

CHAPTER 3 – RESEARCH METHODS

This thesis will be improving the mobile robot which was previously used for swarm robot purposes, which is done by Dwi Karuna Paramitha. The mobile robot itself already has several components required for this thesis,

3.1. Mechanical Component

Provide basic theory for the simulation model followed up by the formulated model that is going to be developed in the study.

3.1.1. AMR Design (The Robot)

The mobile robot used in this thesis is not new in any sense, but improving an existing mobile robot and the first thing to do was to inspect every part of the existing mobile robot (Figure 3.1).



Figure 3. 1 The Previous Autonomous Mobile Robot by Dwi

After a while of disuse, the mobile robot has a few problems arose such as Loose screws in the mobile robot, not fit, asymmetry (not aligning) the shape of the robot, the robot has not been covered so that it does not look neat and does not look commercially and several other problems have led to the decision to dismantle parts of the frame to make it look

tidier and suitable to the new design. With this decision it creates an opportunity to change several parts of the mobile robot.

The revised robot design will have a shorter and wider frame compared to the previous design. By making the frame shorter and wider, the mobile robot will have more stable structure, since the load sharing will be equally distributed along with the large surface which causes more stable movement for the mobile robot. And for the materials used for the frames (pillars) will use an aluminum profile. Acrylic is used inside and outside for the mobile robot, the outside part will be used for the cover mobile robot so it will look tidier and compact. Meanwhile the acrylic inside the mobile robot will be used as a base in which the electrical components reside. because acrylic sheet minimizes the load from this mobile robot and also acrylic does not conduct electricity, and is thus a safer option to prevent possible short circuits.

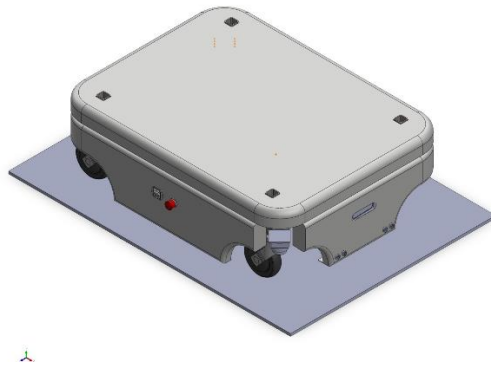


Figure 3. 2 The Autonomous Mobile Robot Design

The Robot has several parts and most of it made from iron plate and iron hollow. The robot has to be really strong because it will carry the items that will placed on cart carrier and delivered or moved the item from one point to other point. In figure () shows the design of the robot and the robot that has been maneuver. The robot that will built in this thesis work will have dimensions are (873 x 659 x 289 mm). This design is assembled to carry 100 kg of load. Furthermore, the robot will also be carrying the motors, batteries and other electronics equipment. The manufacturing method for each part is carried out using several methods, such as; welded, ground, bent, drilled, and threaded in several parts using nuts,

bolts and screws. the robot assambled into several parts, such as; frame, swivel castor, drive mechanism, cover, electrical base plate, and housing for some specified parts.

3.1.1.1 Steel Hollow Frame Design

The frame of this robot is bigger than previous thesis work. The reason of this robot was design larger then previous thesis work because of the distribution of the load is being spread equally to all direction. Secondly, electrical base of this design only have one level which different from previos design that has 2 level of electrical base. The benefit of the lower level of this base is, if in the future the part of the robot need to be fixed or changed, this design can be easily assembled nor disassembled. The frame were made from steel hollow, because this frame is used for the main foundation of this robot, which will later become a support for other parts such as the cover, plate and additional housing. Furthermore, steel hollow is perfectly suitable for this thesis work because it has lighter weight than shaft iron but it can still hold the weight of all parts and easier to manufacture.

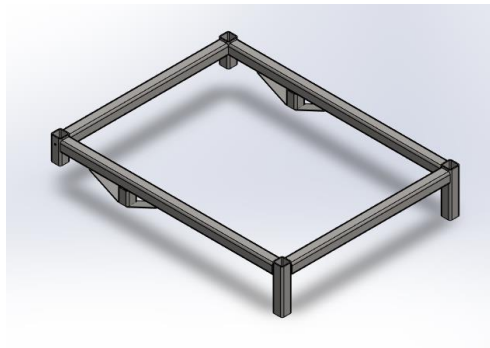


Figure 3. 3 AMR Frame Design

As in the picture, it can be seen that this frame has 6 support points and will be made of steel hollow. These 6 support points will be used for the position of placing 2 pairs of castor wheels and 1 pair of BLDC motors.

3.1.1.2 SeeSaw Drive Mechanism

A pair of castor wheels for the long support (front) mounted directly on the support. While for the rear castor wheel and BLDC motor, it is installed with additional mountings that are connected to the center support. This final design decision was made after several adjustments that had been discussed and adjusted during the manufacture in the field.

