March 26, 2021
Dr. Craig Scratchley
School of Engineering Science
Simon Fraser University
Burnaby, BC, V5A 1S6

Re: ENSC 405 Design Specification for Rise's *Roll24*

Dear Dr. Scratchley,

Please find attached to this letter the design specifications document for Rise's Roll24. This purpose of this document is to specify the design requirements for Roll24, an automated solution for rotating a bedbound patient. Roll24 will use machine learning to recognize a patient's posture and position on the bed and periodically rotate them using software and a microcontroller. This product is a low-cost solution to improve a patient's wellbeing.

This design specifications document first introduces the overall product design, then outlines the software, hardware, and mechanical subcomponents of the system. This document will detail how the *Roll24* product intends to use the Kinect V2 camera to monitor the patient, the circuit schematics of the system, the hardware used to control the rotation, and the physical design of the *Roll24* product. This document will also describe how the subsystems will communicate and interact with each other.

Our team consists of five senior engineering students in the SFU program – Jonathan Choy, Joon Kwon, Wilson Liu, Tyler Rasmussen, and Himson Chick. Our diverse team is made up of students in Computer Engineering, Systems Engineering and Electronics Engineering.

Thank you for reviewing this design specifications document. If you have any questions or concerns, please contact our Chief Communications Officer, Wilson Liu, through Canvas, Company 4's Gitlab, or through email at yla361@sfu.ca.

Sincerely,

Himson Chick
Chief Executive Officer
Rise

Requirements Specifications

For

Roll24

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Submitted To	DR. CRAIG SCRATCHLEY	ENSC405W
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Abstract

This document will provide the design specifications for Rise's autonomous bedsore relieving device, the *Roll24*. The *Roll24* design is split into 3 main categories, software, hardware and mechanical. Outlined below are the components involved in each category:

Patient Monitor

1. Kinect V2 for depth and IR capabilities to detect skeletal structure of the patient, location of the patient and the boundaries of the bed.
2. The processed raw image data is used to determine the activity of the motor based on the patient's safety.

Hardware

1. Stepper motors used to move the aluminum frames necessary to roll the patient
2. Microcontroller which receives data resulting from the Kinect V2 depth sensor which then controls the stepper motors
3. Control panel to setup the device and provide options such as time intervals for rotating patients

Mechanical

1. Aluminum T-slot frames to mount the hardware to the bed and adjust the sling which is used to roll the patients onto their side

The *Roll24* takes inspiration from the motions performed by health care givers in hospitals to rotate a patient and with the use of sensors, motors, and metal structures; create an autonomous device capable of performing the same action which would then allow the health care givers to focus on more dire tasks. The main task of replicating the rolling motions and achieving device autonomy assists the team of experienced engineers at Rise with constraints that helps narrow down the design choices when selecting the appropriate components. The design choices made, components selected and their justification to meet our objective are laid out within this document.

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1 Introduction

1.1 Background

Bed sores are serious problems for elderly [1]. "Pressure injuries are listed as the direct cause of death in 7-8% of all patients with paraplegia. As many as one third of hospitalized patients with pressure injuries die during their hospitalization. More than half of those who develop a pressure injury in the hospital will die within the next 12 months." [1]. Our solution is aimed at tackling this problem in residential setting by fully automating the rotation of patients through the night while caretakers are not available. There are other similar products in the market but are extremely expensive [2]. Our goal is to create an affordable, automated option that can work for many bedbound patients in residential setting.

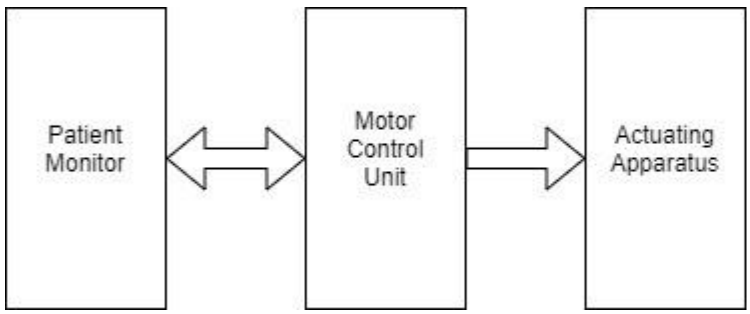


Figure 1: *Roll24* Block Diagram

1.2 Scope

This document provides the technical specifications for the design choices made for the *Roll24.* The design choices made are with respect to the functional requirements outlined in the Requirement Specifications [3] document for the *Roll24* and the technical specifications expands on those design choices. The three categories, Software, Hardware, and Mechanical for the *Roll24* will consists of design choices, justification, and the technology and physical components used.

Attached at the end of the document in the appendix is a User Interface and Design section that addresses the user interface as well as Test Procedures will verify the design choices made and the technology used in the *Roll24*.

1.3 Design Requirements Classification

For this document, the following convention will be used to label the functional requirements:

Des [Section].[Subsection].[Requirement Number]-[Design Stage]

The different design stages are abbreviated as:

AP – Alpha Phase

BP – Beta Phase

PP – Production Phase

2 System Overview

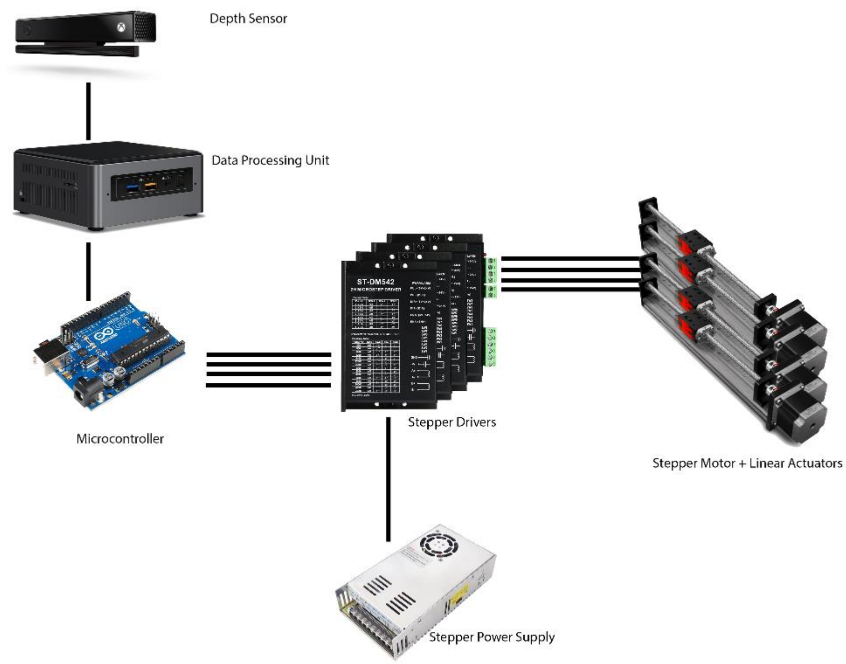


Figure 2: System Overview

Roll24 requires the implementation of a software component, a hardware component, and a mechanical component. The overall general and performance requirements for *Roll24* are listed below. Further details for the specifications on each subcomponent of *Roll24* will be discussed in their corresponding sections laid out in the document. The general design specifications for the *Roll24* are listed below:

2.1 General Design Specifications

Table 2.1: General Design Specifications

[Des 2.1.1-AP]	*Roll24* must be able to roll the patient onto their side
[Des 2.1.2-AP]	*Roll24* should be able to visually determine a patient's position
[Des 2.1.3-AP]	*Roll24* should be easy to assemble/disassemble
[Des 2.1.4-AP]	*Roll24* must attach to the ends of the bed frame
[Des 2.1.1-AP]	*Roll24* must be able to roll the patient onto their side
[Des 2.1.2-AP]	*Roll24* should be able to visually determine a patient's position

3 Patient Monitor Design

The automation for *Roll24* is achieved by combining the patient monitor and the motor control module. The patient monitor is the main software component for *Roll24* which will determine whether it is safe to proceed and complete the task of rotating the patient based on the patient's position.

Patient Monitor is comprised of three primary components: the camera sensor, the data processor and the motor control module. The camera sensors send the raw image data to be processed to determine the position and orientation of the patient on the bed. This information is used to determine the action to be done by the motor control module and will send a halt signal if the patient is unsafe. The data flow between the camera sensors, data processor and the motor control module are shown in the figure below.

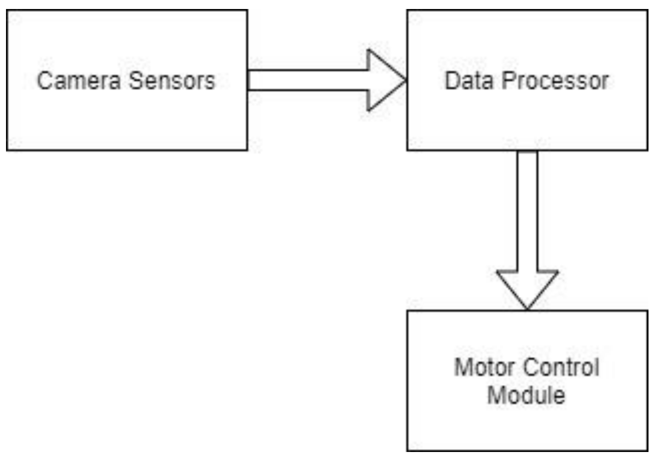


Figure 3: Data flow diagram between the camera sensors, processor, and the motor control module

3.1 Camera Sensor

Table 3.1: Camera Sensor Requirements

[Des 3.1.1-AP]	The camera sensor must have an infrared light emitter
[Des 3.1.2-AP]	The camera sensor must be able to detect depth up to 5 meters
[Des 3.1.3-AP]	The camera sensor must be able to send raw image data to the Data Processor via USB 3.0
[Des 3.1.4-AP]	The camera sensor must have a minimum field of view wide enough to view the entire bed when mounted at a minimum of 1.5m from the patient
[Des 3.1.1-AP]	The camera sensor must have an infrared light emitter
[Des 3.1.2-AP]	The camera sensor must be able to detect depth up to 5 meters

For the camera sensor, the Kinect V2 was chosen [4]. The Kinect V2 contains an infrared sensor and receiver in addition to its colour camera. This sensor was designed with recognizing human shapes in mind and is intended to operate at ranges we intend to use the *Roll24* camera sensor [4]. Also, the

Windows SDK for Kinect allows us to interface with the sensor easily and has lots of online support forums and documentation [5]. These two factors combined made the Kinect V2 a clear choice for the *Roll24*.

Figure 4: Kinect V2[7]

In accordance with **[Des 3.1.4-AP]**, the Kinect V2 must be able to view our entire bed when mounted at a minimum height of 1.5m (59.0551 inches). Our work below in Figure 4 shows that the Kinect V2 will suffice with its 70.6° x 60° field of view [4].

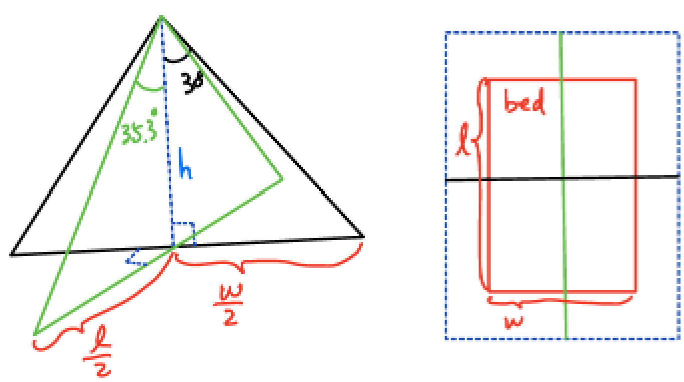


Figure 5: Sketch of the Bed with Angles

$$w = 45\ in$$

$$h_{min} = \frac{\frac{w}{2}}{\tan(30^o)}$$

$$h_{min} = \frac{22.5\ in}{\tan(30^o)}$$

$$h_{min} = 39\ in$$

OR

$$l = 80\ in$$

$$h_{min} = \frac{\frac{l}{2}}{\tan(30^o)}$$

$$h_{min} = \frac{40\ in}{\tan(35.3^o)}$$

$$h_{min} = 56.5\ in$$

Equation 1: Calculation for Bed Height

3.2 Data Processor

Table 3.2: Data Processor Requirements

[Des 3.2.1-AP]	The Data Processor must efficiently determine the boundary of the bed to be labelled as a safe zone by using distance threshold on the raw image data from the camera sensor
[Des 3.2.2-AP]	The Data Processor must efficiently determine the patient's location and whether or not it is within the safe zone by using distance threshold on the raw image data from the camera sensor
[Des 3.2.3-BP]	The Data Processor must efficiently determine the orientation of the patient to determine if they are in a safe position
[Des 3.2.4-BP]	The Data Processor must be able to process data stream from the camera sensor with no noticeable lag
[Des 3.2.5-BP]	The Data Processor must be able to send a signal to Motor Control Module if the patient is detected outside of the safe zone

The data processor for the Roll24 will be responsible for some fairly computationally complex calculations. As such, we have chosen to use a CPU running Windows 10 as our data processor [7]. Specifically, we will be using an Intel® Core™ i7-8700K Processor [8]. This choice guarantees that we will be able to satisfy **[Des 3.2.4-BP]** and allows us to use computers already readily available to our group. In addition, this choice simplifies the interfacing between the data processor and the camera sensor as the Kinect V2 SDK we used for our camera sensor is intended to run on a Windows operating system [5].

