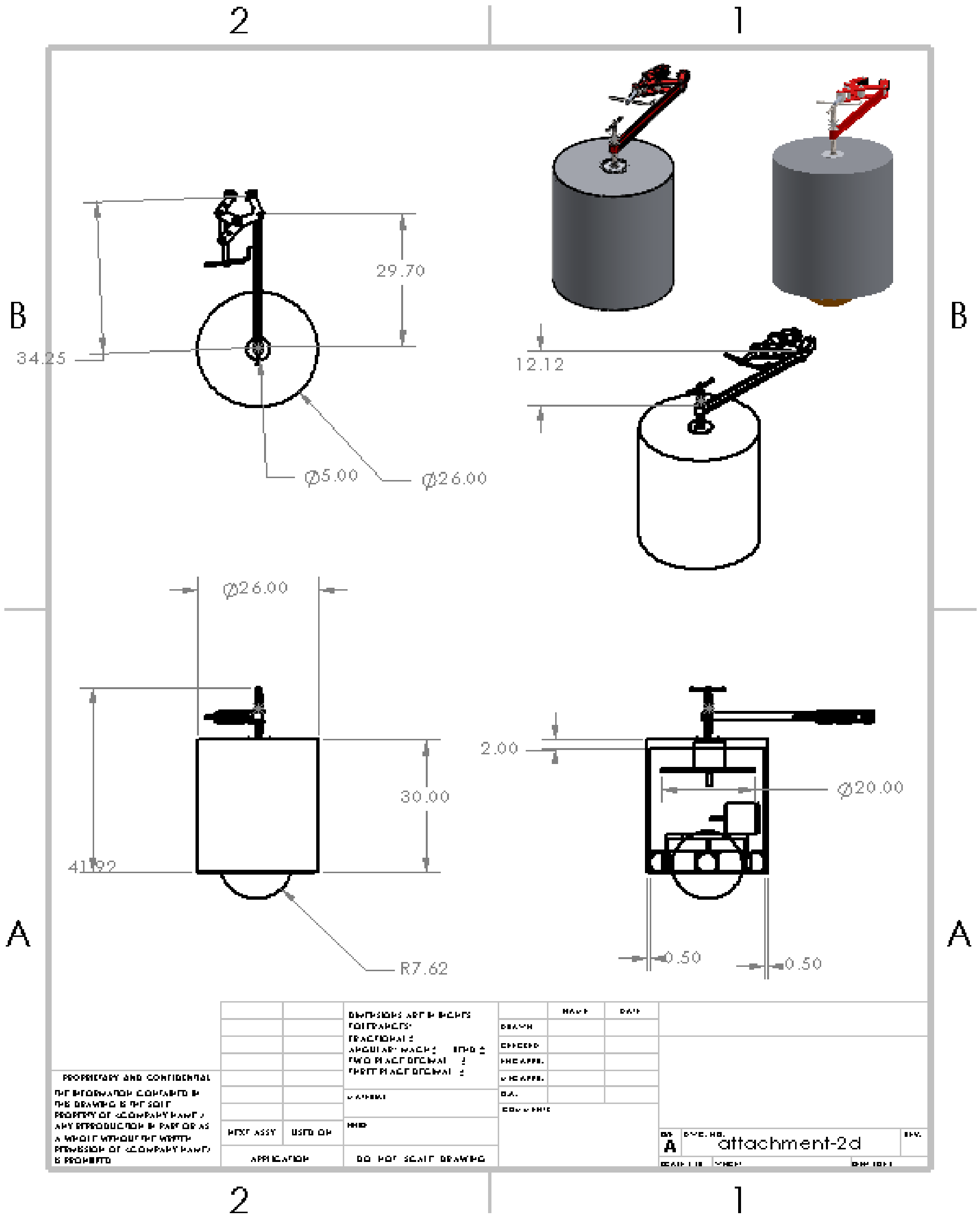

Figure 7: *Dimensions of external attachment (centimeters)[2][3][4]*

3.2 Electrical Design Specifications

Table 5 provides a general overview of all electrical specifications including motors and battery components that are required for the operation of Chairable.

Design Requirement ID	Description	Expected Changes for future Designs	Related Requirement Specifications
D 3.2.1 A	Motors must be able to provide acceleration of $2\ m/s^2$, up to a slow walking speed of $2\ m/s$.	May explore moving the device at higher speed	Req 3.1.3 B
D 3.2.2 A	Motor system consists of two motors: a main driving motor capable of moving the combined weight of user and chair and a rotational motor to alter the drive motor direction	None.	Req 3.1.4 B Req 3.1.5 B Req 3.2.3 B
D 3.2.3 A	Motor-wheel system must be able to move the weight of the office chair.	Improve design/motors to carry the combined weight of a person and a chair, weighing up to 125 kg combined.	Req 3.1.5 B
D 3.2.4 A	The batteries can safely sustain all components for a full day's use	Incorporate wall charging to reduce complexity	Req 3.3.1 A Req 3.3.2 A Req 3.3.3 B Req 3.3.4 B

Table 5: *Electrical design specifications*

3.2.1 Motor Requirements

The motor wheel system consists of a main driving motor and a rotational motor. The torque required for the primary driving motor is a function of the total mass and the gear/wheel ratio. In table 6 below, a list of specifications and accompanying constants for calculations can be found that describe Chairable.

Specification	Value	Symbol
Velocity	2m/s	v
Acceleration	2m/s^2	a
Time to accelerate to full speed	1s	t
Ball radius	3in or 0.0762m	r_b
Motor wheel radius	1in or 0.0254m	r_m
Maximum total mass (Including chair)	125kg	m
Assumed rolling resistance coefficient [18]	0.035	C_{rr}
Assumed static friction coefficient [19]	0.9	μ_s
Gravity constant	9.8m/s^2	g

Table 6: *Required specifications and constants*

Given these values, the following calculations can be made:

1. **RPM**

   RPM will be a function of the velocity and wheel size:

$$RPM = \frac{60\ revolutions}{1\ second} \cdot \frac{v}{2\pi \cdot r_w} = \frac{60 \cdot \frac{2m}{s}}{2\pi \cdot 0.0762\text{m}} \approx 250\ rev/min$$

Equation 1: *RPM requirements*

2. **Force**

   To meet the specifications of 2m/s^2 acceleration capable of pushing 125kg, the force required to start the system from rest can be calculated as:

$$F_m = m \cdot a = 125kg \cdot 2m/s^2 = 250N$$

Equation 2: *Static Force requirements*

   The force required to keep the system rolling given a rolling resistance coefficient of 0.035, as taken from a study of castor wheels on a hard surface, can also be calculated [18]. This assumes that a significant portion of the normal force is placed on Chairable's mechanism and the existing chair castors are used primarily for stabilization.

$$F_r = m \cdot g \cdot C_{rr} = 125kg \cdot 9.8m/s^2 \cdot 0.035 \approx 43N$$

Equation 3: *Rolling Resistance Force requirements of drive motor*

   For the purposes of the analysis, the force required to start the system from rest will be used.

3. **Torque**

   From here, the Torque required can be calculated as a function of the spherical wheel radius to motor wheel radius ratio, the coefficient of friction, and force required:

$$\tau_m = \frac{r_b \cdot F \cdot \sin(\emptyset)}{\mu_s} \cdot \frac{r_m}{r_b} = \frac{0.0762m \cdot 250N \cdot \sin(90°)}{0.9} \cdot \frac{0.0254m}{0.0762m} \approx 7.05N \cdot m$$

Equation 4: *Torque requirements of drive motor*

4. **Motor Power**

   Given the calculated torque requirements as well as the RPM requirements, the power requirements are calculated to be:

$$P_m = \frac{2\pi \cdot \tau_m \cdot RPM}{60} = \frac{2\pi \cdot (7.05N \cdot m) \cdot 250rev/min}{60} \approx 185W$$

Equation 5: *Power requirements of drive motor*

3.2.2 Driver Motor Selection

The above calculated requirements can be further reduced with the assistance of gear ratios. However, as cost is an important aspect of the device, finding a motor with these requirements is relatively simple and cost-effective due to the hobby and RC enthusiast community. High powered motors in this category are often priced lower than motors more closely matching the calculated specifications due to existing demand and large supply. Therefore a high power motor can be selected to run below its maximum rated specifications to achieve maximum efficiency and a low power consumption.