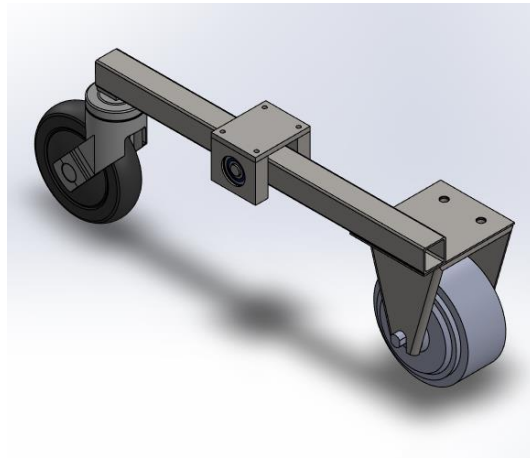


Figure 3. 4 Seesaw Mechanism

As can be seen in the picture, the method of the system is like a seesaw, it uses a pair of ball bearings with a customized housing to support it, which functions to flank one long steel hollow as a place to support a castor wheel to support it. the back of the robot and supports the BLDC motor on the other side, which is located in the center of the robot.

The purpose of this form of design is so that the robot can move according to a slightly bumpy terrain, so that there is no slippage in the movement of the wheels.

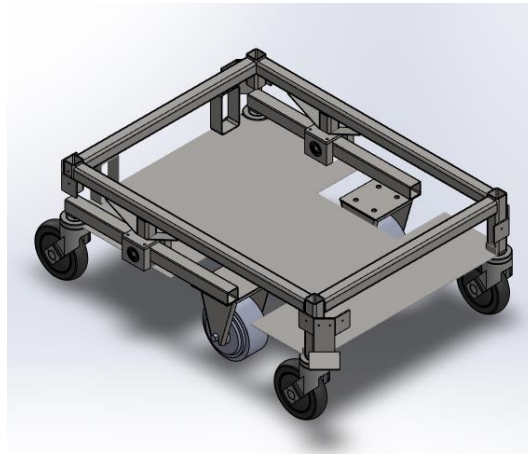
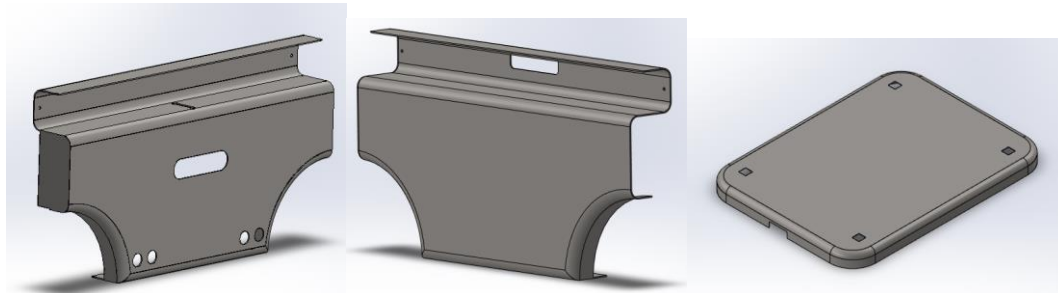


Figure 3. 5 AMR Base

This is final design, where all the drivers and plates for supporting the electrical parts have been installed on the robot frame.

3.1.1.3 Covers

The covers of the robots itself divided into 7 parts; Top Cover, Front Cover, Back Cover, Right Cover, Left Cover, and a couple of Side Cover.



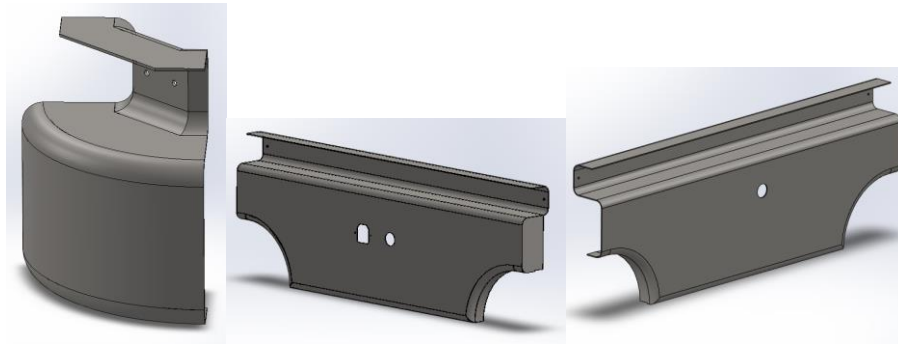


Figure 3. 6 AMR Covers

This design aimed to be aesthetic than previous thesis work or other design so it can be made for mass production.