4 Hardware Design

4.1 Motor

Table 4-1: Stepper Motor Requirements

[Des 4.1.1-AP]	Motor must be National Electrical Manufacturers Association (NEMA) compliant
[Des 4.1.2-AP]	Motor must move more than 13.5kg vertically and horizontally
[Des 4.1.3-BP]	Motor must be securely mounted to chassis

Roll24 will have 4 NEMA23 bipolar stepper motors based on design requirement **[Des 4.1.1-AP]**. To meet **[Des 4.1.2-AP],** there will be two stepper motors placed horizontally across the front and back of the bed and another two stepper motors vertically placed and supported by the two horizontal stepper motors. These motors are current driven and will be powered individually from the stepper motor driver. *Roll24* will be using DC voltage and will require a motor capable of supporting the user's weight. In the *Roll24* proof-of-concept design, each stepper motor will take an input voltage of 6V DC. The FUYU FSL40 stepper motor was chosen because this stepper motor has precise rotational control, has low noise, and has a reliable operation [9]. Further justifications will be provided in the Mechanical Design section of this document.

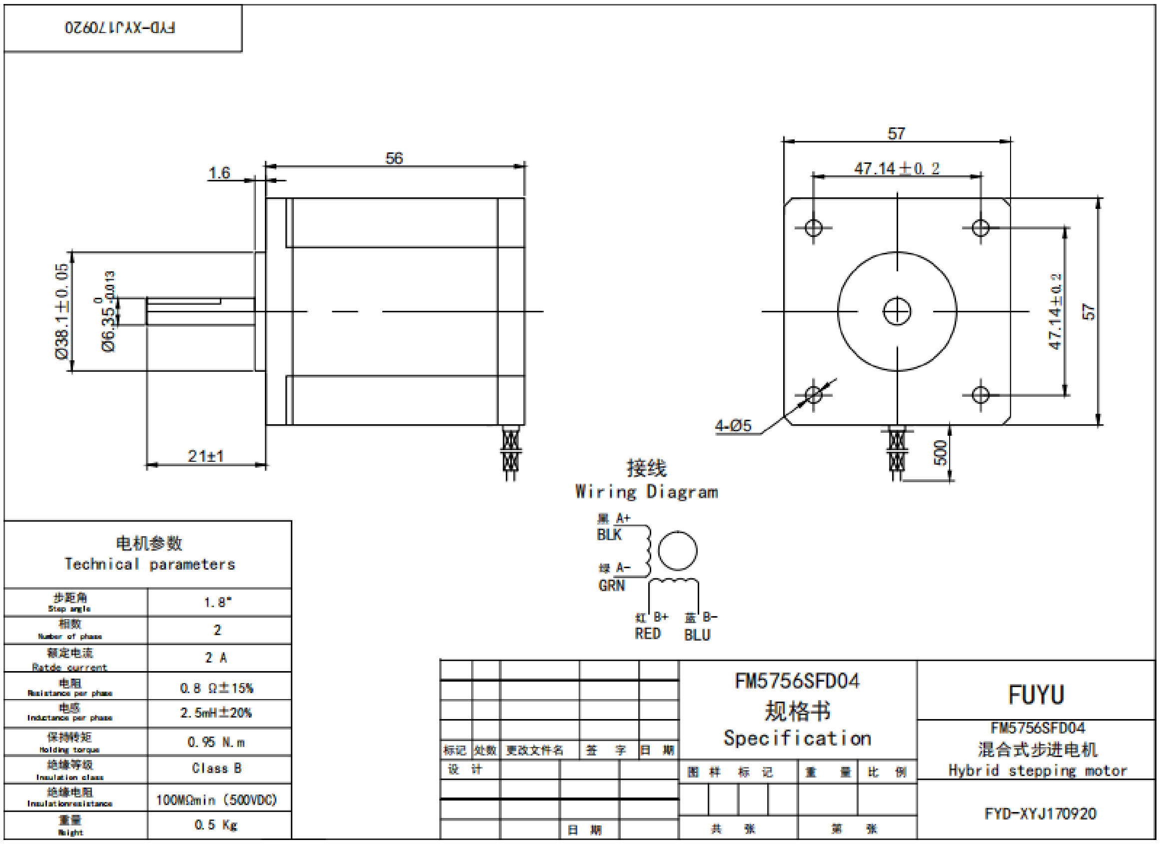


Figure 6: Stepper Motor—FM5756SFD04 Specifications [10]

The values in the Technical parameters table, shown in the figure above, are listed in the table below.

Table 4-2: Stepper Motor Technical Parameters

Step angle	Motor flange size	Motor length	Holding torque	Current	Resistance	Inductance	Rotor Inertia	Lead wire
(°)	(mm)	L (mm)	(N.m)	(A)	(Ω)	(mH)	(g.cm⊃2;)	(No.)
1.8	57	56	0.93	2.0	3.0±20%	3.19	200	4

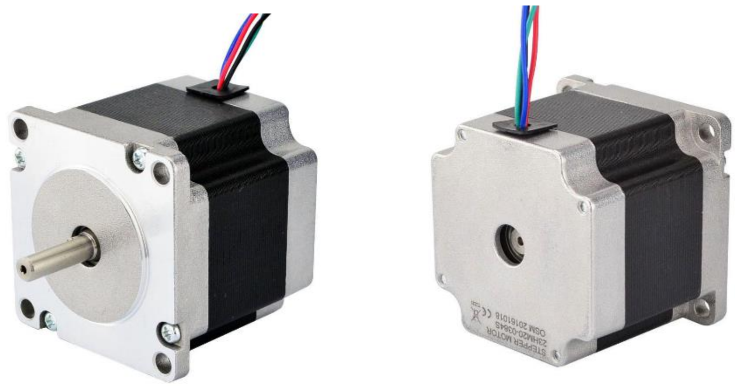


Figure 7: Standard Nema23 Stepper Motor [11]

The figure below is the wire diagram of the wire connection between the microcontroller, the stepper motor driver, and the stepper motor.

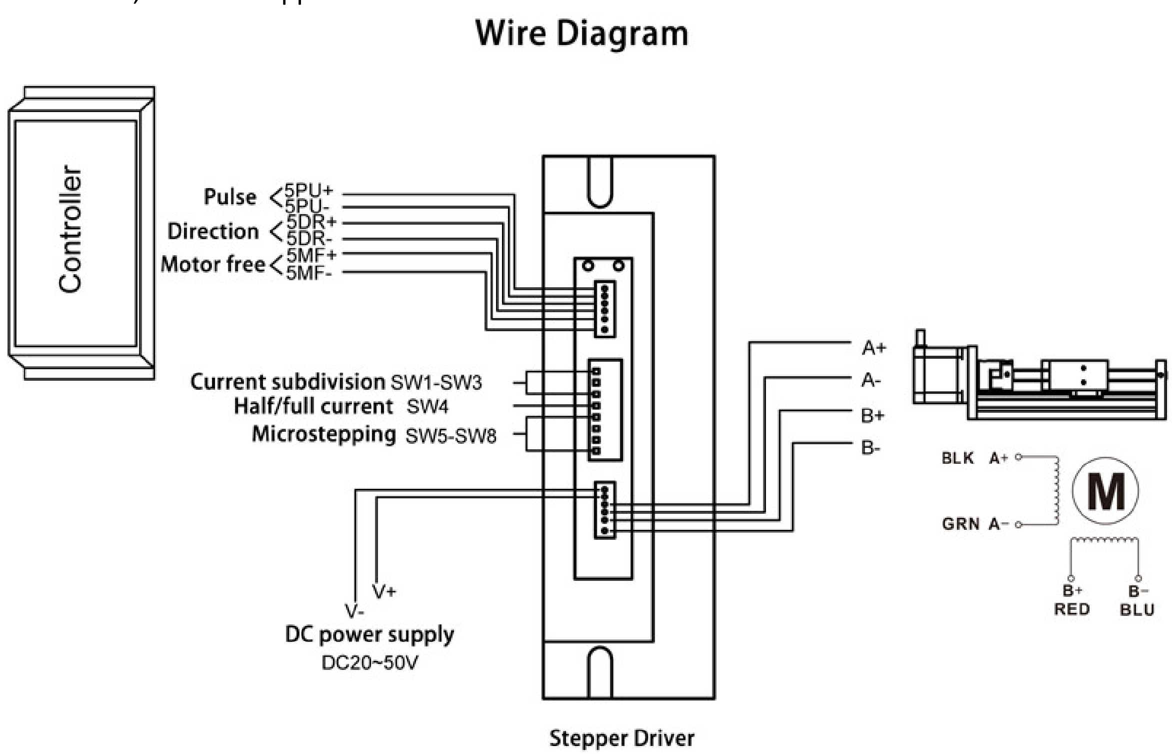


Figure 8: Wire Diagram [9]

4.2 Microcontroller

Table 4-3: Microcontroller Requirements

[Des 4.3.1-AP]	The microcontroller must transmit/receive signals from stepper driver in real-time
[Des 4.3.2-AP]	The microcontroller must receive data from data processing unit

[Des 4.3.3-AP]	The microcontroller must operate and rotate the motors for the interval set by the patient
[Des 4.3.4-BP]	The microcontroller must stop transmitting signals to stepper driver when failsafe switch is pressed, or abnormal conditions are present
[Des 4.3.5-BP]	The microcontroller must limit motor operation to the frames dimension or upon receiving patient out of bounds signals from the Data Processor

A microcontroller will be used to communicate with the Kinect V2 camera in real-time and to send control signals to the stepper motor driver. *Roll24* will use an Arduino board for a simpler proof-of-concept prototype design, its accessible stepper motor library, and because these boards are affordable and compact. These factors allow the programming process of the stepper motors to be easier and allow the PC to communicate and power the Arduino through an USB interface to meet requirement **[Des 4.3.1-AP]**. The Arduino board selected must have enough I/O ports to support 4 stepper motor drivers. *Roll24* will use the Arduino Uno Rev3 which uses the ATmega328P microcontroller.

The figure below is the pinout diagram of the Arduino Uno Rev3 board.

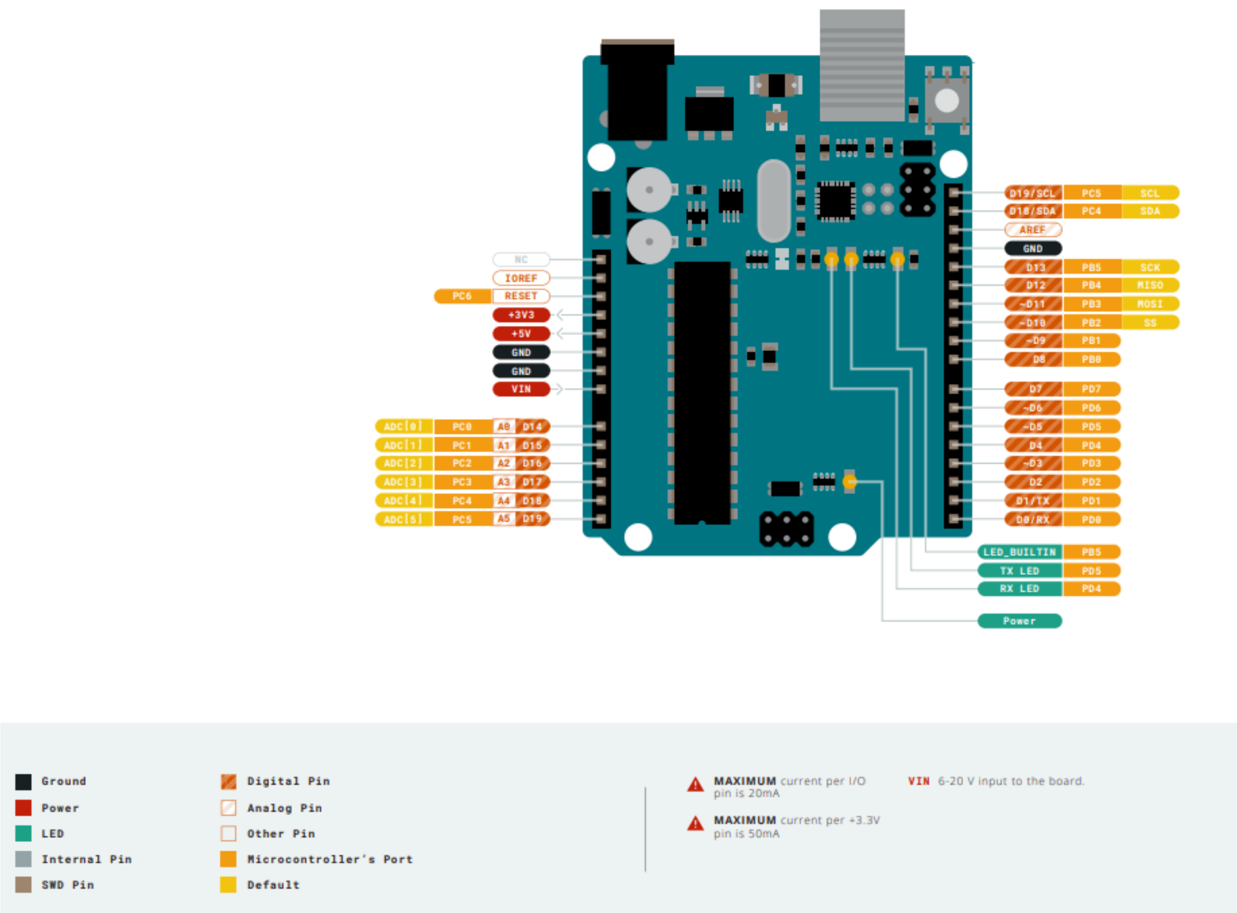


Figure 9: Pinout Diagram of Arduino Uno Rev3 [12]

The figure below is the technical specifications of the Arduino Uno Rev3 board.