As such, the Turnigy Aerodrive SK3 - 6364-190KV Brushless Outrunner Motor has been selected. Figure 8 shows that when this motor is run below its rated specification, there are benefits of increased power efficiency, which is maximum around a torque value of roughly 16kg·cm.

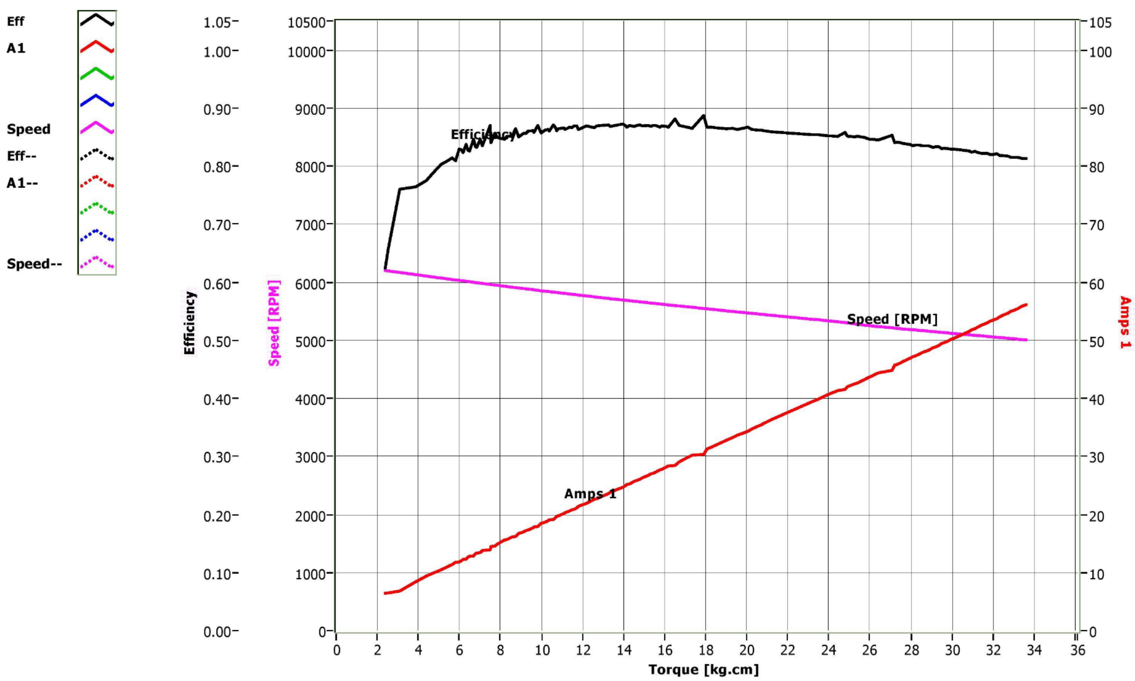

Figure 8: *Torque-amperage efficiency curve for SK3 - 6364-190KV brushless motor [20]*

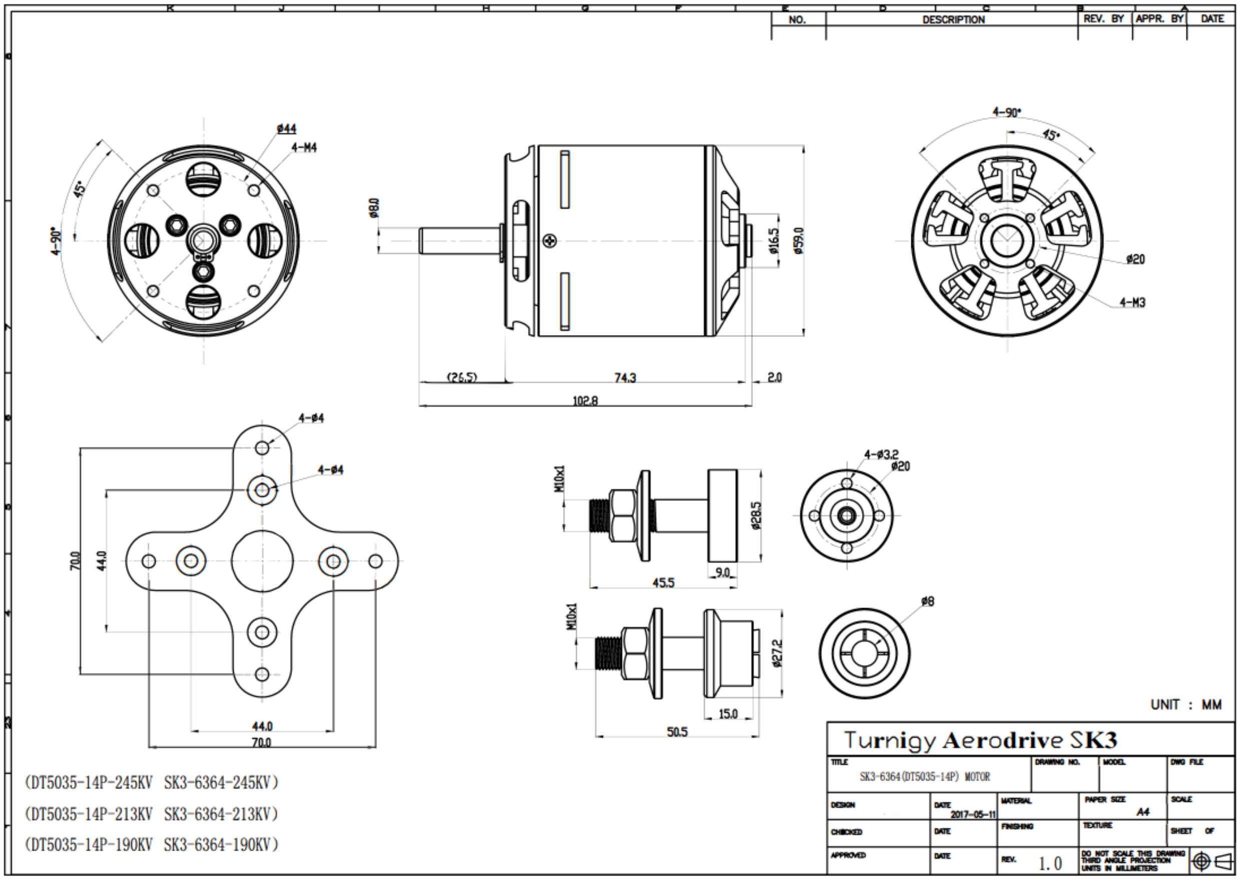

Figure 9: *Dimensions of SK3 - 6364-190KV brushless motor including bearings [1]*

Item	Specification
Shaft Length (mm)	8.00
Length (mm)	73.00
Can Diameter (mm)	63.00
Can Length (mm)	64.00
Total Length (mm)	103.00
Max Current (A)	65.00
Max Voltage (V)	37.00
Resistance (mh)	0.00
Power (W)	2450.00
Kv (rpm/V)	190

Maximum RPM	7030
Turns (T)	18
Battery Type (Maximum)	10S LiPo
Internal resistance (Ohm)	0.028
Bolt holes (mm)	32mm
Bolt thread	M4
Weight (g)	697
Motor Plug	4mm Bullet Connector
Motor Polarity	14–pole

Table 7: *Specifications of the SK3 - 6364-190KV brushless motor [1]*

3.2.3 Rotational Motor selection

The rotational motor requirements are significantly reduced compared to the driver motor as it only requires enough power to rotate the driver motor. For this device, the JGB37-545 has been selected due to its balance of cost, torque, and power requirements.