3.1.2. Locking System

The Autonomous Mobile Robot must be capable of carrying loads on it, so that AMR can be used as a mobile robot in a manufacturing environment that can move products or even be used as a room-sterilizing robot as an autonomous mobile UV-C robot. Subsequently, an autonomous mobile robot will need a device for this task assignment to help it maintain its transportation so that while doing its work, it is not separated from the mobile robot. The method used to retain the conveyance is to lock pins with rack and pinion gear, An aluminum shaft and Stepper motor.

The rack and pinion gear mechanism are used in this locking pin operation to erect the aluminum shaft in lock mode and retract the aluminum shaft back to its initial position when unlocking. A stepper motor is used on each locking pin to drive the rack and pinion gear when operating the locking pin system.

This design chosen as the final design of locking mechanism because it easier to used, operate, and the benefit will be continuously upgraded for the next study. In case, in the future the robot wants to be used not for only for moving product, this locking pin can just disassembly from the robot, and can be used for other accessories. For instance, the robot

wants to be used for sterilizing a room with UV light or self-sterilize disinfectant, it can change to the accessories needed.

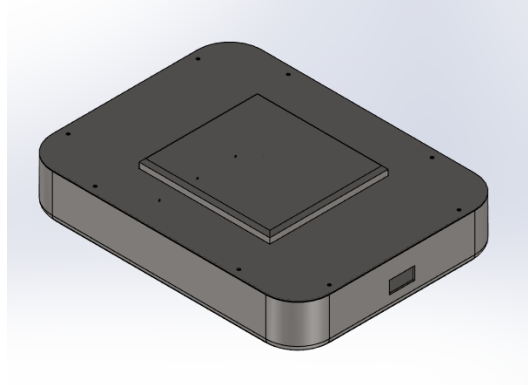


Figure 3. 7 The Locking Pins

In picture...., There are several parts in the platform. The outer part consists of the body cover that have square box shape, and the top cover that have flat shaped. The inner part consists of the upper body and the lower body. In this thesis, a locking system mechanism will be developed, which functions to lock and carry additional carts to support additional goods/loads that are carried and moved.

3.1.2.1 The Outer Square Box

The outer square box covering all parts of mechanism in locking system. So, the inner part could not be seen and present properly. Furthermore, it can be seen perfectly fit covering the robot from the top view.

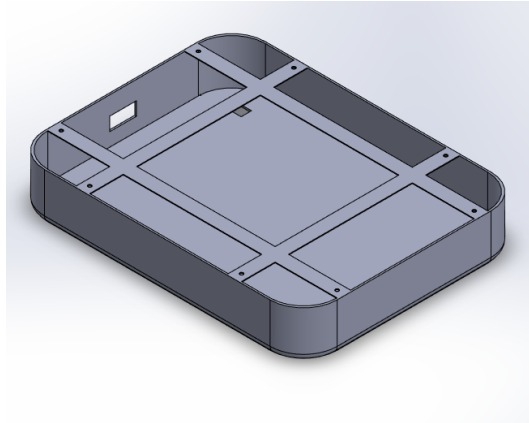


Figure 3. 8 The Outer Square Box

In the middle of the base outer, it was made mounting to lock inner lower body. Support is located at the top outer square box functionated to prop and lock the outer top flat cover.

3.1.2.2 The Outer Top Flat Cover

The outer top flat cover works covering the outer square box. It has the same function as the outer square box. However, this part is covering the inner upper body part.

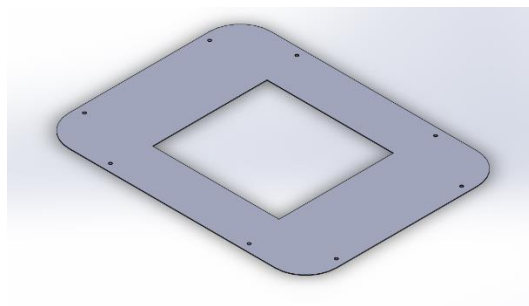


Figure 3. 9 The Outer Top Flat Cover

3.1.2.3 The Inner Upper Body

In the back of this part, the Stepper motor mount that has been welded. The 4 shaft was place in every side of corner.