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Figure 10: Technical Specifications of Arduino Uno Rev3 [12]

The figure below is the block diagram of the ATmega328P.

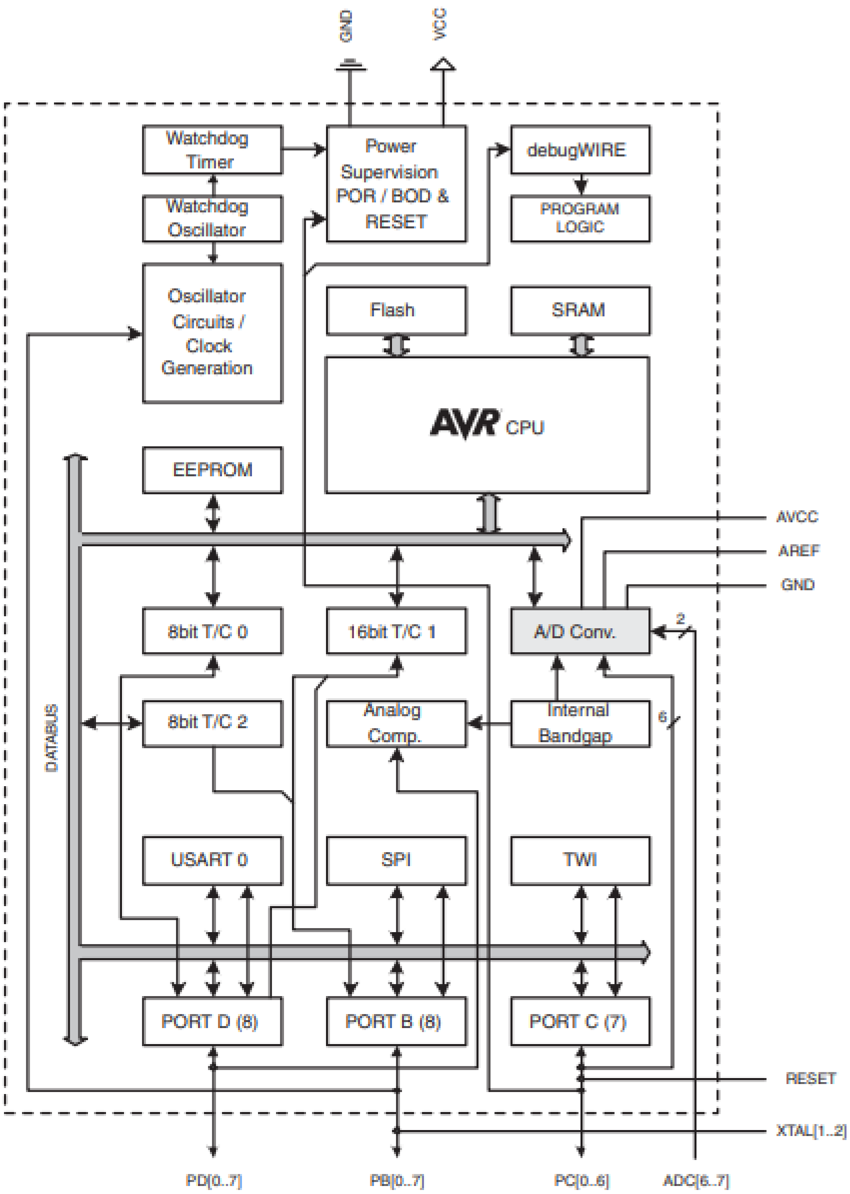


Figure 11: Block Diagram of the ATmega328P [13]

4.3 Stepper Motor Driver

Table 4-4: Stepper Motor Driver Requirements

[Des 4.4.1-AP]	Stepper Motor Driver must be capable of transmitting/receiving signals from the stepper motor.
[Des 4.4.2-AP]	Stepper Motor Driver must be compatible with National Electrical Manufacturers Association (NEMA) stepper motors.
[Des 4.4.3-AP]	Stepper Motor Driver must be suitable for a quiet, residential environment.

[Des 4.4.4-AP]	Stepper Motor Driver output current matches current rating of stepper motor for proper functionality

There will be 4 stepper motor drivers in *Roll24*. According to **[Des 4.4.1-AP]**, each will be uniquely connected to a stepper motor because there will be less issues compared to running connections with multiple motors to a single stepper motor driver. If one of the stepper motors fails, there may be an inrush of current being driven to the other motors which can cause failures or cause the motor to stall by triggering the over-current protection. Therefore, this idea justifies the design with individual stepper motor drivers to an individual motor. Also, the cost of purchasing the stepper motor driver is cheaper than replacing the motors and drivers in the long run if problems occur. Each stepper motor driver in the alpha phase design will take an input voltage of 24-48V DC from the power transformer and can output more current than required based on the 2A and potential 3A current rating of the NEMA23 motor [14]. These drivers will be used to control and power the stepper motors presented above in 4.1. The DM542 was chosen because this stepper motor driver is compatible with NEMA23 stepper motors and has functions suitable for a quiet, residential environment to meet **[Des 4.4.2-AP]** and **[Des 4.4.3-AP]** [14].

Figure 12. DM542 Stepper Motor Driver [15]

4.4 Power Supply

Table 4 5: Power Supply Requirements

[Des 4.5.1-AP]	Power supply must supply a minimum voltage of 24V DC to each of the four stepper motor drivers
[Des 4.5.2-AP]	Power supply should be able to supply 345.6 W
[Des 4.5.3-AP]	Power supply must use power derived from a North American wall outlet.
[Des 4.5.4-BP]	Electronic components and wires must be enclosed in a chassis
[Des 4.5.5-BP]	Device must have a mechanical failsafe switch to quickly and easily shutdown device [16]
[Des 4.5.6-PP]	Device must have efficient voltage conversion

The *Roll24* system will use separate power systems to power the Kinect V2, the microcontroller, and the stepper motors.

General System Power Supply

The Kinect V2 Depth sensors will use its own proprietary power supply connected to the standard power outlet and the Data Processing Unit will use a standard ATX or SFX power supply which is also connected to a standard power outlet. As the microcontroller is connected to the Data Processing Unit via USB for serial communication, it conveniently makes use of USB to power itself reducing the need for its own power supply and converter.

Stepper Motor Power Supply

Power supply chosen was based on the requirements needed for 4 stepper motors. For the stepper motor chosen, it required 2A to operate and maintain the torque rating specified in its data sheet. Assuming a 20% margin as referenced from [17], and the general equation for power calculation, P=IV, the resultant power required for 4 stepper motors is:

P - Power (Watts)
n - number of motors
I - current rating of motors (A)
V - Driving voltage from stepper drivers
e - recommended overhead for power calculation of the motor, 20% overhead is used

$$P = n * I * V * e$$
$$= 4 * 2A * 24V * 1.2$$
$$= 230W \text{ required for four } 2A \text{ stepper motors with a power supply that can output more than } 8A$$

Equation 2: Calculation for 2A Stepper Motors

Giving ourselves enough overhead in the event that the motors are not strong enough and for cost saving measures, a 3A NEMA23 motor with a higher torque rating was used to calculate the needed power.

$$P = n * I * V * e$$
$$= 4 * 3A * 24V * 1.2$$
$$= 345.6W \text{ required for four } 3A \text{ stepper motors [18]}$$

Equation 3: Calculation for 3A Stepper Motors

For NEMA23 motors, the typical driving voltage required to ensure that the current rating of the motor is achieved is 24V to 48V DC. Such high voltage is required because there is an initial drop in potential required to hold the current rating when the motor is initially ran due to the inductance of the coils and the back electromotive force which opposes the change in current which is induced. A 115VAC to 24VDC switching power supply was selected as it was to be tested if a faster response was required for the stepper motors for our application as they are meant to periodic starts and stops based on the intervals set.

The NEWSTYLE LED-277 was chosen because it meets design requirements **[Des 4.5.1-AP]** and **[Des 4.5.2-AP]**. This power supply takes an input voltage of 110V AC, **[Des 4.5.3-AP]**, and can supply an output voltage of 24V DC at a maximum current of 15A [19].

Figure 13: Image of the NEWSTYLE LED-277 power supply [19]

Page Break

5 Mechanical Design

The mechanical design for *Roll24* consists of three major assembly: the bed, the supporting frame, and the moving apparatus. The bed supports the patient; the frame supports the motors and actuators; the actuators move the patient. Since the goal is to reposition the patient for a long period of time, the system needs to be sturdy, stable and slow moving. This section will detail our design reasonings and justifications of each individual component choice.

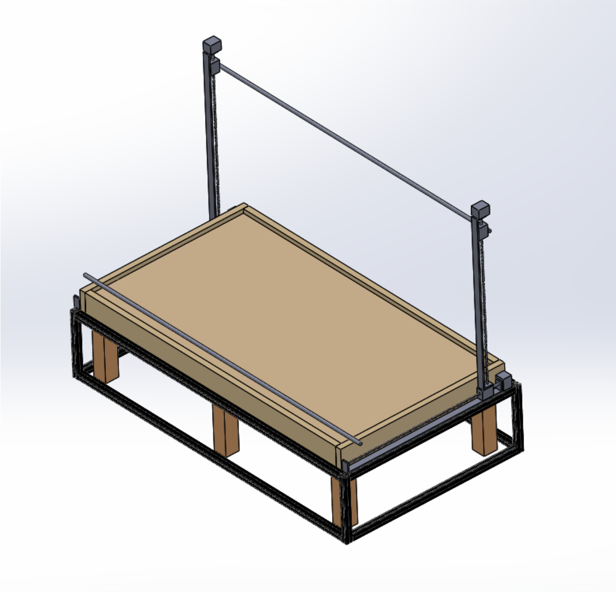


Figure 14: overall appearance

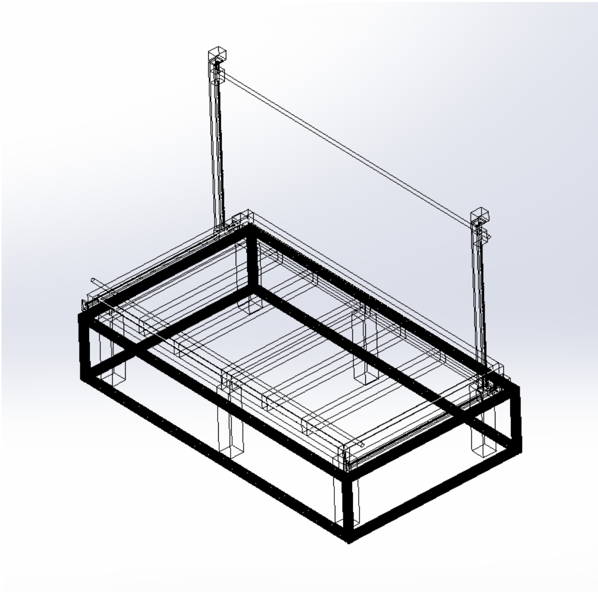


Figure 15: Perspective view with hidden lines

5.1 Mechanical Design Specifications

The Design specifications for the mechanical system are listed below in Table 5.1.