Item	Specification
Operating Voltage (V)	12 ~ 36
Nominal Voltage (V)	24
Free-run speed at 24V (RPM)	12
Free-run current at 24V (mA)	135
Stall Current at 24V (A)	3
Stall torque at 24V (kg.cm)	76
Gear ratio	1:506
Weight (g)	280

Table 8: *Specifications of the JGB37-545 gear motor [2]*

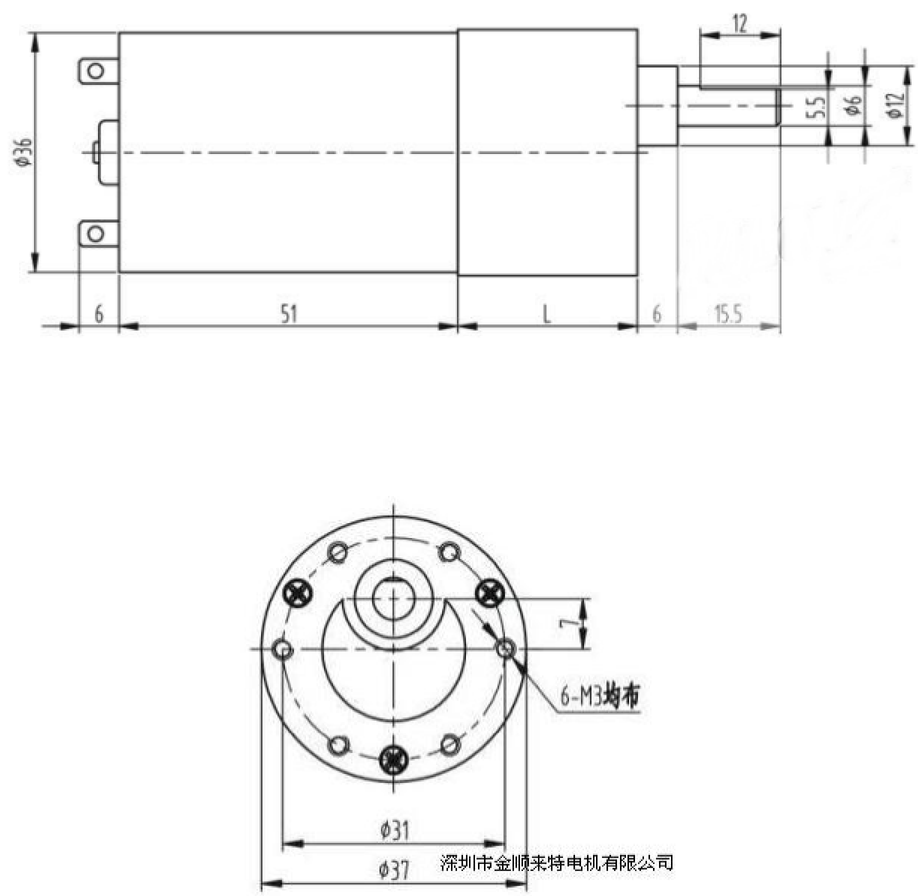

Figure 10: *Dimensions of the JGB37-545 gear motor [2]*

3.2.4 Battery Selection

To power the overall circuit, a Lithium Polymer (Lipo) Battery has been selected due to its balance between energy density, capacity, environmental impact, and cost. The ZIPPY Compact 5000mAh 6S1P 30C Lipo Pack w/XT90 has been selected to balance the voltage and current requirements as well as cost requirements. Higher voltage 12s Lipo batteries could have been selected, however due to their high cost for equivalent capacity and low availability, a 6s cell was chosen instead. Additionally, this battery can power the driver motor safely without the need to introduce DC to DC converters or additional circuitry.

Item	Specification
Capacity (mAh)	5000.00
Max Charge Rate (C)	2.00
Discharge (c)	30.00
Peak Discharge (10sec) (c)	60.00
Length A (mm)	144.00
Height B (mm)	51.00
Width C (mm)	50.00
Configuration	6S1P
Voltage (V)	22.2
Cell Count	6
Weight (g)	730
Charge Plug	JST-XH
Discharge Plug	XT90

Table 9: *Specifications of the ZIPPY Compact 5000mAh 6S1P 30C LiPo Battery [3]*

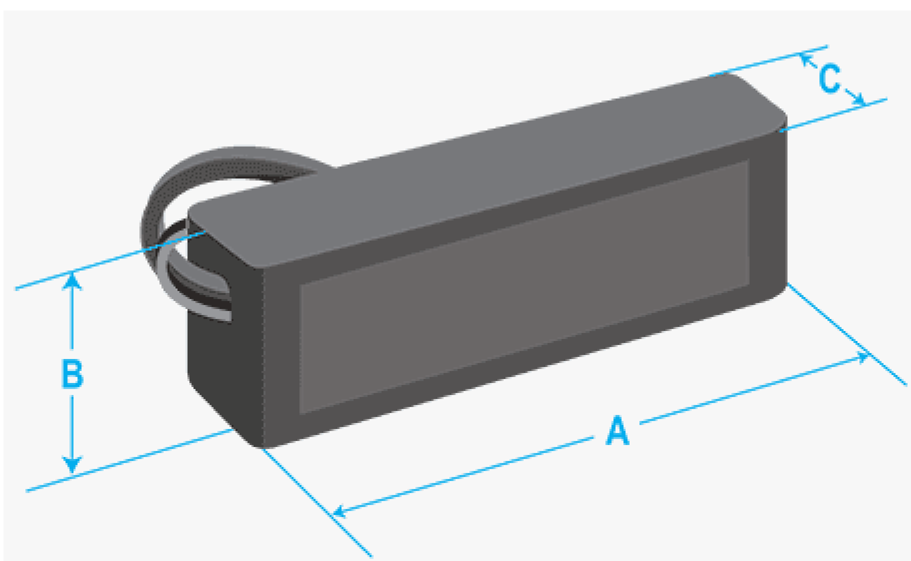

Figure 11: *Dimensions of the ZIPPY compact 5000mAh 6S1P 30C LiPo battery [3]*

This battery can be calculated to give the following charge given the motor's specifications:

$$I = \frac{P}{V} = \frac{185W}{22.2V} = 8.3A$$

Equation 6: *Current requirements with given power calculations*

However, this value will be reduced using gear ratios to match the required output rpm as supplying a voltage of 22.2V will give an RPM value of 3307.8 RPM instead of the required 250RPM.

$$RPM = V \cdot kV = 22.2V \cdot 149\, {}^{rpm}/_{V} = 3307.8\ RPM$$

Equation 7: *RPM output for given battery voltage input*

See section 3.2.5 for a detailed explanation of the required gear ratio.

By using a gear system, the total torque requirements, power consumption, and current consumption of the main driver motor system reduces to the following values:

$$\tau_o = \tau_m \cdot Gear\ Ratio = (7.05N \cdot m) \cdot \frac{1250}{5513} \approx 1.6N \cdot m = 16.3kg \cdot cm$$

Equation 8: *Adjusted drive motor torque requirements with gear system*

Note: From the earlier torque efficiency curve graph presented in section 3.2.2, optimal efficiency is achieved using this calculated gear ratio and power requirements of ~16.3kg.cm.

$$P_o = \frac{2\pi \cdot \tau_o \cdot RPM}{60} = \frac{2\pi \cdot (1.6N \cdot m) \cdot 250rev/min}{60} \approx 42W$$

Equation 9: *Adjusted drive motor power requirements with gear system*

$$I_{drive} = \frac{P}{V} = \frac{42W}{22.2V} = 1.9A$$

Equation 10: *Adjusted drive motor current requirements with gear system*

The rotational motor will draw a maximum of 2A. The arduino Uno and other circuit components will draw a combined maximum of 1A. Therefore, the total current draw is:

$$I_T = I_{drive} + I_{rotational} + I_{arduino} = 1.9A + 2A + 1A = 4.9A$$

Equation 11: *Maximum current draw for the system under load*

Therefore, the 5000mAh capacity of the battery will provide approximately an hour of continuous run time throughout the day.

3.2.4 Battery Charger

A standard 6 cell Balance Charger can be used for recharging the device in the engineering product stage. The Turnigy Accucel 6 Balance Charger has been selected due to its low cost and compatibility with the selected battery. This charger will be able to fully charge the selected battery given a full hour of charging time.

Figure 12: *Turnigy Accucel 6 balance charger [4]*

3.2.5 Gear Ratio Calculations

To reduce the output of 3307.8 RPM, a gear box system is used to reduce the speed and power requirement.

$$Gear\ Ratio = \frac{Wheel\ Torque}{Motor\ Torque} \cdot \frac{Sphere\ Radius}{Motor\ Wheel\ Radius} = \frac{250RPM}{3307.8RPM} \cdot \frac{0.0762\text{m}}{0.0254\text{m}} = \frac{1250}{5513} \approx \frac{1}{4}$$

Equation 12: *Gear ratio to achieve required RPM*

Therefore a gear ratio of approximately ¼ will be used.