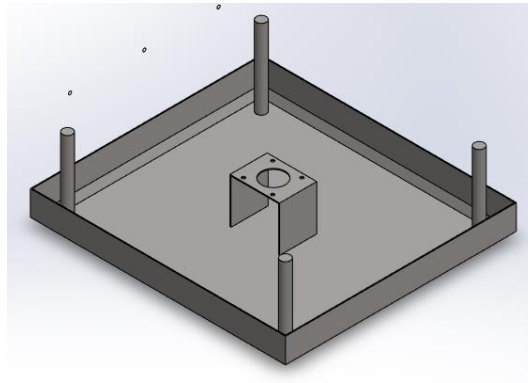


Figure 3. 10 The Inner Upper Body

3.1.2.4 The Inner Lower Body

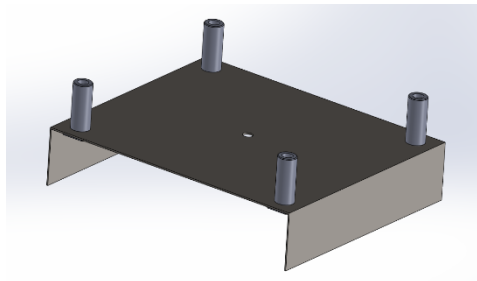


Figure 3. 11 The Inner Lower Body

This part was made to support the upper part, so the dimensions is exactly the same. However, the inner upper body and the inner lower body totally different parts. The inner lower body part used linear ball bearing. There also has 4 linear ball bearing that support the upper body, so when the robot locking the cart and try to pull the cart, those 4 shaft and linear ball bearing will hold it so the steeper motor shaft will not have much load that can caused the motor shaft bending. Because when the inner upper body part is in locking position, it will have different function as it is in the lower position. It will be an anchor to pull the car carrier.

3.1.3 The Cart Carrier

The Cart Carrier made with 2 level platform. The purpose of both levels it can carry an item that need to be moved from one point to another point. The other reason this cart carrier mechanism been chosen because it made the load distribution evenly distributed on each leg and cart caster wheels and will not receive direct load to the robot



Figure 3. 12 The Cart Carrier

This is also a consideration to the load that BLDC motor does not receiving too much pressure, and also does not need to provide bigger torque.

As for the square frame made with hollow in the first platform later will be used as the locking mechanism, so after the locking pin is in locking position the robot will be followed by the cart carrier to anywhere until the locking system is put back to normal position.

3.1.4 Swivel Castor Wheel

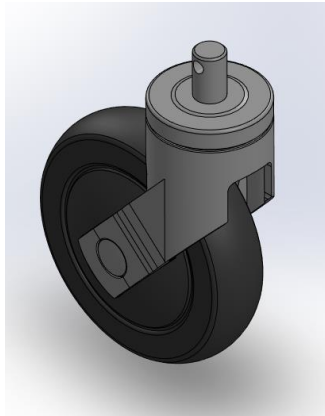


Figure 3. 13 Castor Wheel 5 inch

In this thesis work, swivel castor wheel with no brake will be used as a driver for the AMR robot and the cart carrier. It will be made from high grade synthetic materials, double ball bearing swivel head, solid plug fitting. Swivel castor wheel is chosen in this thesis work because it can rotate 360 degrees. Thus, it can move freely to any direction.

3.2 Electrical Component

Because this study only for the mechanical improved, so in this testing only need some component to test it, is this improved can works as it planned from beginning. As it seems there actually many parts need to be used for an AMR, but for this testing its only needs: the BLDC itself as the center wheels / legs, the BLDC motor driver, the lithium-ion battery, the stepper motor Nema 23 and driver of Nema 23 and also Arduino.

3.2.1 BLDC Motor

This BLDC has been chosen because it has some advantages than previous BLDC motor. With the newest concept of prototype, almost all the part are made of steel alloy. Therefore, the weight is heavier. While the weight of the robot is already heavy plus it will be added by another loaded. Therefore, Motor that has higher torque and lower speed is better for

this situation. Furthermore, this rotor has been used in our university. Base on the data sheet of this BLDC motor, this BLDC motor will be suited with the robot design that will be made.

Basis info

Model No	ZLLG45ASM200
Type	DC Motor
Brand	Zltech
Holding Torque	6n. M
Peak Current	30A
Max Speed	400rpm
Protection Level	IP65
Ambient Humidity	20%~80%
Weight	3KG
Transport Package	4PCS Motors in one package
Origin	Shenzhen, China

Table 3. 1 Basic Info BLDC Motor

The BLDC motor has IP65 protection level means it complete protection against accidental contact, Protection against ingress of dust and Protection against water jets from any direction. Total weight of two motors is 6kg.

Based on the table., this BLDC motor has 30A peak current and holding torque 6n. M with maximum speed 400 RPM.

Structure and Working Principle	Brushless
Certification	ISO9001,CCC,CE
Size	4.5inch
Rate Current	5A-15A
Rated Speed	300rpm

Load	150kg/2sets
Shaft	Single shaft Double
Encoder	1024-Wire Optical
Trademark	ZLTECH
Specification	30.5cm*30.5cm*20cm
HS Code	8501310000

Table 3. 2 BLDC Speciation 1

The size of each motor is 4.5 inch. The rated current required 5A-15A depends on weight received and torque released. The total load that the motor can hold is 150kg with 2 sets motor.