Table 5-1: Mechanical Design Requirements

[Des 5.1.1-AP]	Moving apparatus must not bend or distort when a patient (up to 250lb) is using it
[Des 5.1.2-AP]	The supporting frame should be mounted around the bed
[Des 5.1.3-AP]	The sling must support the patient weight
[Des 5.1.4-AP]	The sling should be detachable and washable
[Des 5.1.5-BP]	Chassis must include mechanism to prevent patient from falling off the bed
[Des 5.1.6-BP]	Chassis must shield the moving mechanical components to prevent body parts catch in the machine
[Des 5.1.7-PP]	Chassis should be lightweight and adjustable dimensions for various sizes of bed

The bed

For our proof-of-concept design, *Roll24* is intended to operate with a twin-sized bed. For a standard twin sized bed, the dimensions are by 75"L(190.5cm) by 38"W(96.52cm) [19]. We custom built a solid wooden bed with the following dimensions: 199L by 110W by 53.5H (cm). The reason we built this bed ourselves instead of buying one from a furniture store is because it can serve as a good foundation for our prototyping. It can provide many mounting options and act like a generic model for testing.

The supporting frame

Our design aims to lift a real size person using motors and actuators. The stability of the system while under full load is paramount to its success and to patient's safety. The plan is to build a frame around the bed and mount the moving apparatus onto the frame. We chose to use 80/20 inc. ‘s modular T-Slot aluminum frame to secure our motor systems, due to its ease of assembly, customizability and high quality.

The moving apparatus

The heart of the design is to coordinate the motors and actuators in such a way that mimics the rolling motion of nurse when the patient needs a repositioning. Mechanically, we would have four motors, two on each ends of the bed, synchronized in both horizontal and vertical directions. They would move a metal bar that attached to one side of a sling and rolling to bed bound patient to desired position.

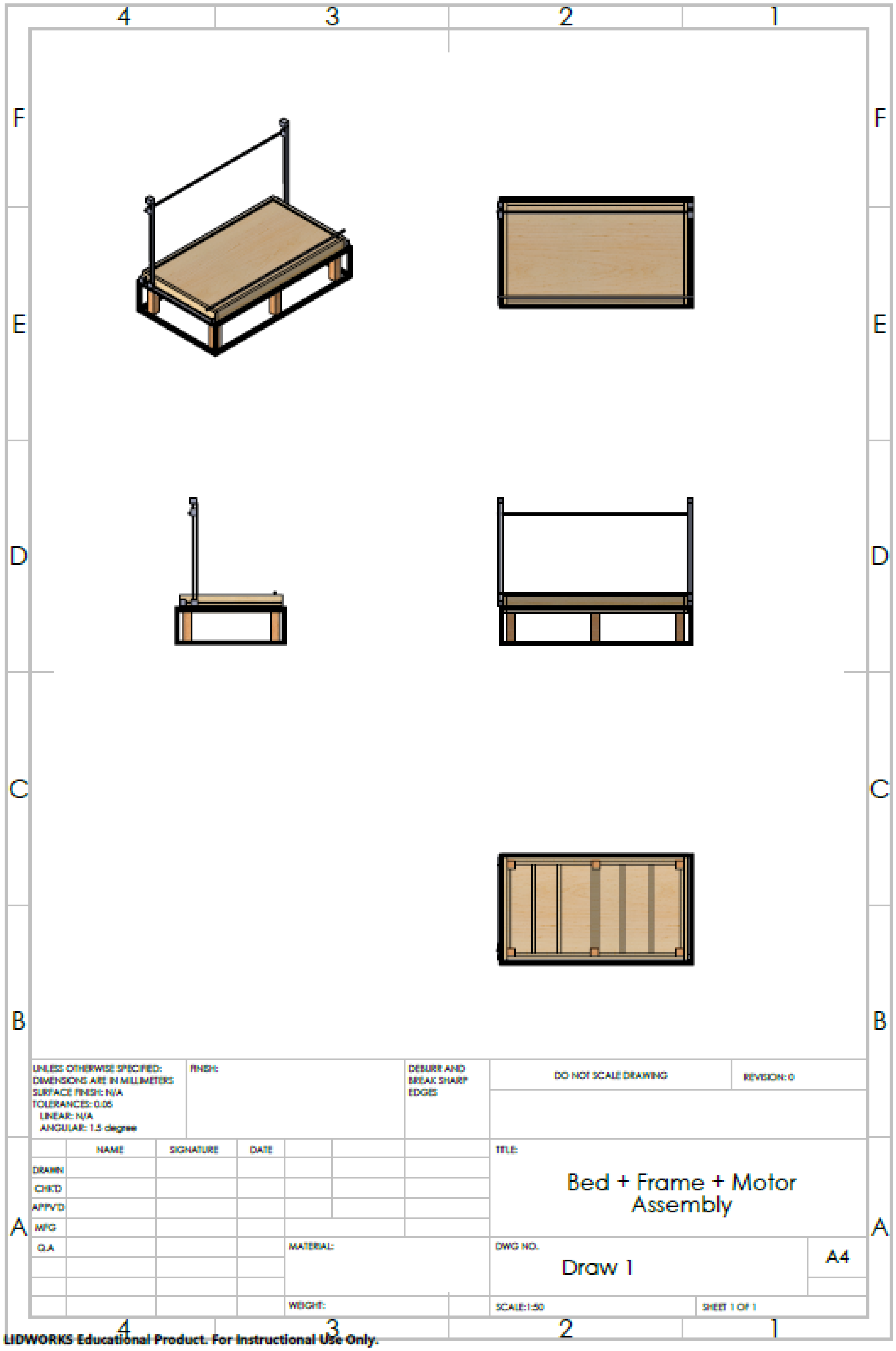


Figure 16: Different Topologies of the Assembled Product

5.2 Sling

Sling is virtual part of the design, it makes direct contact with the patient, and without it the product will simply not work. The sling should be strong, durable, washable and detachable according to **[Des 5.1.3-AP] [Des 5.1.4-AP]**. Since there are wide variety of medical grade sling available on the market, it's unnecessary to manufacture our own sling at stage of product development. Therefore, we decided to go for a commercial sling on Amazon. LVA2000 is inexpensive and comes with a one-year warranty. (even has 50% discount!) The sling is made of Nylon mesh, so it's water-resistant, strong and durable. Note: a discrepancy between the user manual and web page for the load limit, one says 400 lb and the other says 600 lb. We only need 250 lb for the project. We would consider partnering up with sling factory to make our OEM sling in mass production phase.

Specifications

Uses:
- For safely transferring, lifting or repositioning a patient or loved one

Dimensions:
- 48" by 30"
- Supports up to 400 pounds

Materials:
- Water-resistant nylon

Color:
- Blue

Care Instructions:
- Hand or machine wash on the gentle cycle in cold water with a mild detergent
- Hang dry or machine dry on low
- For spot cleaning, wipe the surface with a damp cloth. Allow to air dry

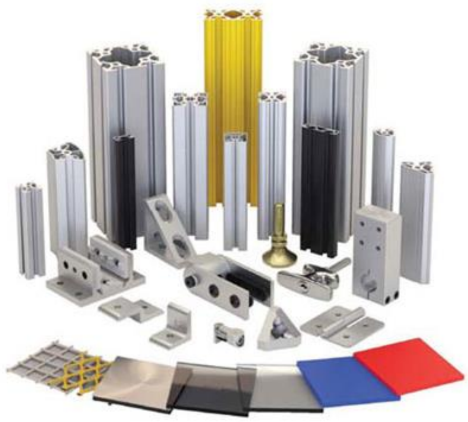
What's Included:
- Vive Patient Lift Sling
- One year guarantee

UPC: 818323025088
Product Number: LVA2000BLU
Shipping Weight: 1.8 pounds
User Manual: Patient Lift Sling PDF Manual

Figure 17: LVA2000 and its Specifications [20]

5.3 T-Frame made by 80/20 inc.

80/20 inc. provides a wide range of options for our frame construction, we chose 1515-LITE 1.5" X 1.5" LITE T-SLOTTED beam because it fits our required strength and budgeting need.



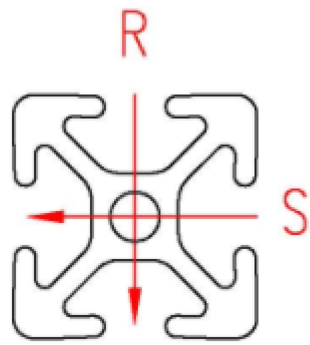


Figure 18: 80/20 Product Line [21] **Figure 19: 1515-LITE cross section 1.5'' x 1.5''**

Deflection Calculation:
80/20 provides convenient calculation tools for their product selections. Using this method, we just need to select the T-frame type and enter the load parameters.

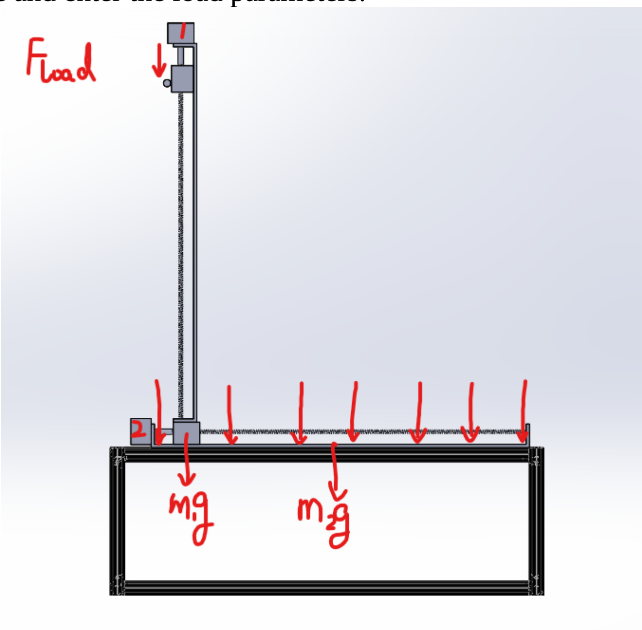


Figure 20: Forces acting on the T-frame

From the above picture, both linear actuator assemblies are mounted onto the top horizontal T-frame bar. Since we are mounting using the back side of the track of assembly2, we can assume the forces are evenly distributed on the frame. Using the tested 13.5 Kg as the load, the total force is:

$$F_{load} = 13.5kg = 30.0lb$$
$$F_{motor} \cong 10lb$$
$$\begin{aligned} F_{total} &= F_{load} + F_{motor1} + F_{motor2} \\ &= 30.0 + 10 + 10 \\ &= 50lb \end{aligned}$$

Equation 4: Calculation for the Total Force

Entering 50 lb to deflection calculator gives us the following result. We can see on the first results on the right-hand side, it shows every little deflection which mean it will be very stable under maximum load. Note: the deflections are generally proportional to the load parameter within its elastic range. Even when we input five times the maximum load factor, the deflections are still barely noticeable. Therefore, we conclude the frame is extremely capable for this project.