3.3 Circuit Design Specifications

Design Requirement ID	Description	Expected Changes for future Designs	Related Requirement Specifications
D 3.3.1 A	The two microcontrollers should be able to communicate from a range of under a meter without losing connection	Using a Wi-Fi module instead of the RF module.	Req 3.4.4 A Req 3.4.5 A
D 3.3.2 A	The Motors should be linearly controlled and provide responsive throttling in both clockwise and counterclockwise directions	None.	Req 3.4.2 A Req 3.4.3 A
D 3.3.3 A	The user controller should consist of a joystick, status leds, and a power switch	Each Led should be labeled with the corresponding color code	Req 3.1.1 A Req 3.1.2 A Req 3.1.6 B
D 3.3.4 A	The user controller should be able to fit comfortably in the user's hand	A custom casing that incorporates the ability to easily change batteries	Req 3.1.2 A
D 3.3.5 A	Drive and controller circuit should use components that have an operating voltage range consistent with the voltage supplied	None.	Req 3.3.2 A
D 3.3. B	Device power and control wires should be routed to allow full range of motion regardless of rotational orientation	None.	Req 3.1.4 B Req 3.3.5 B

Table 10: *Circuit design specifications*

3.3.1 Driving Control System

The Chairable driving control system circuit diagram is shown in figure 13 below.

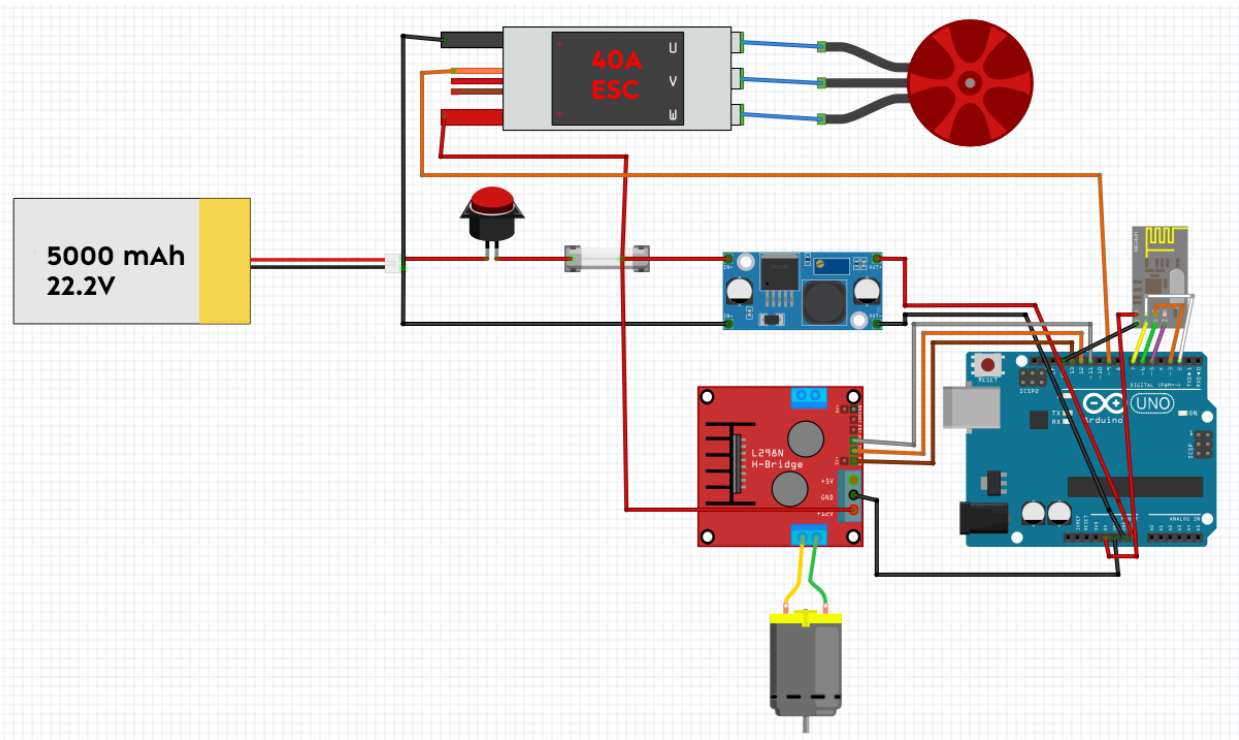

Figure 13: *Overall circuit diagram for the main motor-wheel system*

This control system uses an Arduino Uno microcontroller to control motor speed and communicate with the various power delivery circuits. This system is powered off the single LiPo battery and uses a LM2596 DC-DC Step-Down Voltage Regulator to adjust the battery output voltage of 22.2V to the Arduino's required voltage of 7V.

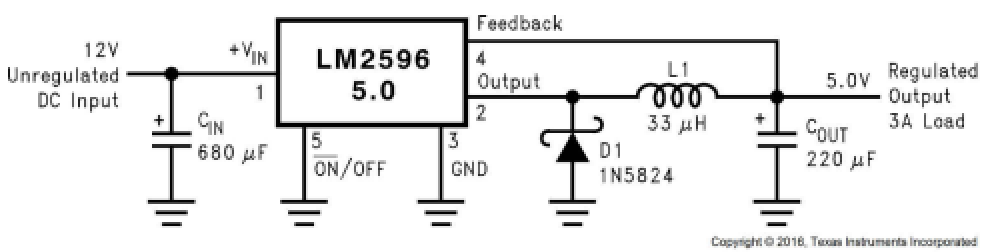

Figure 14: *Schematic for LM2596 DC-DC step-down voltage regulator [21]*

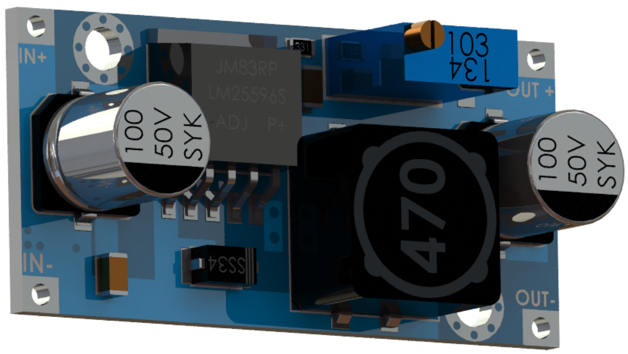

Figure 15: *CAD rendering for LM2596 DC-DC step-down voltage regulator [22]*

Item	Specification
Input Voltage Range (V)	4.5 ~ 40
Output Voltage Range (V)	1.25 ~ 37
Stable Output Current (A)	2.00
Maximum Output Current (A)	3.00
Low power standby current draw (μA)	80
PCB Dimensions (mm)	14.986 x 10.16
Operating temperature (℃)	-40 ~ 125
Efficiency	73%

Table 11: *Specifications for LM2596 DC-DC step-down voltage regulator [21]*

The rotational motor is controlled using the L298N Motor Driver module. This allows for bidirectional rotation and is directly connected to the Arduino Uno for both 5V logic power and PWM control signals.