Brand	ZLTECH	Max Torque	12N.m
Product Name	HUB SERVO MOTOR FOR ROBOT, AGV	Rated speed	300RPM
P/N	ZLLG454ASM200 Double Shaft, Tire with Pattern, with Oil Seal	Max Speed	400RPM
Wheel Diameter	128MM	Rated Phase Current	5A-15A
Weight	3.0KG	Max Phase Current	30A
Voltage	24V DC	Poles No.	10 Pairs Polo
Output Power	200W	Encoder	1024-wire Optical
Rated Torque	6N.m	Tire	Rubber with Pattern
		Brake	Electric Brake
		Protection Level	IP65
		Load	150KG/2 Motors
		Adapted Driver	ZLAC706, ZLAC706-CAN, ZLAC706-RC, ZLAC8015

Table 3. 3 BLDC Speciation 2

This motor requires 24V as an input and with that input power, this motor can provide maximum output power 200W and produce certain torque that will move the robot. The

maximum continuous torque available is 6N.m. and maximal rotational force 12n.M. The rated speed of motors is 300 RPM and maximum speed 400RPM.

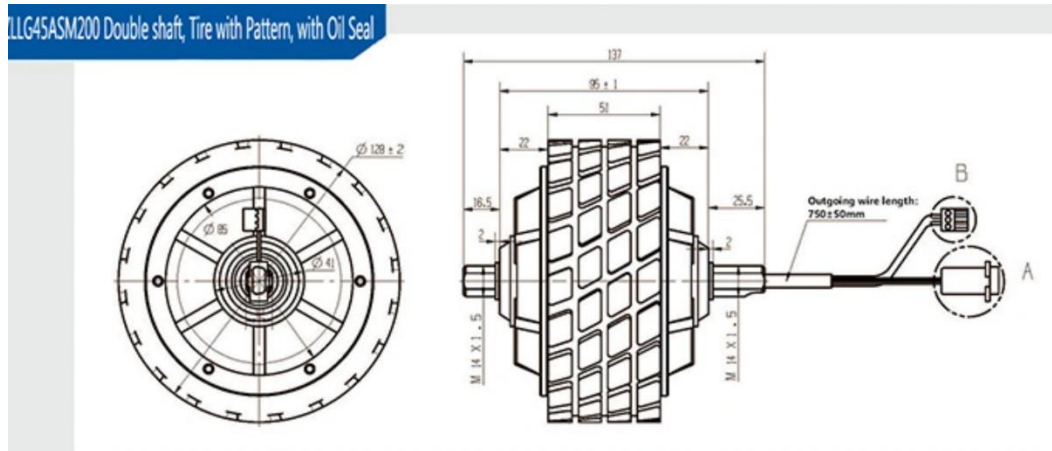


Figure 3. 14 ZLtech BLDC Motor

3.2.2 Driver BLDC

This driver is manufactured by Zltech company same as BLDC motor that has been mentioned before and this driver is chosen because it is coming with one package with the BLDC motor.



Figure 3. 15 ZLtech BLDC driver

Brand	ZLTECH
Product Type	Servo Driver for Hub Servo Motor
P/N	ZLAC8015
Dimension	118.0x75.5x33.0mm
Work Voltage	24-48V DC
Output Current	15-30A
Control Method	CANOPEN, RS485
Adapted Motor	Hub Servo Motor with Power Less than 500W

Table 3. 4 Driver BLDC Speciation

This driver has 24-48V working voltage as input and output. Current on this driver can supply 15-30A to the BLDC motor, this current can achieve the torque that motor needs to move the AMR robot afterwards. This driver used CANOPEN and RS485 as communication control method.

3.2.3 Stepper Motor

Stepper motor, in the context of this thesis, is used to power the locking system with some adjustment. The adjustment that been made for this mechanism is by connected the stepper motor shaft to lead screw with a coupler the one that making it attach.

This stepper motor will be used in this thesis work is NEMA 23. The selected Nema 23 has model number J-5718HB340, This Nema 23 motor was chosen because it has a fairly high torque with a maximum peak current at 4.4A and has a holding torque of 2.3Nm, which is more than enough to support and move the locking system. This will be used in locking pin system to lift up the inner upper body with total weight of 4 kg. The stepper motor will be assembled with the inner upper body where the stepper motor will be attached to the mounting on inner upper body.