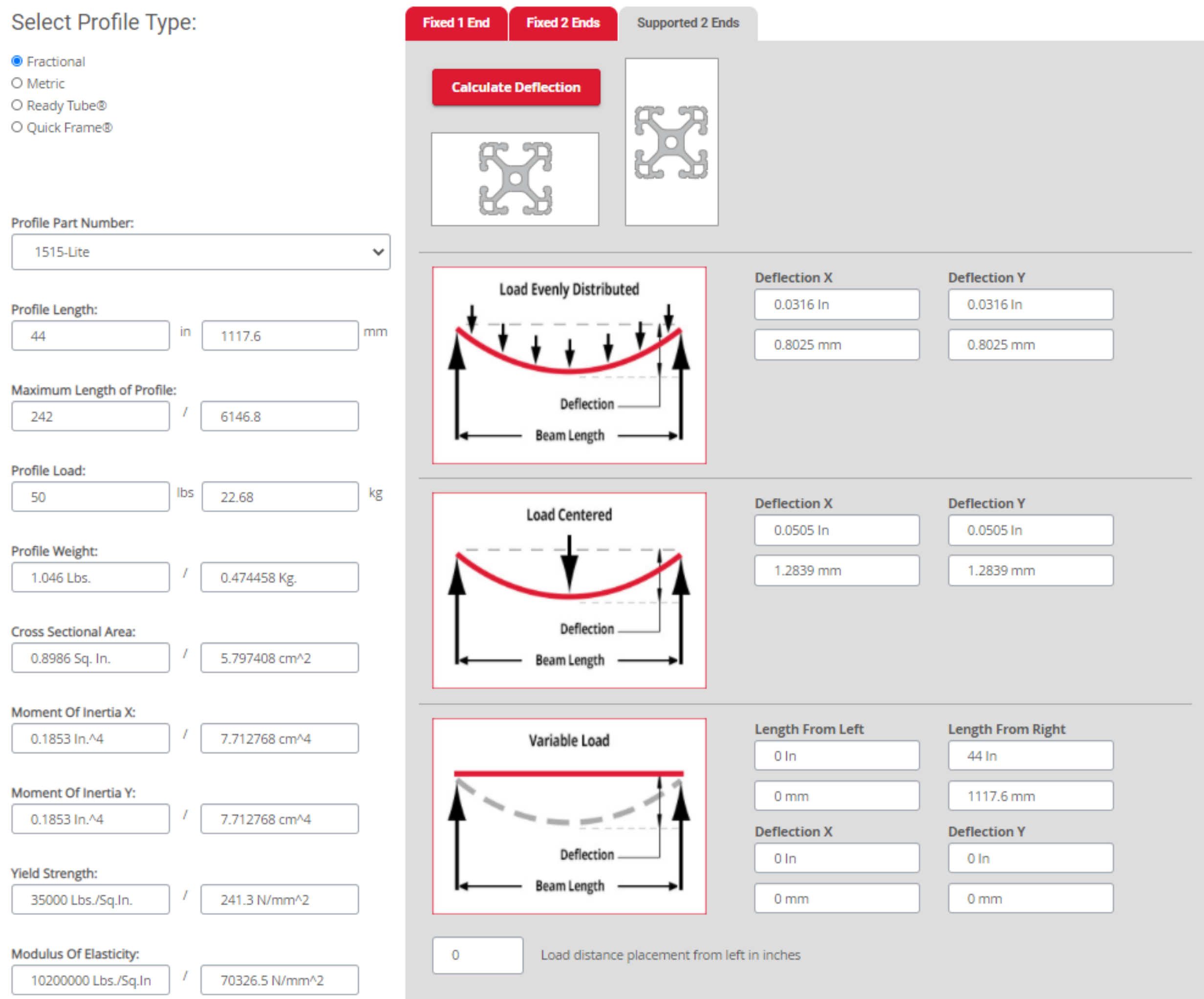


Figure 21: T-Frame Deflection Calculated Using the Online Calculator [22]

The material specifications for the T-Frame are listed below.

Table 5 2: T-slot Profile Specifications [23]

Yield Strength	35,000 p.s.i. (min)
Tensile Strength	38,000 p.s.i. (min)
Elongation	A5 minimum 10%
Elasticity E	10,200 k lb/in.sq
Hardness	Rockwell approximately E-88
Flatness	.004” per 1 inch of width
Straightness	0.0125 inches per 1 foot of length not to exceed 0.118 inches over 20 feet of length
Twist	Per 1 foot of length not to exceed .25 de gree and total twist over 20 feet of length not to exceed 1.5 degrees

The aluminum beams can be pieced together with the following internal fasteners. They also have many different connector designs that fits different needs.

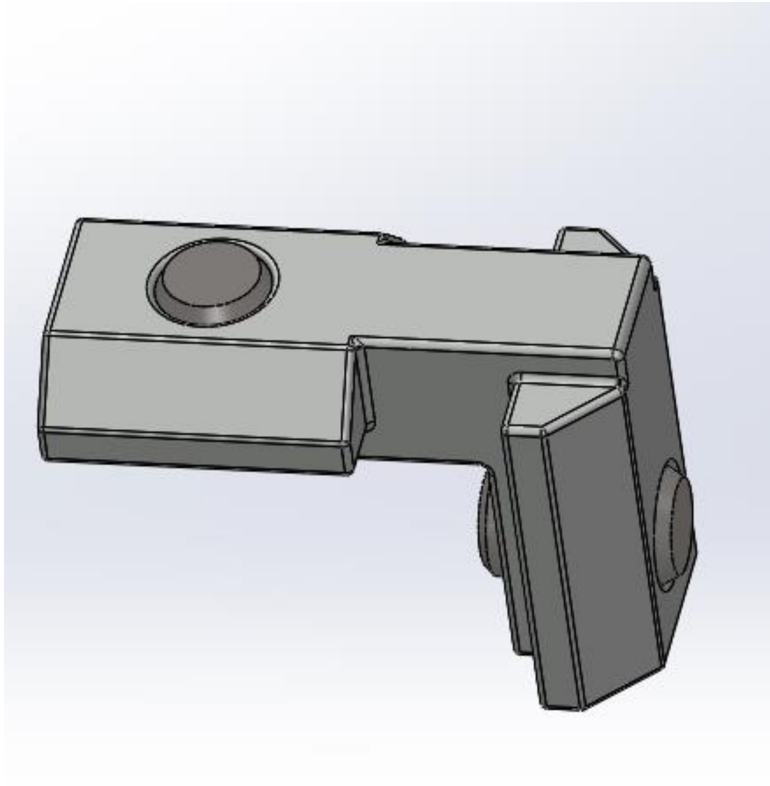


Figure 22: Fasteners Used to Piece the T-Frame Together.

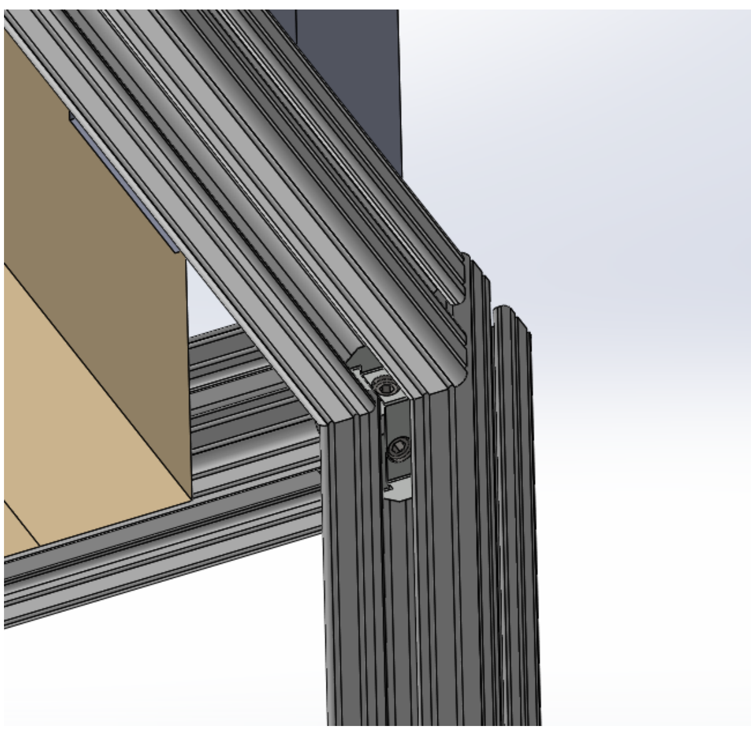


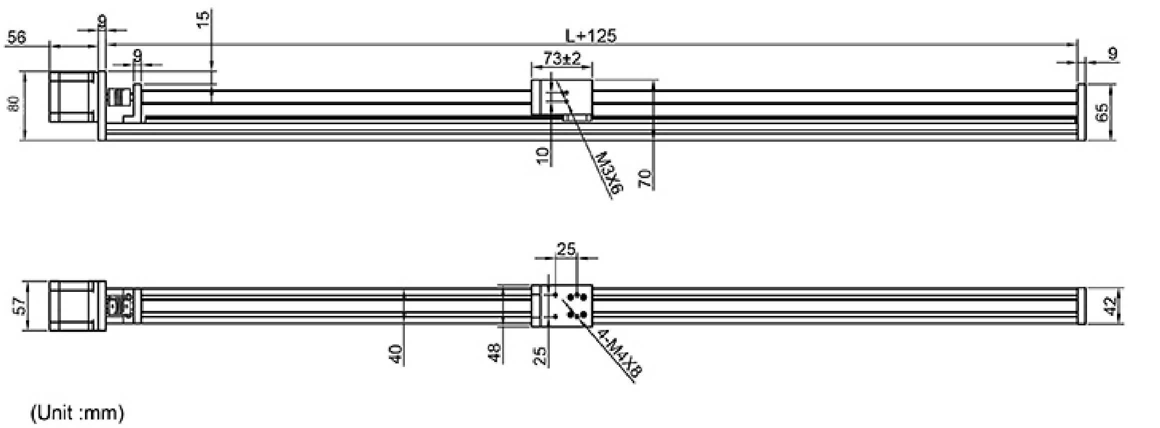
Figure 23: T-frames Pieced Together using the Fastener

5.4 The Actuating Apparatus

We conducted testing with two electronic scales on a 60kg and a 110kg person, found that the most force exerted when only vertical motion applied to the sheet/sling, maximum reading for 60kg is about 7.5kg and for 110kg person is about 13.5kg, that is lifting the person on their side as high as one meter to the surface the person lies on. The maximum occurs when there is an imbalance distribution of the force between the two electronic scales. It has a significant lower reading if horizontal motion applied to mimic the rolling action of the nurses.

5.4.1 Stepper Motors and ball screw drive module

Four modular apparatuses are implemented in our design, each includes a stepper motor, a ball screw drive, and a custom-made track for a linear actuator, the following diagram show its dimension and specification.



Technical parameters	
Step angle	G1605/G1610
Ball screw accuracy	C7
Max Horizontal Load	30 Kg
Max Vertical Load	10 Kg
Effective Stroke	XXXmm
Max speed (no load)	0-200 mm/s
Motor Parameters	
Step angle	1.8°
Number of phase	2
Rated current	2.5A
Holding torque	1N.m
Motor length(L1)	56

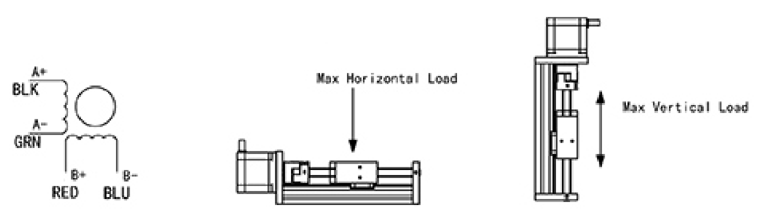


Figure 24: Manufacturer's Schematics and Technical Specs [9]

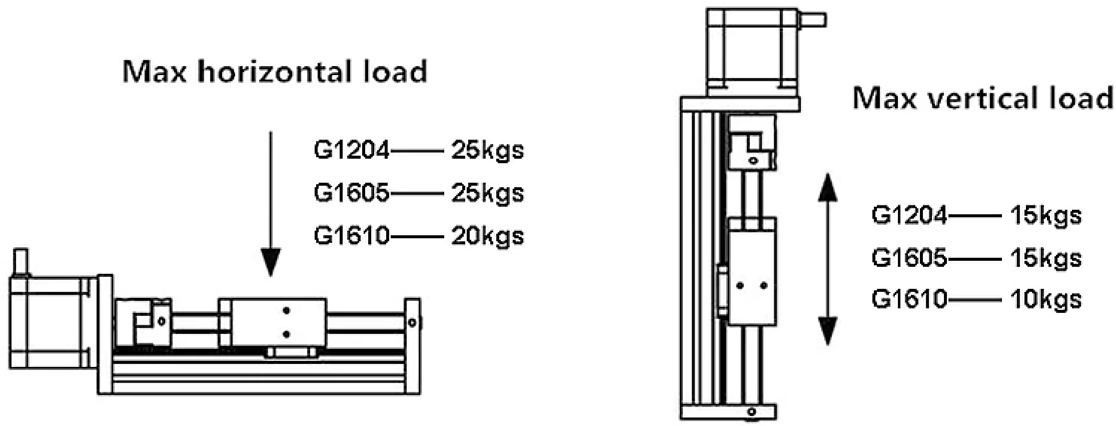


Figure 25: Manufacturer Specification on Horizontal and Vertical Load (G1605 was used) [9]

Figure 26: Linear Actuator Assembly with Stepper Motor [24]

5.4.2 Stepper Motors

Motor details presented in section 4.1.