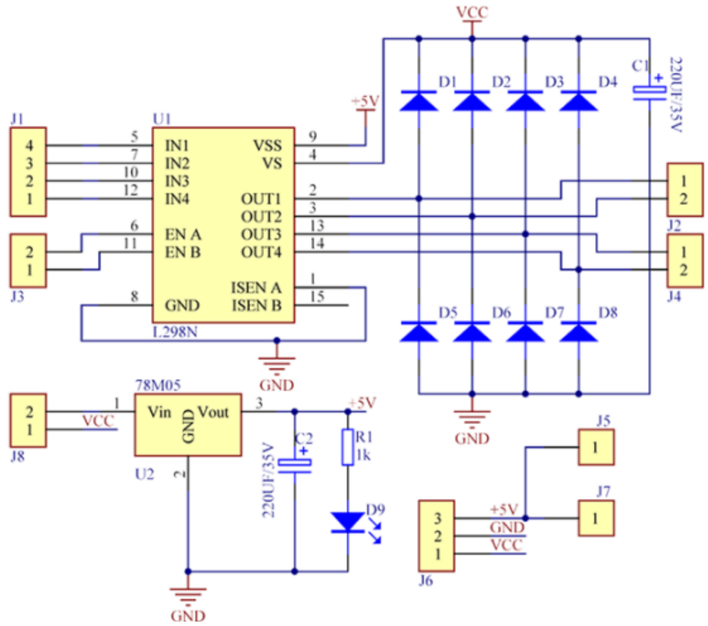

Figure 16: *Schematic for L298N motor driver [23]*

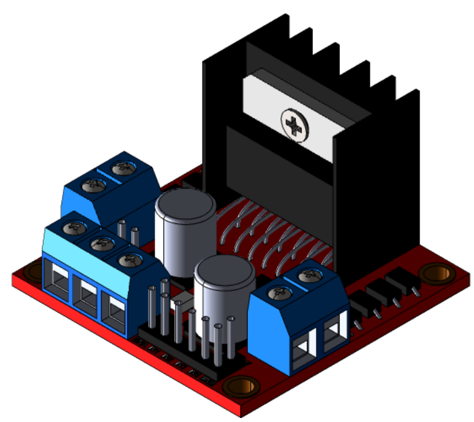

Figure 17: *CAD rendering for L298N motor driver [24]*

Item	Specification
Driver Voltage Range (V)	5 ~ 35
Motor Supply Voltage Maximum (V)	46
Driver Current (A)	2.00
Motor Supply Current Maximum (A)	2.00
Logic Voltage (V)	5.00
Logical Current Range (mA)	0 - 36

Maximum Power (W)	25W
Control signal Low Range (V)	-0.3 ~ 1.5
Control signal High Range (V)	2.3 ~ Vss
Operating temperature (℃)	-25 ~ 130
PCB Dimensions (mm)	34 x 43 x 27

Table 12: *Specifications for L298N motor driver [23]*

The main driver motor is controlled with a bidirectional ESC that regulates the motor's power and RPM. This ESC communicates with the Arduino Uno via a PWM control signal.

Figure 18: *Readytosky bidirectional 40A brushless ESC [8]*

Item	Specification
Maximum Current (A)	40
Voltage Range (V)	7.4 ~ 22.2
UBEC Voltage output (V)	5.00
UBEC Current output (A)	3A
Direction Mode	Bidirectional

Table 13: *Specifications for Readytosky bidirectional 40A brushless ESC [8]*

To account for safety specifications, Chairable has two systems in place. First, the driver circuit is equipped with an emergency stop button which physically disconnects the battery from the rest of the circuit. In the event of an emergency, a user may manually hit the emergency stop button and immediately bring the system to a halt.

Figure 19: *Emergency stop push button [10]*

Additionally, to prevent overcurrent scenarios, the driver circuit is also equipped with a 30A fuse to protect the circuit in the event of an unintentional overload. This will ensure that the 40A ESC controlling the main driving motor is protected, while providing plenty of overhead for the typical current draw of the system.

Figure 20: *30A fuse with protective casing [12]*

To communicate with the remote control system, the nRF24L01 RF module has been incorporated into the driving system and interfaces with the Arduino Uno. This RF module exhibits a low maximum current draw of 13.5 mA, which further decreases to below 0.1 mA in standby mode [25]. The module also supports data transfer rates of up to 2 Mbps, which is ample for the application [25]. The weight and size of the module is also negligible.

Item	Specification
Operating Voltage (V)	1.9 ~ 3.3
Receiving Max Current Draw (mA)	13.5
Transmitting Max Current Draw (mA)	11.3
Air Data Transfer Rate(s) (Mbps)	0.25, 1, 2

Table 14: *nRF24L01 module specs [25]*

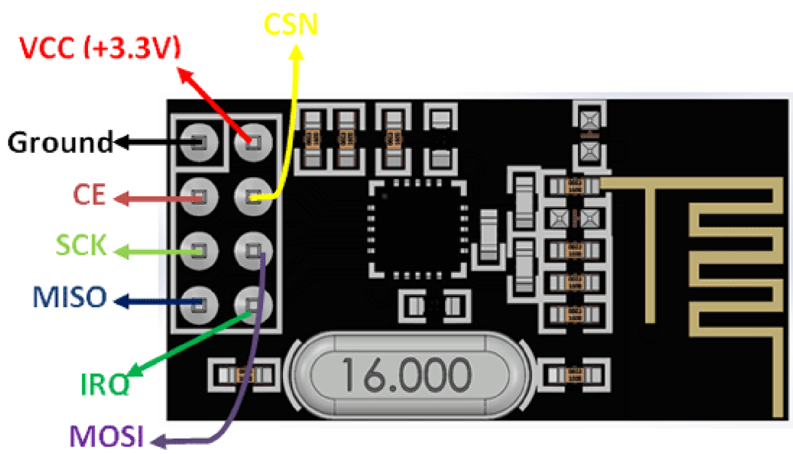

Figure 21: *nRF24L01 module pin layout [26]*

3.3.2 User Control System

Chairable's user interface consists of a small custom made remote control. This system's circuit diagram is shown below in figure 22.

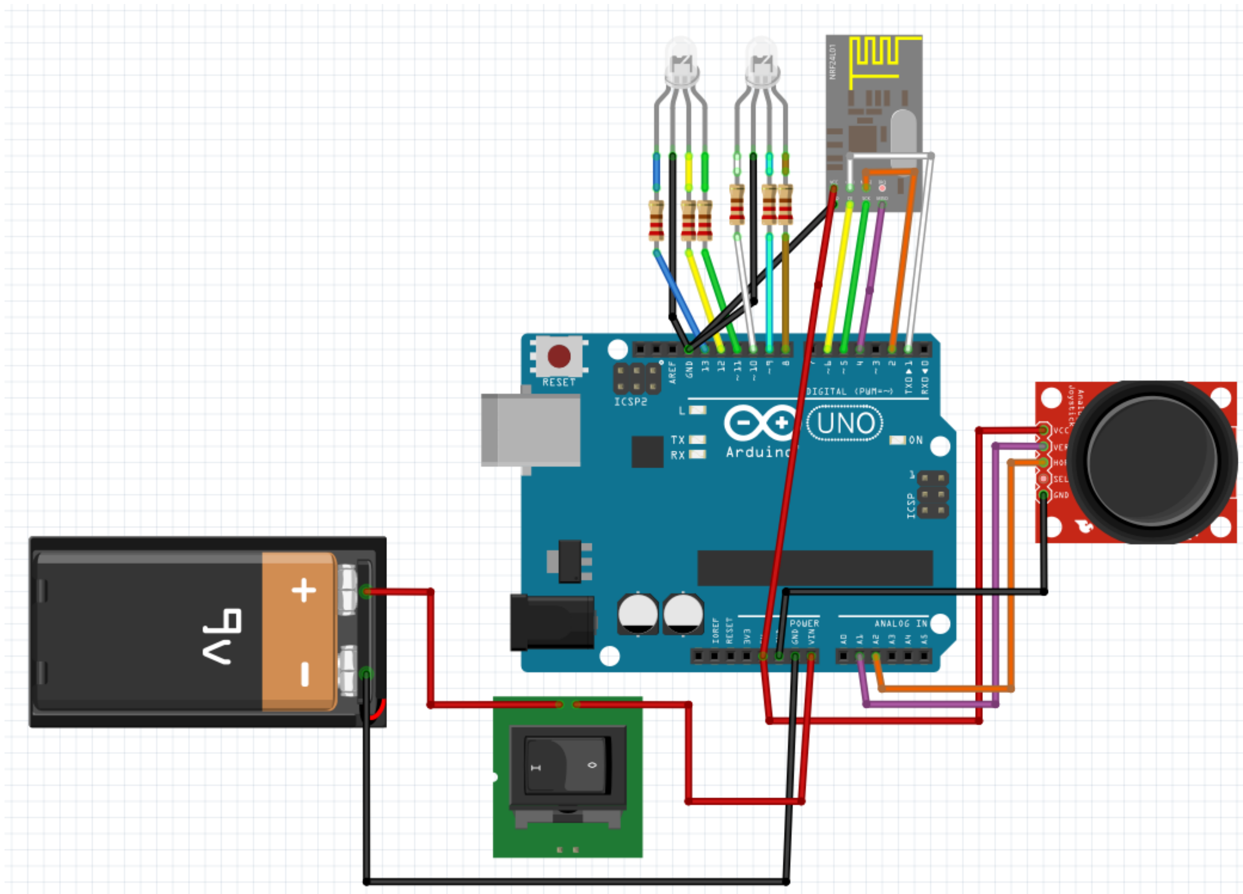

Figure 22: *Overall circuit diagram for the user controller system*

A mechanical overview of the overall controller system can be found in figure 23 below:

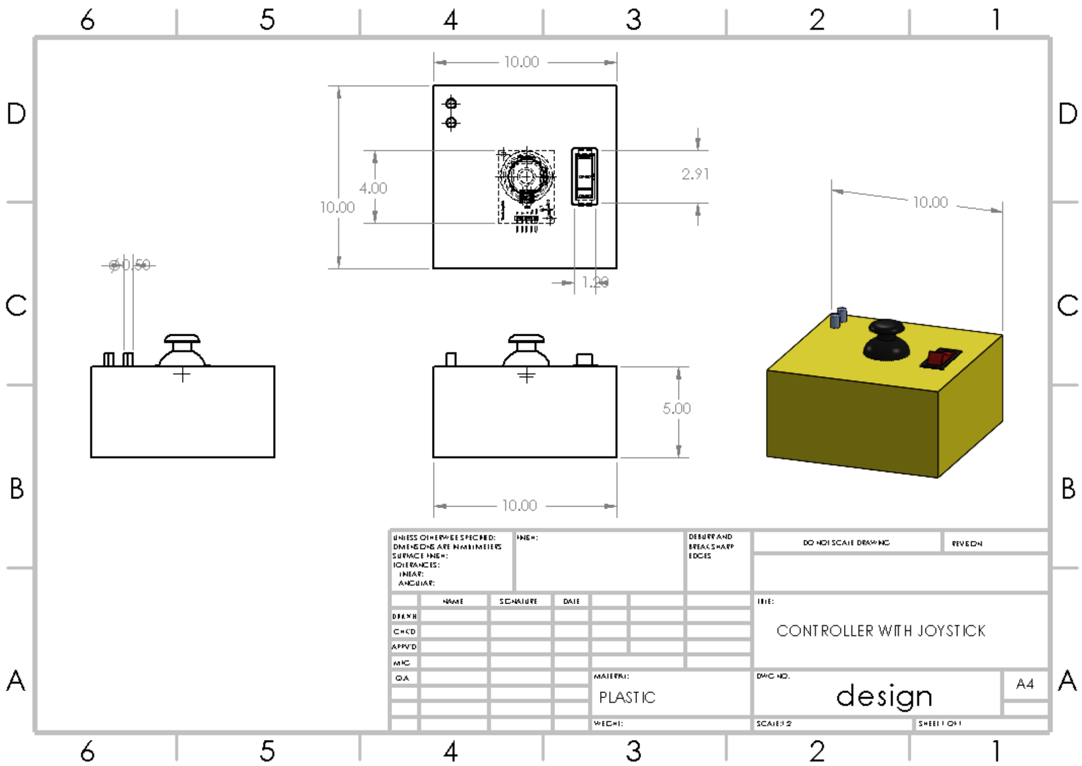

Figure 23: *CAD rendering and dimensions of user controller*

Like the main driving circuit, the controller circuit relies on the Arduino Uno microcontroller in conjunction with the nRF24L01 RF module to communicate between both circuits. To facilitate easy and efficient movement control, a PS2 joystick module has been incorporated into the design.

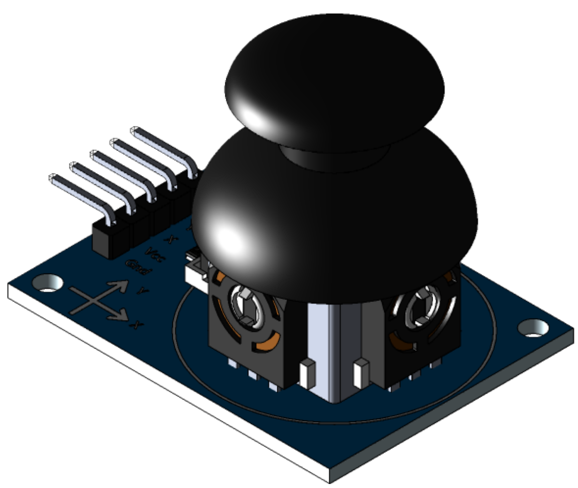

Figure 24: *CAD rendering of PS2 joystick module [27]*

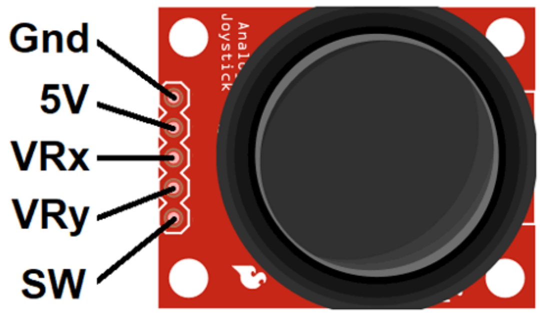

Figure 25: *PS2 joystick module pinout [28]*

Item	Specification
Operating Voltage (V)	5
Internal Potentiometer resistance (Ohms)	10k
Operating temperature (℃)	0 ~ 70
Dimensions (mm)	40 x 26 x 32

Table 15: *Specifications for the PS2 joystick module [28]*

The user controller component contains 2 LEDs, one that displays when the system is moving and one for the battery status. Chairable will utilize RGB 4-Pin LED diodes that allow for multiple colors using the same LED, with a maximum current draw of 20 mA [29]. This current draw is low enough to maintain low power usage, and the weight/size of the LEDs is negligible.

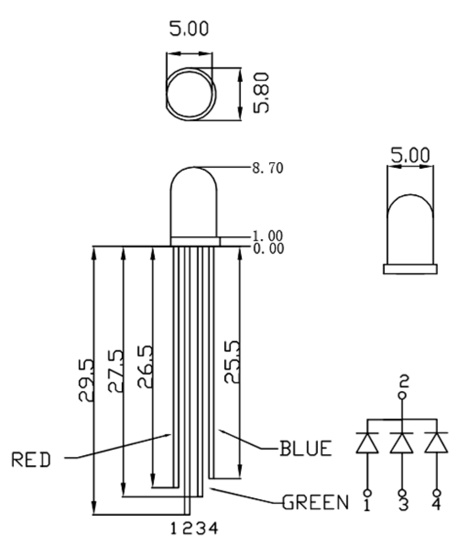

Figure 26: *2D model of the RGB LED [29]*

Pin No.	Description
1	Controls the Red color of the LED
2	Ground
3	Controls the Green color of the LED
4	Controls the Blue color of the LED

Table 16: *pin-layout for the RGB LED [29]*

3.4 Software Design Specifications

Design Requirement ID	Description	Expected Changes for future Designs	Related Requirement Specifications
D 3.3.1 A	The microcontroller maps the input from the attached joystick to the corresponding direction, and then provides correct instructions to the microcontroller.	None	Req 3.4.2 A
D 3.3.2 A	The microcontroller maps the input from the attached joystick to the corresponding speed, and then provides correct instructions to the microcontroller.	None	Req 3.4.1 A
D 3.3.3 A	RF communication is used to send signals between the microcontroller and the motor controller.	Using a Wi-Fi module instead of the RF module.	Req 3.4.4 A, Req 3.4.5 A
D 3.3.4 A	The microcontroller turns on the battery LED to the correct color based on the status of the battery.	None	Req 3.3.1 A, Req 3.1.6 B
D 3.3.5 A	The microcontroller will activate the movement LED when the device is moving.	None	Req 3.1.6 B

Table 17: *Software design specifications*

3.4.1 User Input Mapping - Joystick Control

The main function of the software in Chairable is to interpret user input and translate it into direction and speed commands. With two motors being operated by a single joystick, the software converts the input from the joystick into instructions that can be understood by the motor controller in order to achieve the desired outcome. The motor controller then sends a PWM signal to each motor to control their direction and speed. The primary driving motor controls the speed based on the distance from the joystick's center in the corresponding direction, enabling it to move the chair. On the other hand, the rotational motor utilizes the X and Y input of the joystick to determine the desired direction for rotation.