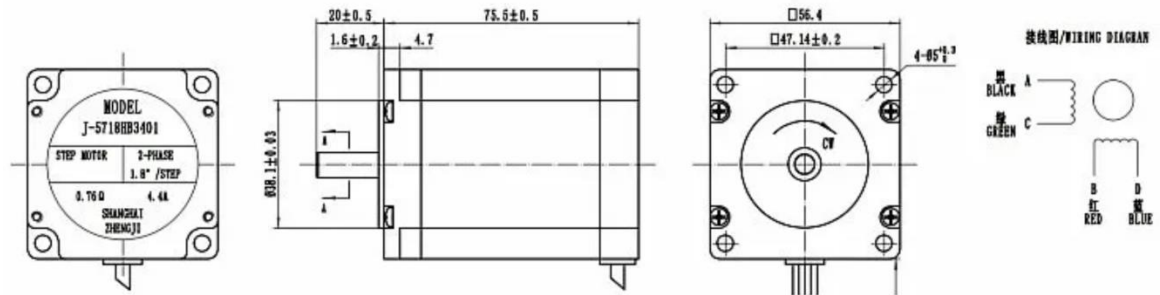


Figure 3. 16 Stepper Motor Nema 23

After several consideration, Nema 23 is been use for this task, The selected Nema 23 type has the following specifications:

型号 MODEL	保持转矩 HOLDING TORQUE		额定电流 RATED CURRENT	相电阻 RESISTANCE	相电感 INDUCTANCE	引线数 LEAD WIRES (PINS)	转动惯量 ROTOR INERTIA		重量 MASS	厚度 L
	N·m	oz-in					g·cm ²	oz-in ²		
J-5718HB3401	2.3	326	4.4	0.76	2.5	4	450	2.46	1.04(2.29)	75.5(2.97)

STEP ANGLE	1.8° ±5%
PHASES	2
RATED VOLTAGE	3.34 V
RATED CURRENT	4.4 A
RESISTANCE	0.76 ohm±10%(20℃)
INDUCTANCE	2.5 mH±20% (1Vrms, 1k Hz)
HOLDING TORQUE	2.3 N.m (327 oz-in) MIN(备注1)
DIELECTRIC STRENGTH	600 V DC 1S
INSULATION RESISTANCE	100 MΩ以上/MIN
INSULATION CLASS	B级
ROTOR INERTIA	450 g.cm ² (2.46 oz-in ²)
WEIGHT	1.04 kg



This Stepper motor later on will be controlled with Arduino Mega and Stepper motor driver, which has been programmed according to the mechanism locking system.

3.2.4 Stepper Driver

Stepper motor requires a driver to control. The driver that is used here is TB6600.



Figure 3. 17 Stepper Driver TB6600

This driver should support the stepper motor working current, because the maximum stepper motor peak current is on 4.4A and the highest peak current that this driver have is 4A, it should be works normally.

Electrical Specifications:

Parameters	Min	Typ.	Max	Unit
Output current	0.7	-	4.0 (3.5 RMS)	A
Supply voltage	+9	+36	+40	VDC
Logic signal current	8	10	15	mA
Puls input frequency	0	-	20 when duty cyle is 25 high / 75 low 13 when duty cycle is 50 / 50	kHz
Insulation resistance	500			MΩ

Further Specifications:

Microsteps / 1,8 °	200		6400
PUL / DIR		yes	
NEMA sizes	17		24
Motor type Mecheltron	42BYGH-XXXX		60BYGH-XXX

Table 3. 5 Stepper Driver Speciation

3.2.5 Bottle Type Battery Pack

This battery is chosen due to the availability of the battery in the workshop in and after some consideration about the voltage and ampere that is required by the electrical part such

as; BLDC Motor, Driver BLDC Motor, Stepper Motor, Driver Stepper motor and Arduino this batter perfectly suit to the robot. Furthermore, this battery more efficient, has more capacity, and higher battery cycle rather than previous thesis work.

With the capacity of the battery has, it requires more than one battery. However due to some limitation, the battery on this theses work will be used only 2 batteries.

Battery Model	SP-36V 12Ah	Continuous Discharge Current (A)	≤ 10
Material System	NCM	Peak Discharge Current(A)	≤ 20
Normal Voltage(V)	36	Cycle life (100% DOD) (Times)	≥ 800
Normal Capacity (Ah)	12	Capacity Retention Rate at °C	$\leq 90\%$
NatteBattery		Self-Discharge Ration	$\leq 5\%$
Dimension(L*W*H)	350*107*76	Temperature Charge	0°C-45°C
Batter Weight (kg)	3.1	Temperature Discharge	-20°C-55°C
Continuous Charge Current (A)	2-4	Temperature Storage	-20°C-45°C
Charge Period (hours)	3-6		
Discharge Cut-off Voltage (V)	28		

Table 3. 6 Battery Speciation

Based on the table, it shows the specification of all electrical component. Also, the diameter of this battery is 10 cm with 32.0 cm length and weight 4 kg. However, it does not long lasting until the battery drain.