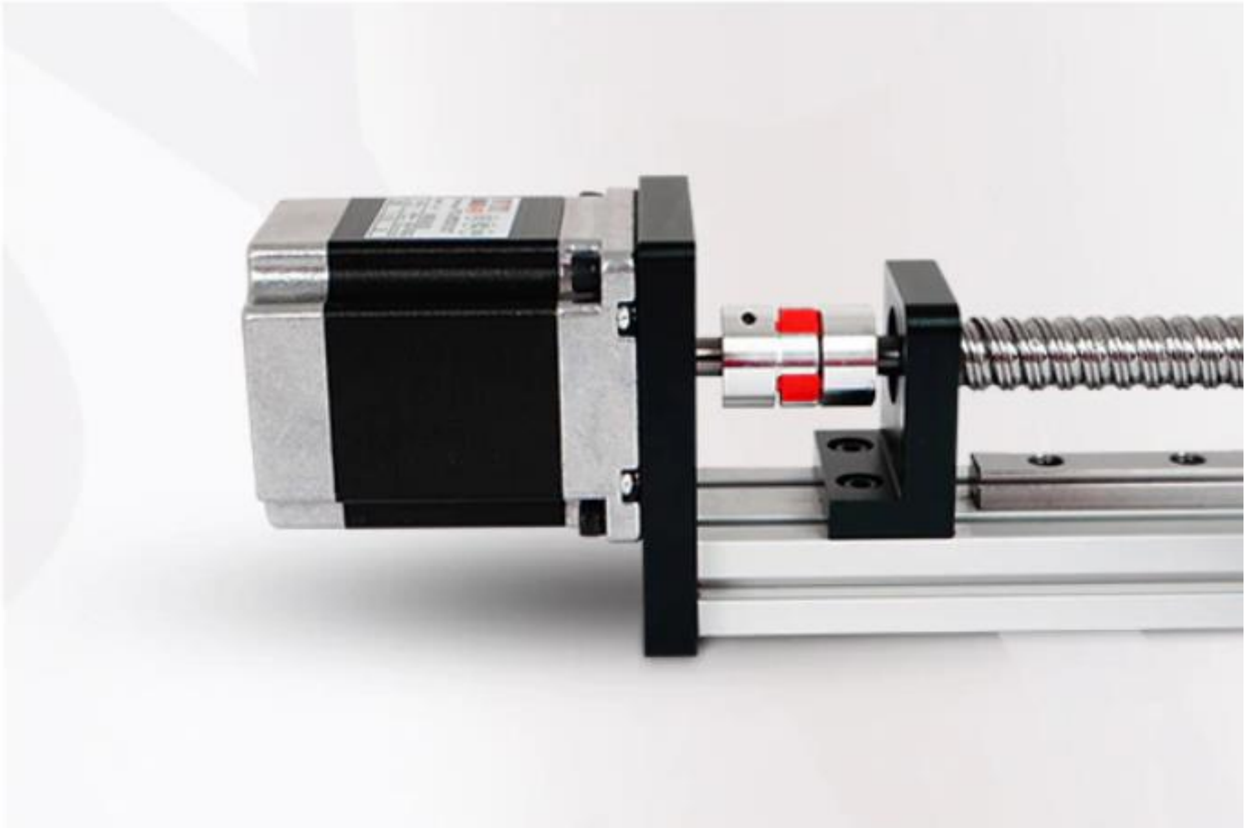


Figure 27: Stepper Motor Attached at the Ball Screw Drive Track [9]

Stepper motor torque calculation:

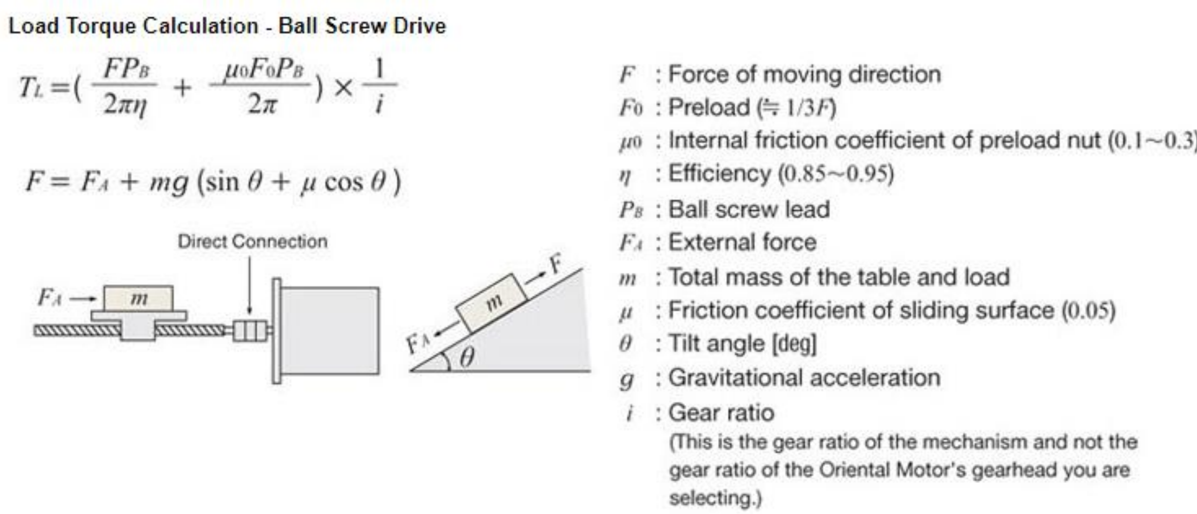


Figure 28: Formula for Calculating the Stepper Motor Torque Calculation [25]

To make sure the selected motor can move the 13.5kg mass vertically, the b, we used the above equation to calculate the mass:

$$T_L = \left(\frac{FP_B}{2\pi\eta} + \frac{\mu_0 F_0 P_B}{2\pi}\right) \times \frac{1}{i}$$

$$i = 1 \qquad g = 9.81m/s^2 \qquad T_L = 0.93Nm$$

$$P_B = 5mm \qquad \mu = 0.2 \qquad \eta = 0.9$$

$$T_L = \left(\frac{FP_B + \mu_0 \eta \frac{1}{3} FP_B}{2\pi\eta}\right)$$

$$= \frac{\left(1 + \mu_0 \eta \frac{1}{3}\right)}{2\pi\eta} FP_B$$

$$T_L = 0.187FP_B$$

$$F = mg$$

$$M = \frac{T_L}{0.187P_B g} = 101.4kg$$

Equation 5: Mass Calculation

5.4.3 Linear Actuator Assembly

The linear actuator assembly consists of a ball screw with supporting end brackets coupled to stepper motor which is connected to T slot frame and linear guide rails. From there a coupler connects the ball screw to the stepper motor spindle allowing for the bracket/table combination on the ball screw to travel along the screw when the motor is running. The attached linear guide assists with the movement of the bracket/table combination by ensuring a straight and smooth travel path.

The G1605 model ball screw was selected based on measured load. It was required to have a ball screw that can handle more than 13.5kg of vertical load. Testing is required to determine if selected ball screw can handle the vertical load without issues for the intended application.

Figure 29: 16mm ball screw [26]

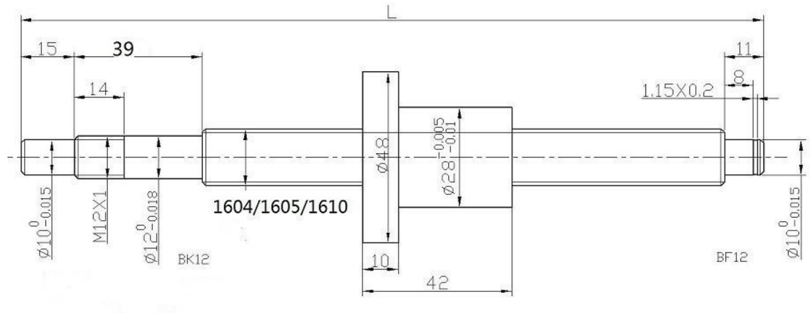


Figure 30: 1605 Ball screw dimensions [26]

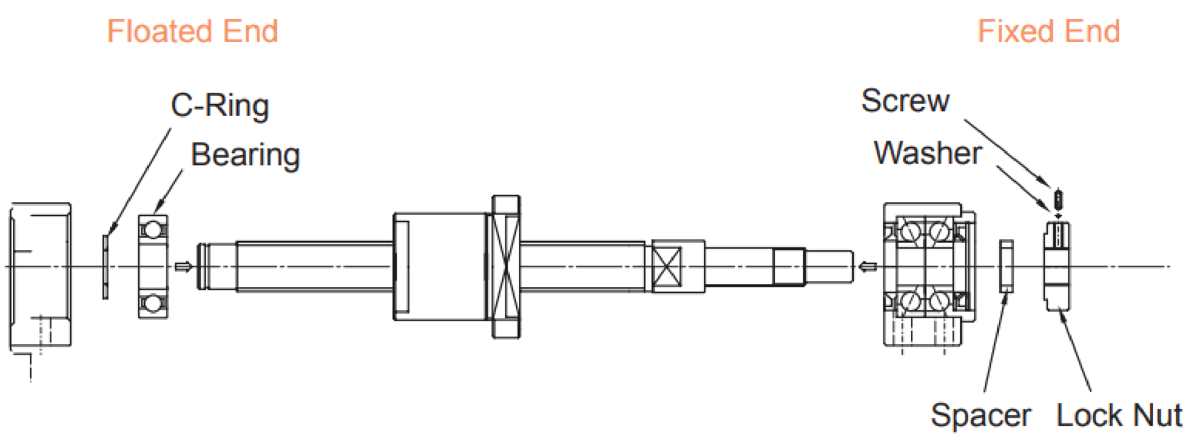


Figure 31: Mounting Ball Screw to End Mounts which then are Mounted onto the Linear Guide Rail which sits on top of the T-slot Frame [27]

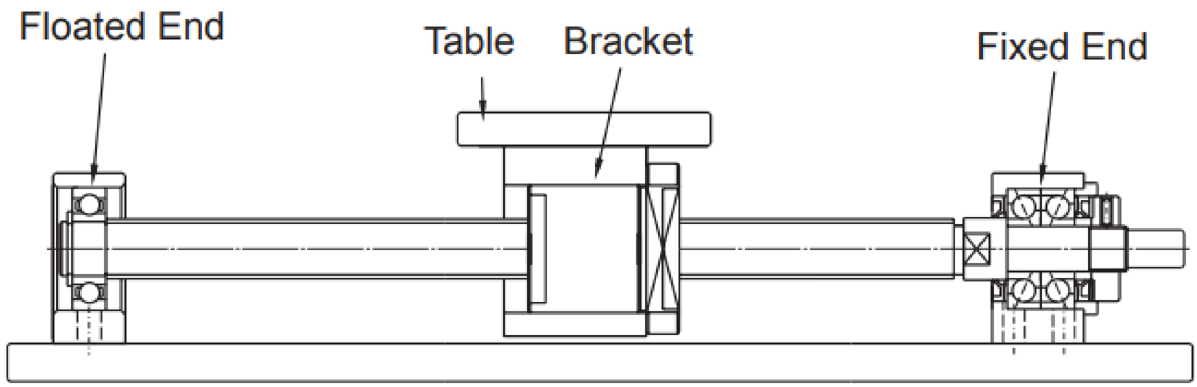


Figure 32: Bearing Block attached to Ball Screw and Sitting over Linear Guide Rails [27]

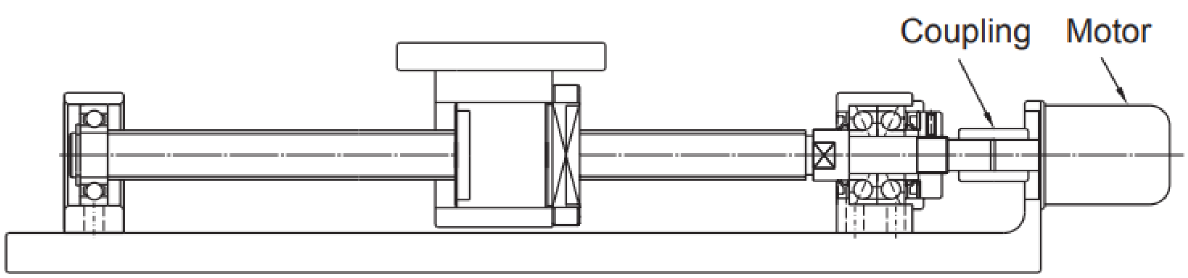


Figure 33: Ball Screw Attached to Motor via Coupler [27]

6 Conclusion

This design specifications document outlines our analysis of each component of the *Roll24* and the justification for each design decision made by our team. We designed each component to use economical and readily available components that could accommodate the majority of our target audience for our proof of concept.
A summary of specific design decisions for each component are as follows:

1. Patient Monitor
    a. Camera Sensor: Monitors the patient's position on the bed using an infrared depth sensor
    b. Data Processor: Calculates whether the patient's orientation is safe and sends a halt signal if the patient is not
2. Hardware
    a. Motors: Generates force to power the actuating apparatus
    b. Microcontroller: Translates data from data processor into motor control signals
    c. Stepper Motor Driver: Interfaces with microcontrollers to synchronize stepper motors
    d. Power Supply: Provides power to all components
3. Mechanical
    a. Sling: Lifts patient during rotation and is detachable for sanitation
    b. Frame: Provides structural support for *Roll24's* actuating apparatus

c. The Actuating Apparatus: Transforms motor torque into rolling motion

This design specification will be the starting point for the *Roll24*, but it is not final. As we progress, we will review the viability of our design with the test plans listed in the appendices attached to this document. If need be, we will alter the design and revise the design specifications accordingly.