3.4.2 RF Communication

Chairable will integrate wireless technology, eliminating the need for a direct wired connection between the user controller component, which includes the joystick and a microcontroller, and the motor controller component, which consists of another microcontroller and the motor driver. This wireless configuration mitigates the risk of wire tangling and potential breakage, providing the flexibility to adjust and attach the controller to either side of the chair without requiring extra caution. The two microcontrollers will each be connected to a RF module. The RF module, nRF24L01, is a transceiver, allowing for two-way communication. This module is operated and configured via a SPI (serial peripheral interface). To facilitate communication between the two devices, the software will utilize several libraries. The RF24 library, a radio driver library, provides functions for nRF24L01 based communication [30]. The SPI library will also be used, which allows for serial port interfacing with the microcontroller as the driver [31]. The microcontroller connected to the user controller component will primarily use these libraries to send the user input to the other one. The second microcontroller will send the battery level, as well as some additional feedback, back to the primary microcontroller.

3.4.3 LED Control

In addition to mapping the joystick input to direction, the microcontroller, using the software, also manages the control of the LEDs. The first LED it controls is the System Movement LED. This LED is activated when the device is in motion, indicating that the microcontroller is actively receiving input and sending output signals to the motor controller. This provides the user with the active feedback on the status of the device. The states of the LED, kept simple, are shown in Table 18. The second LED it manages is the System Battery LED. This LED displays the status of the battery, with different states for when it is ample charge, low charge, and charging. The color is determined by the microcontroller and the corresponding PWM signal is sent to the LED. The states of the System Battery LED are shown in Table 19.

System	Movement LED State	LED Color
Device Off	Off	-
Device On and not moving	Off	-
Device On and moving	On	Blue

Table 18*: Movement LED's different states and colors*

System	Movement LED State	LED Color
Device Off	Off	-
Device On with sufficient charge	On	Green
Device On with low charge	On	Red
Device On and Charging	On	Yellow

Table 19*: Battery LED's different states and colors*

4 Conclusion

RollTech seeks to provide individuals with a device that will allow them to have a fun and novel way of navigating in the office in the form of a device that will motorize a chair. This design specification document will guide the team at RollTech in the implementation and development of Chairable. The specification document lists out the mechanical, electrical and software requirements and provides the details for the reasons the requirements were selected.

Some of the requirements listed below:

1. Mechanical Requirements
    - Structural frame made out of aluminum so its lightweight and sturdy
    - Rubber driving wheel for high grip
    - Plastic Ball for omni-direction ball so it is durable
    - Small plastic balls for lateral movement of system
    - Lower supportive disk to be smooth

2. Electrical Requirements
    - Motor-wheel system must move the weight of the office chair
    - Motors should be linearly controlled and provide responsive throttling in both directions

3. Software Requirements
    - Microcontroller maps input to speed and direction then provides correct instructions to itself
    - RF communication is used to send signals between microcontroller and motor controller
    - Microcontroller will control the activation of different LEDs

The device specification document will guide the team in implementing Chairable through the proof-of-concept, engineering prototype and production stages. Chairable is an attachment that can be clamped onto the central column of an office chair in order to motorize it. Chairable is made up of two motors and a ball enclosed in a metal frame that spreads pressure evenly over the ball’s surface. The user controls chairable with a joystick that communicates with a microcontroller connected to the rotational and main motors.

RollTech will continue to develop and refine Chairable until it is able to function as expected and provide a device for users who want to experience an exciting change in a monotonous office environment.

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6 Appendix A: Design Alternatives

6.1 Input Choices

The input choice is crucial to the operation of Chairable, but is constrained by the specified requirements. As stated by Req 3.1.2, the device should be able to be controlled by a hand-operated or handheld controller. Furthermore, the user interface must be intuitive and easy to use, mentioned in Req 3.1.6. The available options for user input to control the device's movement, based on these requirements, include a joystick, a 4-button layout, and a steering wheel. The joystick was selected due to its ability to offer the user precise and accurate steering in all directions. Additionally, the joystick simplifies the fulfillment of additional requirements, such as Req. 3.4.1, which mandates the software's ability to adjust and control motor speed based on user input. The joystick not only offers intuitive control of direction but also serves as an input for controlling speed.

If a 4-button layout were chosen, with one button assigned to each direction, there would be several concerns. One such concern is that diagonal movement would require the simultaneous pressing of multiple buttons. As a result, achieving true omnidirectional navigation capabilities would be challenging, and controlling the device would not be intuitive for the user. Furthermore, an additional input for controlling speed would be required. On the contrary, while the steering wheel would offer the user excellent precision, it would likely require the use of both hands. However, using a steering wheel alone would also not address the speed control concern, and an additional input for controlling forward and reverse movement would likely be necessary.

6.2 Wheel Material

The choice of material for the wheel was crucial to consider due to its specific requirements, including the necessity for it to be shaped as a sphere/ball. Requirement 3.1.7 specifies that the wheel should provide adequate traction on common flooring materials, while Requirement 3.1.8 states that the wheel should not leave any marks on the surface floor. In order to meet these requirements, three different types of existing balls were identified as potential options for use as wheels, including an inflatable ball, a plastic ball, and a rubber ball. The plastic ball was selected as the optimal choice due to its consistency and high durability among the identified options. The inflatable option raised concerns regarding long-term usage, as it would require consistent maintenance of the psi to ensure reliable and replicable results, as deflation could adversely affect the rolling ability of the ball. Furthermore, there is a risk of puncture, rendering it unusable and potentially requiring frequent replacements. The rubber ball option also faced concerns with its usage, as it may not have been hard enough to withstand deformation, similar to the inflatable ball. Alternatively, there is the option of 3D printing a wheel instead of using an existing ball. However, this approach would be costly and offer limited room for error or testing. In contrast, the hard plastic ball provides comparable characteristics at a significantly more affordable cost and is readily available.

6.3 Frame Material

When considering the material for the device frame, trade-offs between weight, durability, and price were taken into account to determine the most suitable option for the application. As mentioned in Req 3.1.10, the device should be durable enough to withstand collisions without sustaining significant damage. The weight is constrained by Con 3.5.5, as the weight of the entire device should be under 20kg, while Con 3.5.1 specifies the entire device should be packaged for less than $800. Therefore, three options for the frame material were identified, which included wood, aluminum, and steel. Aluminum was selected as the frame material based on it offering the best balance among the traits that were considered. Aluminum is about three times stronger and three times heavier than wood, and similarly, steel is three times stronger and three times heavier than aluminum [32].

Wood, despite being the most affordable and potentially the easiest to work with, is the least durable among the other options in terms of strength. Wood has a higher likelihood of chipping and cracking, particularly given the possibility of minor collisions and the use of dynamic moving parts, making it less suitable for Chairable [33]. On the other hand, steel, with its strength, poses challenges in terms of workability and is unlikely to be effectively machined using hand tools. Therefore, it was determined that aluminum would be used for the frame as it was stronger than wood, but lighter than steel. Additionally, aluminum is relatively easy to work with and offers better aesthetics compared to wood, although the aesthetic aspect may not be important in this context.

6.4 Wireless Technology

Chairable will provide a wireless user controller to meet Req 3.3.5 B, which states that wires must not tangle or break. By going wireless, the user can adjust the user controller as preferred with no risk of wire issues, as mentioned in the design specifications. Two different technologies, RF and Wi-Fi, were explored as potential methods of implementing wireless communication. RF was selected as the method of communication due to easier implementation and low power usage. RF communication has a multitude of available libraries to facilitate device communication, while Wi-Fi boards utilize their own set of instructions and modes that can be more challenging to handle. Moreover, the RF module, nRF24L01, selected for Chairable, consumes significantly less power than an equivalent Wi-Fi board, such as the ESP8266 ESP-01, with a maximum current draw of 13.5 mA compared to up to 170 mA for the Wi-Fi board [25,34]. The mentioned RF module is also about half the cost of the Wi-Fi board, with pricing of approximately $2.50 and $4.25 per unit respectively [35,36]. Although the Wi-Fi board offers additional connection capabilities compared to the RF board, these capabilities are not advantageous for Chairable since none of its subsystems require an internet connection.

7 Appendix B: Test Plan

7.1 Introduction

This appendix consists of the test plan. The plan covers comprehensive acceptance testing of Chairable, ensuring that the product meets all specified requirements.

7.2 User Testing

The following tests will be conducted to ensure the user interface operates correctly.