Figure 3. 18 Battery

3.2.6 Arduino

Since this program is one of the easiest programs, it is easier to understand and the knowledge of this program is can be found anywhere on the internet. This locking system use stepper motor to make the locking system works go upper or lower the inner upper body



Figure 3. 19 Arduino Mega

The microcontroller is chosen to control BLDC motor and stepper motor. This Arduino will be the microcontroller that is chosen in this thesis work and can control both motors. Arduino is open-source system where this system has been done before by a lot of people and can be done to reach the goals only by some improvements and development.

MICROCONTROLLER	ATmega2560
OPERATING VOLTAGE	5V
DIGITAL I/O PINS	39+15 PWM
ANALOG INPUT PINS	16

Table 3. 7 Arduino Speciation

This Arduino will be operating at 5V. However, the recommended input voltage is between 7V-12V. This Arduino mega provide 54 digital pins consist of 15PWM output. Also, it has 16 analog pins.

3.2.7 Limit Switch

This limit switch is used in locking pink systems. This limit switch will provide data with signal sign to inform Arduino and stepper motor driver that the motors is already in normal position or locking position. In this thesis work, it will be used 2 limit switches.

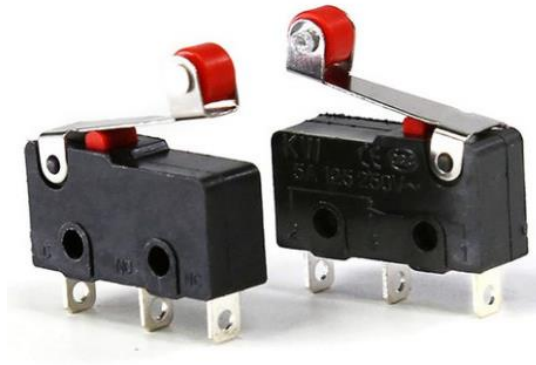


Figure 3. 20 Limit Switch

3.3. Experimental Method

In a concise description, outline the time and venue, the materials and equipment and the experimental procedure to carry out the experiment.

3.3.1. AMR Movement Test

In this test, the robot will be tested by moving the robot forward at certain speed. After that the result data will be obtained. From the data, it can be analyzed the voltage and ampere is required to move the motor with the robot weight and the total robot weight loaded with product or item. From the data, it can be calculated power of the robot and how much the voltage and ampere of the battery is taken. Lastly, the life span battery capacity of this robot can be calculated to know the detail how long the battery needs to be charged after the battery drain. This test result was taken by measuring the movement of the robot going forward using Zltech application.



Figure 3. 21 ZLtech Application Software

In figure () it showed Zltech application. It will be worked by connecting all the cable from motor, driver and the battery that will be connected with driver using communication RS485 to the computer. After all connection is connected, the communication of computer to the driver is open. So, it can be set up.

By clicking menu file and COM settings, port can be selected.

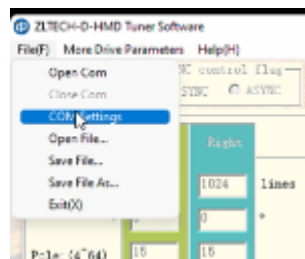


Figure 3. 22 Com Settings

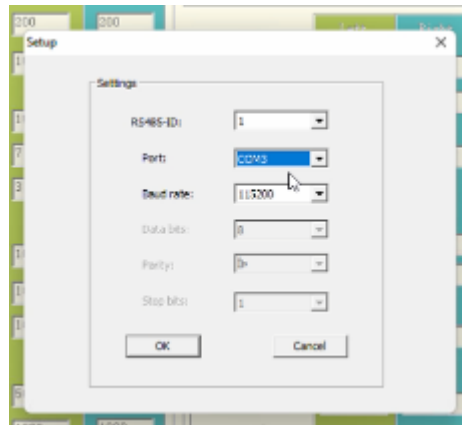


Figure 3. 23 Select Port Setting

Then after selecting the port, selecting the open COMs in menu will be showing the communication between the driver and application on the computer has connected.

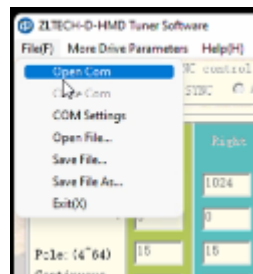


Figure 3. 24 Open Com

When the communication is already open, the control mode is filled with velocity mode.