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Appendix A: User Interface and Appearance Design

A1. Introduction

Purpose

The *Roll24* system has been designed to be almost entirely automatic, and as a result, will not rely heavily on user interfacing. With this in mind, the purpose of the User Interface and Appearance Design appendix is to address which user interface features have been deemed necessary, our initial plan to implement these features, and our plan to validate our design with users. Our goal is to minimize the interaction between a caregiver and the *Roll24* while still providing necessary information and intuitive control to the user. This document will take into consideration the ENSC405W lectures and *The Design of Everyday Things* book for the design process of *Roll24* [28].

Scope

This appendix will cover the graphical presentation, user analysis, technical analysis, engineering standards, analytical usability testing, and empirical usability testing. These factors will be essential and covered in the design of *Roll24*'s UI.

- The User Analysis section will specify the knowledge and prior experiences required for the user to properly use *Roll24*.
- The Technical Analysis section will cover the "Seven Elements of UI Interaction" (discoverability, feedback, conceptual models, affordances, signifiers, mappings, constraints) [28]. These factors will be considered in the design process of *Roll24*.
- The Engineering Standards section specifies the relevant engineering standards that *Roll24* must be compliant with.
- The Analytical Usability Testing section will specify the test scenarios and test procedures that the designers at Rise will use and implement, in the design process, to ensure a functional and working product.
- The Empirical Usability Testing section will specify the test procedures for users to verify if the *Roll24* interface is functioning properly and intuitively. This will allow us to potentially iterate on the design of the *Roll24's* interface if users react poorly.
- The Graphical Presentation section will showcase the appearance and features of our User Interface.

A2. Graphical Presentation

In this section, Rise's engineers have presented an illustration of the User Interface design. The control panel will have a power button, an LCD, an alarm speaker, push buttons to set the total rotation time, and an LED light to indicate the status of the device.

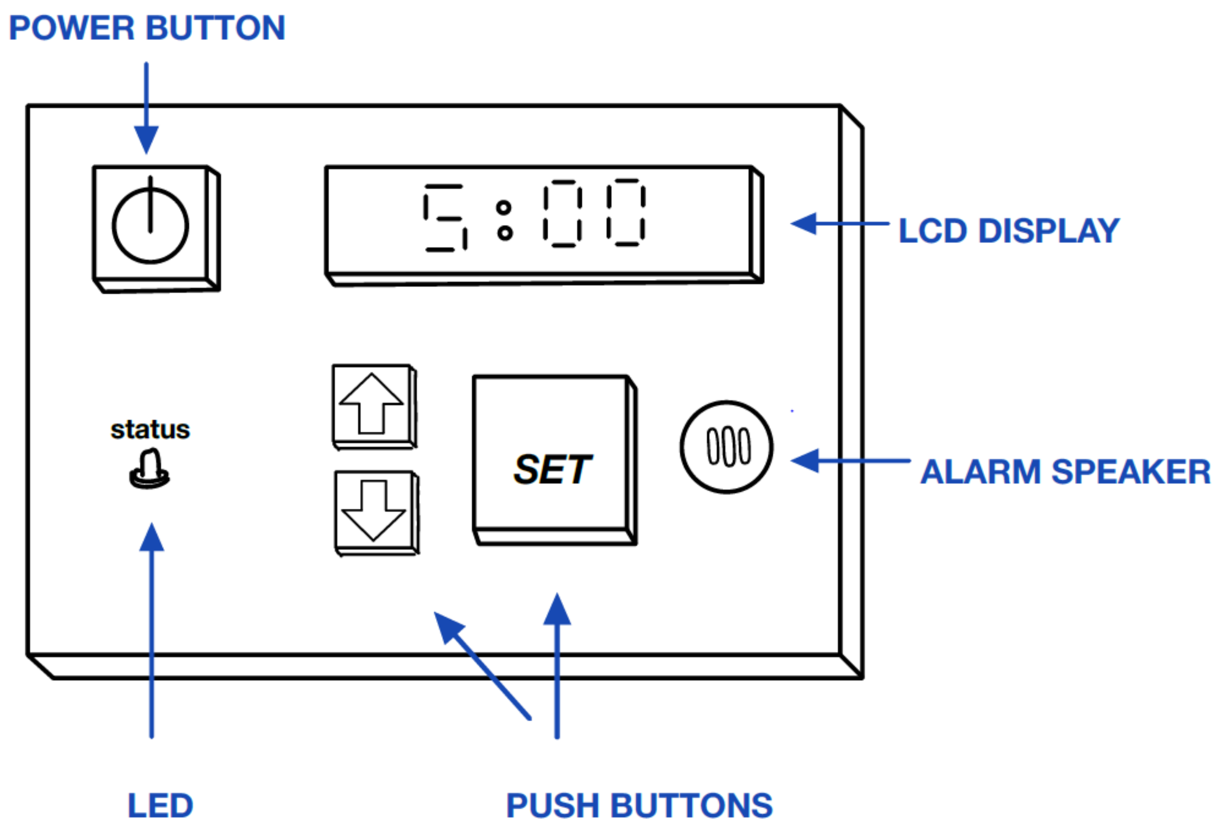

Figure 34: Physical User Interface Design

A3. User Analysis

Target audience of *Roll24* are health care workers/giver and patients in long term care homes that physically are unable to reposition themselves or require assistance in doing so. *Roll24* is designed to be fully autonomous with manual override controls if needed. Users that have experience setting a timer or playing crane games at an arcade should see no difficulty using the *Roll24.*

Majority of the operation is during setup where the user would position the patient to be in view of the depth sensor, setting a time and interval for rolling the patients onto their side, and if needed, manually turning dials or pushing buttons to override autonomous operation. There are plans to implement a feature that alerts the user when the patient is in distress or if there is an issue during operation that requires the user's immediate attention.

A4. Technical Analysis

The *Roll24* design takes into account the seven fundamental elements of UI interaction from Don Norman's book, "The Design of Everyday Things"[28], discoverability, feedback, conceptual models, affordances, signifiers, mappings, constraints.

Discoverability

Discoverability refers to a design that is easy for the user to figure out what the device's actions are, the current state of the device, where an action is performed and how to implement it.

The *Roll24* follows this design principle by having a very simple and easy to use control panel with status LEDs, clearly defined buttons, and an LCD display providing information for the user.

Feedback

Feedback refers to the constant stream of information of the status of the device such as its current action, mode the device is in, or the results of an action. The *Roll24* prototype will implement this design principle by providing status LEDs, and an LCD display letting the user know the current state of the device and execution of an action.

Status LEDs are labelled and shall provide the following feedback to the user regarding the status of the device action:

- Green (Solid): In operation and functioning as intended
  - Example: Motors are on and/or in action
- Yellow (Solid): Initializing functions or undergoing setup
  - Example: Device is powered on for the first time and software is going through initial setup
- Red (Solid): Critical failure. Functions all stop then reset.
  - Example: Camera is unresponsive and no longer providing patient positioning therefore it is unsafe to have the motors in action, stop current action and reset to initial state.
- Off: Device powered off

LCD display:

- If any of the sub system is not operating correctly, display error codes
- If setting up the device, display mode and current actions

Conceptual Model

The conceptual model of the system helps users by providing similar experience to ones they may have encountered before. For *Roll24*, it draws comparison to a few common devices such as a camera where positioning it in a way that captures a great photo or a setting the time to cook on a microwave. By making use of these common devices and actions, the user will be able to quickly and easily learn how to operate the *Roll24*.

Affordances

Affordance refers to actions that are possible due to the design and interaction of the device. The *Roll24* has a simple control panel interface that consists of push buttons for actions like setting rolling time interval, status LED and LCD display outputting current operational status of the *Roll24*.

Signifiers

Signifiers refers to the design choices made to ensure effective use of discoverability and feedback in a way that is obvious to the user. The *Roll24* incorporates status LED and an LCD display to provide easy to see signals notifying current status of the device and allowable actions. Depending on the colour of the LED and/or what is outputted on the LCD display,
certain actions are available to the user. If the LED is Green, it signifies that the *Roll24* is on and is operating correctly. Then the user is able to set the time interval by using the buttons and seeing the time on the LCD display.

Mapping

Mapping refers to relation between the controls and the resulting action. It assists the user by making it easy to understand the controls on the *Roll24* and their resulting actions by visually seeing the status LED or output on the LCD display that the button controls are mapped to. Setting the time interval for rolling the patients can be done by the buttons on and knowing the value it's set at can be seen on the LCD display. Knowing that the status LED will go from OFF to Green when the power button is pressed, helps the user intuitively know that the *Roll24* is powered on.

Constraints:

Constraints refers to the limitations of the design that could limit the user's actions when using *Roll24*. To make the *Roll24* as simple and easy to use, limitations such as the camera's video feed is not provided to the user, instead the status LED and the LCD display will provide feedback and limit the user's available actions. *Roll24* requires power and the user must ensure that each electronic component is powered correctly in order for the Roll24 to function as intended.

A5. Engineering Standards

General Engineering Standards

1. **CSA C22.2 No.0:20**
   General Requirements – Canadian Electrical Code, Part II
   This standard specifies the Canadian Electrical requirements for electrical equipment set by the Canadian Standard Association [29]. The standard will describe the requirements for the definitions, equipment, safety, marking, and tests for electrical devices [29].
2. **ICES-001**
   Industrial, Scientific, and Medical (ISM) Equipment
   This standard specifies the emissions limit for radiated and conducted emissions in Canada and defines the method for measurements [30]. Industrial, scientific, and medical equipment are required to comply with these set standards for the product to meet the labelling requirements [30].
3. **IEC 60601**
   Medical Electrical Equipment – Part 1: General requirements for basic safety and essential performance
   This standard specifies the general requirements for safety features and performance standard for medical electrical equipment [31].
4. **IEEE/ISO/IEC 12207: 2017**
   Systems and Software Engineering – Software Life Cycle Processes
   This standard specifies the requirements and guidelines for each stage in the software development process [32].
5. **IEC 60204-1:2016**
   Safety of machinery – Electrical equipment of machines – Part 1: General Requirements
   This standard specifies the general requirements for safety features and recommendations for components in electrical and electronic equipment [33].
6. **CSA C22.2 No. 127-15**
   Equipment and lead wires
   This standard specifies and describes the requirements for the internal wiring of electrical equipment [34].
7. **CSA C22.2 No. 107.1-16**

Power conversion equipment
This standard specifies and describes the requirements for power conversion equipment set by the Canadian Standard Association (CSA) [35].

8. **IEC 61747-1-1:2014**

Liquid crystal display devices – Part 1-1: Generic – Generic specification
This standard specifies the general requirements and general procedures for implementing liquid crystal displays [36]. This standard also provides the procedures for testing the performance to ensure the product meets the market standard [36].

Safety Standards

1. **RoHS Directive**

Restriction of Hazardous Substances
The electrical components must be compliant with the RoHS directive, to ensure that hazardous or toxic materials are not used in the manufacturing of our device [37].

A6. Analytical Usability Testing

This section details the analytical tests to be performed by the Rise engineering team. The initial feedback will help the design team to gauge the quality of user experience, and possible scenarios where error occurs from the user's point of view. Upon finishing these series of tests, the design team should address any fatal error and major

Power Button
When pressed down, the power button should clearly indicate the device is ON with an embedded indicator light. Pressing the power

Push Buttons for Setting Timer
Push buttons should be mechanical and have good responding time even when pressed rapidly. Up button for adding time and down button for subtracting time from the timer.

SET Buttons
SET button will start the repositioning operation after the timer is set.

Status LED Lights
Upon pressing the Power button, status LED light should first turn yellow to indicating initialization and become green with the actuators are in default position and ready operate. When a hazardous situation is detected by the software, the status light will turn red.

LCD Display Panel
Display welcome message when the power is on. Followed by telling the user to set time by pressing/turning the push buttons/knob. When the push buttons/knobs are pressed/turned, the display will show the time duration in hours.

Alarm Speaker
In the case of emergency (LED turned red), an alarm will make noise to notify the care giver something has gone wrong.

A7. Empirical Usability Testing

This section layouts the empirical tests to be performed by the Rise engineering team. The end users with no prior knowledge of *Roll24* will be performing the test. The end users chosen will be from various age group to gauge the intuitiveness of the UI and design. The feedback of the users will be collected to provide insight on areas of improvement for the usability of our interface design. The end users will be asked to perform the following interactions:

End User Activity 1

Lie on the bed

Feedback Questions

1. Did you experience any discomfort or difficulties when attempting to lie on the bed?
2. Is the sling uncomfortable to lie on?
3. Do you have the same range of motion as you would in a normal bed?

End User Activity 2

Attempt to set up an operation duration on the control panel.