<table>
<tr><td colspan="2">Test: System Movement LED</td><td>Tester:</td></tr>
<tr><td colspan="3">Testing Procedure:</td></tr>
<tr><td colspan="3">1. Attach the wheel component to the chair.
2. Attach the control component to the side of the chair, based on user preference.
3. Ensure the control component is on and the device has sufficient charge.
4. Move the joystick in any direction to move the chair.
5. Stop moving the joystick and return it to center position.</td></tr>
<tr><td colspan="3">Expected Outcome:</td></tr>
<tr><td colspan="3">The system movement LED is on when moving and off when not.</td></tr>
<tr><td colspan="3">Observed Outcome:</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Date: _____________</td><td>Time: ____:____ ___</td><td>Result: Pass/Fail</td></tr>
</table>

Test: Joystick Direction		Tester:
Testing Procedure:		
1. Attach the wheel component to the chair. 2. Attach the control component to the side of the chair, based on user preference. 3. Ensure the control component is on and the device has sufficient charge. 4. Move the joystick in any direction to move the chair.		
Expected Outcome:		
The chair should move in the same direction as the joystick.		
Observed Outcome:		
Date: ______________	Time: ____:____ ___	Result:

Test: Joystick Speed Control		Tester:
Testing Procedure:		
1. Attach the wheel component to the chair. 2. Attach the control component to the side of the chair, based on user preference. 3. Ensure the control component is on and the device has sufficient charge. 4. Move the joystick with alternating distances from the center.		
Expected Outcome:		
The chair moves at varying speeds dependent on the distance from the center, with it moving the fastest when the joystick is pushed the farthest and slowest when closest to the center.		
Observed Outcome:		
Date: ______________	Time: ____:____ ___	Result: Pass/Fail

<table>
<tr><td colspan="2">Test: Joystick Stopping Movement</td><td>Tester:</td></tr>
<tr><td colspan="3">Testing Procedure:</td></tr>
<tr><td colspan="3">1. Attach the wheel component to the chair.
2. Attach the control component to the side of the chair, based on user preference.
3. Ensure the control component is on and the device has sufficient charge.
4. Move the joystick in any direction for one second and then let go of the joystick.</td></tr>
<tr><td colspan="3">Expected Outcome:</td></tr>
<tr><td colspan="3">Once let go, the joystick returns to the center and the device stops moving.</td></tr>
<tr><td colspan="3">Observed Outcome:</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Date: ______________</td><td>Time: ____:____ ___</td><td>Result: Pass/Fail</td></tr>
</table>

<table>
<tr><td colspan="2">Test: Battery Charge LED (Charging)</td><td>Tester:</td></tr>
<tr><td colspan="3">Testing Procedure:</td></tr>
<tr><td colspan="3">1. Connect all components.
2. Attach the charger to the device and plug into the outlet.</td></tr>
<tr><td colspan="3">Expected Outcome:</td></tr>
<tr><td colspan="3">The system battery LED is on and yellow.</td></tr>
<tr><td colspan="3">Observed Outcome:</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Date: ______________</td><td>Time: ____:____ ___</td><td>Result: Pass/Fail</td></tr>
</table>

Test: Battery Charge LED (Battery Level)			Tester:
Testing Procedure:			
1. Connect all components. 2. Turn the power on using the switch on the control component. 3. Measure the voltage of the battery to determine charge. 4. Repeat the test to ensure a wide range of voltage measurements has been covered.			
Expected Outcome:			
The system battery LED is the correct color based on battery charge measured.			
Observed Outcome:			
Date: ______________	Time: ____:____ ___		Result: Pass/Fail

7.3 Electrical Testing

The following tests will ensure the correct functioning of the electrical components.

Test: Power On			Tester:
Testing Procedure:			
1. Connect all components. 2. Turn the power on using the switch on the controller component. 3. Move the joystick in any direction.			
Expected Outcome:			
Device turns on: battery LED on, joystick moves device, and movement LED on when moving.			
Observed Outcome:			
Date: ______________	Time: ____:____ ___		Result: Pass/Fail

Test: Power Off		Tester:
Testing Procedure:		
1. Connect all components. 2. Turn the power on using the switch on the controller component. 3. Move the joystick in any direction. 4. While moving the joystick, turn off the device.		
Expected Outcome:		
Device stops moving and turns off: joystick back to center once let go, all LEDs off.		
Observed Outcome:		
Date: ______________	Time: ____:____ ___	Result: Pass/Fail

Test: Battery Charging		Tester:
Testing Procedure:		
1. Make sure the battery has low power (<10%). 2. Attach the battery to the charging circuit. 3. Take voltage measurements of the battery at 15 minute intervals. 4. Leave on charge until power is full.		
Expected Outcome:		
The battery increases in charge, taking a couple of hours to reach full charge. At this point the charging circuit stops charging the battery.		
Observed Outcome:		
Date: ______________	Time: ____:____ ___	Result: Pass/Fail

7.4 Mechanical Testing

These tests will be executed to ensure the accurate operation of the mechanical components.

Test: Footrest Adjustability/Strength		Tester:
Testing Procedure:		
1. Attach the clamp and footrest components to the chair. 2. Adjust the position of the footrest to various positions. 3. Sit on the chair and use the footrest.		
Expected Outcome:		
The footrest allows moderate adjustability and has sufficient strength to hold position with the weight of feet.		
Observed Outcome:		
Date: ______________	Time: ____:____ ___	Result: Pass/Fail

Test: Clamp Strength		Tester:
Testing Procedure:		
4. Attach the clamp of the wheel component to the chair. 5. Test the strength of the clamp by applying slight force in all directions.		
Expected Outcome:		
When force is applied, clamp remains attached and exhibits little to no movement.		
Observed Outcome:		
Date: ______________	Time: ____:____ ___	Result: Pass/Fail

Test: Friction On Floor			Tester:
Testing Procedure:			
1. Attach all components to the chair. 2. Turn the power on using the switch on the control component. 3. Move the device and the chair, using the joystick, in varying directions and speeds.			
Expected Outcome:			
The device is able to maintain near constant friction with the floor without slips.			
Observed Outcome:			
Date: ______________	Time: ____:____ ___		Result: Pass/Fail

7.5 Software Testing

The following series of tests will be performed to validate the operation of the software components.

Test: RF Communication (Wireless Joystick)			Tester:
Testing Procedure:			
1. Turn on the joystick and confirm if it is connected to the transmitter microcontroller. 2. Connect the motors to the receiver microcontroller. 3. Turn on both microcontrollers. 4. Run test code. 5. Move the joystick.			
Expected Outcome:			
The motors should move in the same direction/speed as the input with minimal delay.			
Observed Outcome:			
Date: ______________	Time: ____:____ ___		Result: Pass/Fail

<table>
<tr><td colspan="3">Test: Joystick Software Mapping</td><td>Tester:</td></tr>
<tr><td colspan="4">Testing Procedure:</td></tr>
<tr><td colspan="4">1. Turn on the joystick and confirm if it is connected to the microcontroller.
2. Turn on the microcontroller and ensure it is connected to the computer.
3. Run test code.
4. Move the joystick in different directions and distances from the center.</td></tr>
<tr><td colspan="4">Expected Outcome:</td></tr>
<tr><td colspan="4">The test code should display the corresponding input/direction from the joystick.</td></tr>
<tr><td colspan="4">Observed Outcome:</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Date: ______________</td><td colspan="2">Time: ____:____ ___</td><td>Result: Pass/Fail</td></tr>
</table>

<table>
<tr><td colspan="3">Test: Motor Direction/Speed Software Mapping</td><td>Tester:</td></tr>
<tr><td colspan="4">Testing Procedure:</td></tr>
<tr><td colspan="4">1. Turn on the joystick and confirm if it is connected to the microcontroller.
2. Connect the motors to the microcontroller.
3. Turn on the microcontroller and ensure it is connected to the computer.
4. Run test code.
5. Move the joystick in different directions and distances from the center.</td></tr>
<tr><td colspan="4">Expected Outcome:</td></tr>
<tr><td colspan="4">The motors should move in the same direction/speed as the joystick input.</td></tr>
<tr><td colspan="4">Observed Outcome:</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Date: ______________</td><td colspan="2">Time: ____:____ ___</td><td>Result: Pass/Fail</td></tr>
</table>