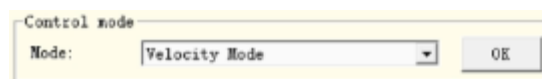


Figure 3. 25 Velocity Control Mode

Lastly, RPM velocity is filled as wanted. In this Test 150 RPM will be used as the velocity for every condition.



Figure 3. 26 Velocity Input Columns

Then by clicking run and write EEPROM, the motor should be running and the Monitor columns will show the data that requires later.

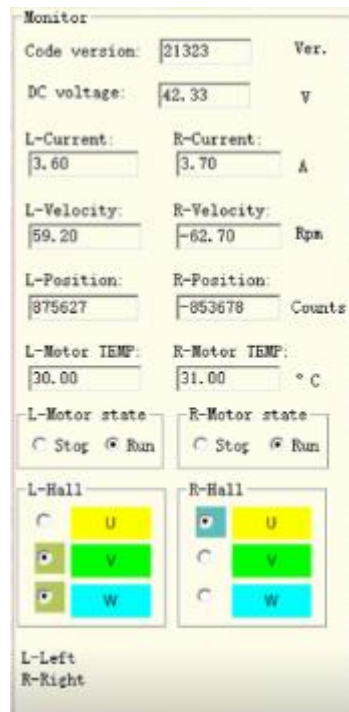


Figure 3. 27 Monitor Columns

In Monitor columns as it seen, there will be given data when the motor start running. The data that been shown in the columns were DC voltage and Current in both motors, this two data result will be used as parameter to calculate the torque that motor generate and to calculate how long the running time of the battery until it totally drains.

3.3.2 Locking Pin Test Up and Down

The checking test of this method is almost the same as previous test. However, this test including stepper motor. This test will make sure does the robot strong enough to tow the cart carrier with maximum item put into the cart carrier. It will also obtain the problem possibility occurs in stepper motor or all component in locking pin.

3.3.3 Stepper Motor Torque Test

In this method, the torque of stepper motor will be tested to know the stepper motor will be strong enough to pull locking pin up and down and holding the locking pin for some time until it goes to the cart. And also, in this method is needed to develop the code to controlling the stepper motor. The code will be made with Arduino IDE, so the stepper can be control with Arduino later on.

3.3.4 BLDC Motor Torque Test

In this method, the torque value will be obtained. This test consists of the robot, locking system, cart carrier and weight item. This test will be resulting the movement of the robot. If the robot does not move, then it requires higher torque even it can break the driver or BLDC motor due to overload current needed. The BLDC motor will be tested to obtain torque and power value required for the BLDC motor to operate in 4 conditions that have been determined as parameter test and another condition including velocity value. In the BLDC Motor torque test, the stipulations that have been set in this test are the distance traveled in 1 meter and the set speed is 1 m/s. and the required voltage for the BLDC motor itself is 42 V. For the torque outcome obtained by using formula;

$$\tau = \frac{5250 \times HP}{n}$$

τ = Torque (N.m)

5250 = constant

HP = Power (1 HP= 746 Watt)

n = revolution per minute (RPM)

To obtain HP value, the power of the motor needs to be calculated by checking how many amperes the motor is draining while operating it in every condition. The power obtained by checking the voltage and ampere. Formula used to obtain the power is;

$$P = V \times I$$

Where;

P= Power (watt)

V= Voltage (volt)

I= Current (Ampere)

Power in watt converted to HP, where the power is divided by 746 watts.

The RPM is obtained by converting speed at 1m/s converted.

Diameter of the wheels is 128mm (0.128m). one revolution in circle assumed as circumference of BLDC motor

$$C = \pi \times d$$

C = Circumference (m)

$\Pi = 3.14$

d= diameter

3.3.5 Battery Durability

In this method, all the voltage and ampere required in BLDC motor will be tested and the running time will be obtained to know how long the electrical component could stay to distribute power until the battery drain out.

With the testing result from Motor torque, the power value of BLDC motor drain will be defined. And from it, can be calculate how long the motor could has running time. For the running time can obtained by using formula;

$$\text{Running time} = \frac{\text{Power Capacity of the Battery}}{\text{The Power Drained by The Motor}}$$

For the Power Capacity of the Battery, itself can be obtain from the data sheet and calculate it with formula;

$$\text{Power Capacity} = \text{Voltage} \times \text{Current Capacity}$$

$$\text{Power Capacity} = 36 \text{ V} \times 12 \text{ Ah}$$

$$\text{Power Capacity} = 432 \text{ Watt hours}$$

So, the capacity that this battery been using have is 432Watt. This value will be used later to calculate the running time.

Beside the calculation from power result, the real experiment data will be also taken and compared to the formula result. In real experiment the battery capacity test will be applying to the conditions when The Robot, Locking System, Cart Carrier, and Extra Load 15kg attach together.