Feedback Questions

1. Is the control panel label straightforward?
2. Did you have any difficulties accessing the control panel?
3. Is the LCD panel helpful in displaying information on the control panel?
4. Did you have any difficulties setting up the desired interval?

End User Activity 3

Have the *Roll24* rotate the user

Feedback Questions

1. Were you able to tell when the rotation would start?
2. Was there a visual indicator of the program's status?

A8. Conclusion

Overall, the user interface for the *Roll24* is intended to have a simple set of features that provide only necessary information and control to the user. Also, inspiration has been drawn from similar device interfaces in the hopes that use of the *Roll24* is immediately intuitive for the user. For the proof-of-concept prototype, we have not focused on implementing the user interface yet. This interface can only work once the independent sub-systems are running as intended and given the simplicity of the interface, it is not a priority. The appearance drafted in this appendix will be implemented in our initial design, and will only be changed if usability testing indicates that our design is not intuitive for the user.

Appendix B: Supporting Test Plans

Tester Name:		Date:	
Patient Monitor System			
Relevant Requirement(s)	Procedure	Result	Comments
Camera Sensor			
Des 3.1.4-AP	Camera shows the bed and the patient when mounted 1.5 meters from the top of the bed.	• Pass • Fail	
Data Processing and Motor Control			
Des 3.2.1-AP	Boundary of safe area established with the depth data from camera sensor.	• Pass • Fail	
Des 3.2.2-AP	Patient and their location detected with the depth data from the camera sensor.	• Pass • Fail	
Des 3.2.3-BP Des 3.2.4-BP	Patient Monitor should be able to determine the skeletal orientation of the patient in real-time.	• Pass • Fail	
Des 3.2.5-BP	Patient Monitor should stop the motor from rotating patient if patient is outside of the safe area.	• Pass • Fail	
Chassis and Sling Requirements			
Req 5.1.1	Chassis has no visible structure bending or distortion with real person lay on it	• Pass • Fail	
Req 5.1.2	Chassis is mounted to the end of the testing bed	• Pass • Fail	
Req 5.1.3	Sling can support a patient weight up to 250 lb	• Pass • Fail	
Req 5.1.4	Sling is detachable and washable	• Pass • Fail	
Operational Safety Requirements			
Req 6.1.1	*Verify that moving parts do not touch patient when in use*	• *Pass* • *Fail*	

Req 6.1.2	*Verify edges of moving parts are covered or rounded*	• *Pass* • *Fail*	
	Material Safety Hazard		
Req 6.3.1	*Verify that electronic components are sealed or covered in an enclosure*	• *Pass* • *Fail*	
	Efficiency		
Req 7.1.1	*Verify circuit schematic and visually inspect power adapter*	• *Pass* • *Fail*	

Tester Name:		Date:	
	Hardware Design		
Relevant Requirement(s)	Procedure	Result	Comments
	Stepper Motor Requirements		
Des 4.1.1-AP	Measure dimensions and ratings and compare to NEMA standards	• Pass • Fail	
Des 4.1.2-AP	Place more than 13.5 kg of weights on linear actuator and run the motor	• Pass • Fail	
	Microcontroller Requirements		
Des 4.3.1-AP Des 4.3.3-AP	Directional signals received from the stepper driver and motor moves in that direction	• Pass • Fail	
Des 4.3.2-AP	Data received from data processing unit	• Pass • Fail	
Des 4.3.5-BP	Motors operational range set to the frame's dimensions	• Pass • Fail	
	Stepper Driver Requirements		
Des 4.4.1-AP	Verify directional signals and pulse are sent from stepper driver to motor	• Pass • Fail	
Des 4.4.4-AP	Output current matches current rating of stepper	• Pass • Fail	

	motor for proper functionality		

Appendix C: Supporting Design Options

C1. Camera Sensor

The Kinect V2 SDK comes with demo code for recognizing human skeletal structure which satisfies **[Req 3.1.5-BP]**. A depth sensor with similar resolution and field of view like Intel RealSense is more expensive than Kinect V2.

Figure 35: Intel RealSense [38]

Intel® RealSense™ Depth Camera D415 Features

- Intel® RealSense™ Vision Processor D4
- Up to 1280x720 active stereo depth resolution
- Up to 1920x1080 RGB resolution
- Depth Diagonal Field of View over 70°
- Dual rolling shutter sensors for up to 90 FPS depth streaming
- Range 0.3m to over 10m (Varies with lighting conditions)

Intel® RealSense™ Depth Camera D435/D435i Features

- Intel® RealSense™ Vision Processor D4
- Up to 1280x720 active stereo depth resolution
- Up to 1920x1080 RGB resolution
- Depth Diagonal Field of View over 90°
- Dual global shutter sensors for up to 90 FPS depth streaming
- Range 0.2m to over 10m (Varies with lighting conditions)
- Intel® RealSense™ Depth Camera D435i includes Inertial Measurement Unit (IMU) for 6 degrees of freedom (6DoF) data

Figure 36: Intel RealSense D415 features [39]

Infrared (IR) camera resolution	512 × 424 pixels
RGB camera resolution	1920 × 1080 pixels
Field of view	70 × 60 degrees
Framerate	30 frames per second
Operative measuring range	from 0.5 to 4.5 m
Object pixel size (GSD)	between 1.4 mm (@ 0.5 m range) and 12 mm (@ 4.5 m range)

Figure 37: Kinect V2 features [40]

C2. Stepper Motor

The figure below is in image of the alternative stepper motor [41].

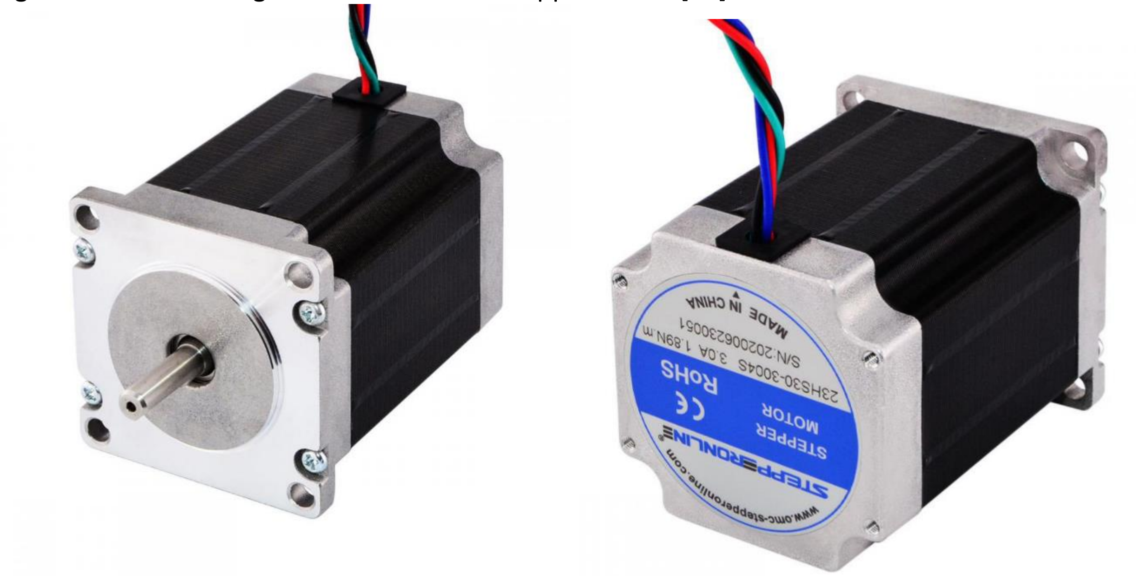

Figure 38: Alternative Stepper Motor [41]

The 23HS30-3004S is a NEMA23 stepper motor that satisfies **[Req 4.1.1-AP]** and **[Req 4.1.2-AP]**. This stepper motor provides higher torque but requires a higher input current when compared with the FM5756SFD04 stepper motor that will be used in the *Roll24* design [42].

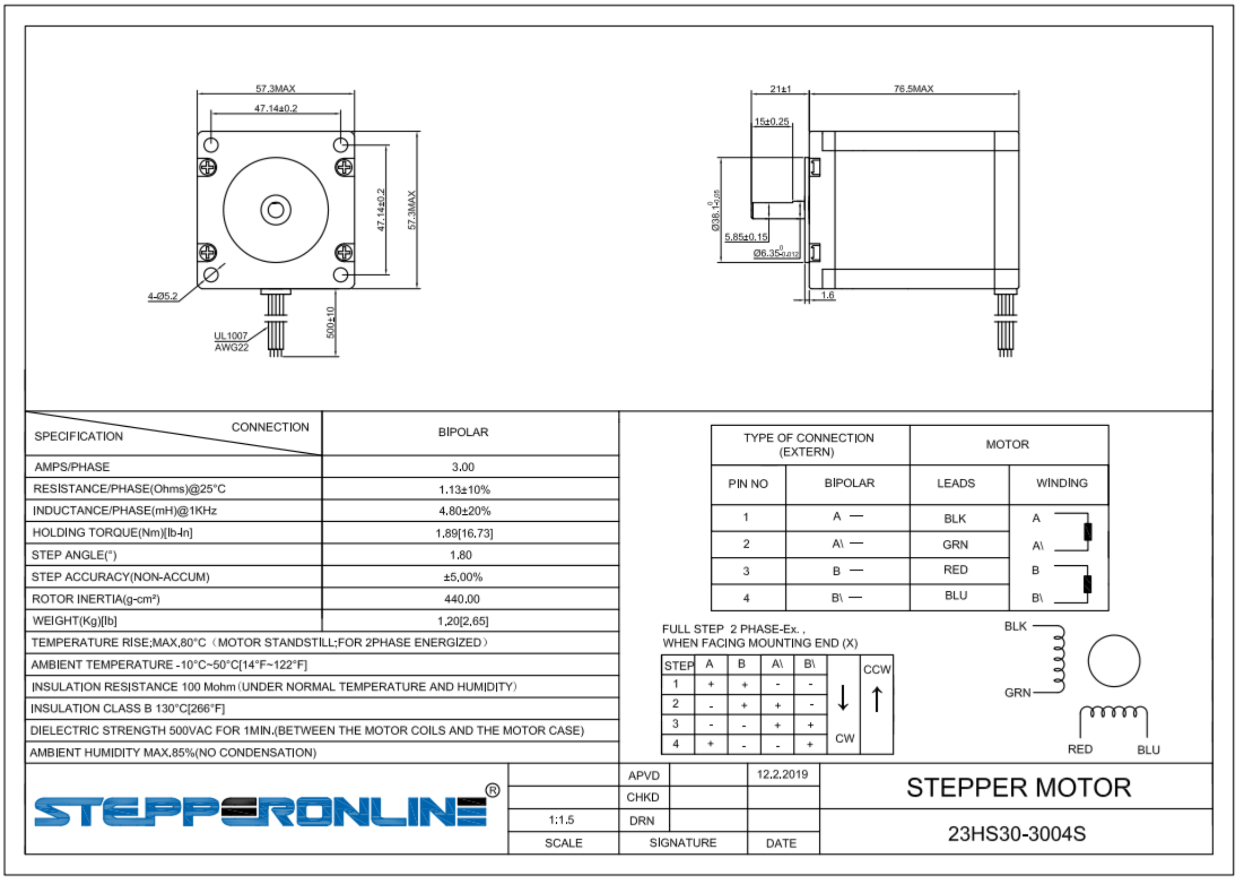

Figure 39: Stepper Motor Technical Specifications [42]

C3. Stepper Motor Driver

The TB6600 is a stepper motor driver that Rise considered in the design of *Roll24*. To meet **[Req 4.2.1-AP]** and **[Req 4.2.2-BP]**, this driver can send control signals to drive the bipolar stepper motors and to control the rotational direction of the stepper motor. This stepper motor driver is a good choice if we need more voltage for a faster response and it's cheaper, but it can also generate more noise due to its higher current output.

Figure 40: Image of the TB6600 [43]

Electrical Specification:

Input Current	0~5.0A
Output Current	0.5-4.0A
Power (MAX)	160W
Micro Step	1, 2/A, 2/B, 4, 8, 16, 32
Temperature	-10 ~ 45℃
Humidity	No Condensation
Weight	0.2 kg
Dimension	96*56*33 mm

Figure 41: TB6600 Technical Specifications [44]

C4. Power Transformer

The ALITOVE AL36V10AT can supply the 345.6W calculated in section 4.4 Power Supply. This power supply takes an input voltage of 110/240V AC, stated in the requirement **[Req 4.3.2-AP],** and has an output voltage of 36V DC which is enough to power the four stepper motor drivers [45]. However, in the design of *Roll24*, the output current of 10A may not be enough to power the *Roll24* system if we wish to power each stepper motor with 3A. [45].

Figure 42: Image of the ALITOVE AL36V10AT [45]