DOĞUŞ UNIVERSITY

INSTITUTE OF ENGINEERING

ACIBADEM CAMPUS

DEPARTMENT OF MECHANICAL ENGINEERING

ME 492

FORKLIFT WITH HIGH MANEUVERING ABILITY

By

ALİ DEĞİRMENCİ

BERRU LAL ALTINBAY

TAYFUN GÜRGEN

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Thanks to our families who have brought us to this day and never withheld your support, our greatest luck in this world.

ABSTRACT

The aim of this project is to increase the maneuverability of the forklifts used in storage so that they can be used more efficiently, making them need less space for their movement.

In this study, we conducted research on the design and manufacture of a multi-directional wheel type called “Mecanum”, which we decided to use to increase the maneuverability of a forklift, and we produced a wheel.

Each wheel, called Mecanum wheel system, has cylindrical wheels placed at a 45° angle to the wheel axis and free-moving wheel wheels on its axis. The wheels are perpendicular to the axis of the wheel while the rotation movement, 45°’li and its own axis to form a vector of motion. In this way, with the changes made in the direction of rotation of the mutual wheels, movement can be achieved in the desired directions. The Forklift can move in any direction in its position. Each wheel has independent stepper motors. The Forklift is remotely controlled by programmable electronic circuits. With the signals coming from the control system, the motors apply drive to the wheels. With the fork, it lifts the load from the front with the reels and belt system. For extra load lifting, the rear load balancing system ensures that the vehicle is in balance.

Some of the technical data of the parts that make up the Mecanum wheel were obtained from the found sources and some were obtained depending on the size and suitability. In addition to making use of the mathematical models obtained from our resources, the model was created by trial and error in the SolidWorks^{tm} program. The model was assembled and tested in SolidWorks^{tm} and confirmed to be working as intended.

ÖZET

Bu projenin amacı depolama alanlarının daha verimli kullanılabilmesi için depolamada kullanılan forkliftlerin manevra kabiliyetlerini arttırarak hareketleri için daha az alana ihtiyaç duymalarını sağlayacak bir hale getirmektir.

Bu çalışmada bir forkliftin manevra kabiliyetini arttırmak için kullanmaya karar verdiğimiz "Mecanum" isimli çok yönlü tekerlek türünün tasarımı ve imalatı için araştırmalarda bulunduk ve bir tekerlek ürettik.

Mecanum tekerlek sistemi adı verilen her tekerleğin üzerinde teker eksenine 45° açı ile yerleştirilmiş silindirik ve kendi ekseninde serbest hareketli jant tekerler bulunmaktadır. Tekerlekler dönme hareketi yaptığı sırada teker eksenine dik, 45°'li ve kendi ekseninde olmak üzere hareket vektörü oluşturmaktadır. Bu sayede karşılıklı tekerleklerin dönüş yönlerinde yapılan değişiklikler ile istenilen yönlerde hareket sağlanabilmektedir. Forklift bulunduğu pozisyonda her yönde hareket edebilmektedir. Tekerleklerin her birinde ayrı bağımsız step motorlar mevcuttur. Forklift, programlanabilir elektronik devreler ile uzaktan kontrol edilmektedir. Kumanda sisteminden gelen sinyaller ile motorlar tekerleklere tahrik uygulamaktadır. Çatal ile önden almış olduğu yükü makaralar ve kayış sistemiyle kaldırmaktadır. Fazladan yük kaldırması için arka kısmına yük dengeleyici sistem yaparak aracın dengede olması sağlamaktadır.

Mecanum tekerleğini oluşturan parçaların teknik verilerinin bir kısmı bulunan kaynaklardan bir kısmı da ölçü ve uygunluğa bağlı olarak elde edildi. Kaynaklarımızdan elde ettiğimiz matematiksel modellerden faydalanmanın yanı sıra SolidWorks^{tm} programında deneme yanılma yolu ile de model oluşturuldu. Oluşturulan modelin montajı yapılıp çalışabilir olduğu SolidWorks^{tm} programında denemesini yapılarak amaçlandığı gibi çalıştığı teyit edildi.

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NOMENCLATURE

Quantity	Symbol	Unit
Diameter	Ø	mm
Radius	R	mm
Mass	kg	kilogram
Force	F	N
Load	L	N

ABBREVIATIONS

CAD	Computer Aided Design
CNC	Computer Numerical Controller
DOF	Degree of Freedom
UART	Universal Asynchronous Receiver Transmitter
PWM	Pulse Width Modulation
USB	Universal Serial Bus
ICSP	In-circuit Serial Programming
SRAM	Static Random Access Memory
EEPROM	Electronically Erasable Programmable Read-Only Memory
IDE	Integrated Development Environment

1. INTRODUCTION

Forklifts used today use conventional wheels to move. However, the movement of conventional wheels is limited to a one-dimensional displacement; this feature is useful in some cases. Because it cannot move in the second dimension due to friction. In Normal wheeled forklifts, it is important to avoid freedom of movement to limit unwanted behavior and make maneuverability more intuitive for the driver. However, considering the lower speeds, this restriction is undesirable, as it forces the system to perform several maneuvers to make simple movements. In these cases, standard forklifts have little maneuverability, so their movement is restricted. To increase the maneuverability of the forklifts, Mecanum adds wheels to increase their movement areas, allowing them to operate in tight spaces. [2]

Mecanum wheeled vehicles have advantages over traditional wheeled mobile robots in terms of mobility, especially in closely spaced environments, e.g. in factories, offices, hospitals, and similar areas. Special wheels and structure are needed for the mobile robot to have versatile maneuverability. Using the four-wheel structure ‘Mecanum wheel’ are examples of versatile platforms.

Especially the transfer or transport of long loads from the production line to the shipment line is a very time-consuming process with conventional fork loaders, while this process will be much more practical with a fork loader capable of crab walking.

1.1. Definition and History of the Mecanum Wheels

The most important feature of Mecanum wheels is that they have three degrees of freedom. This degree of freedom is the biggest advantage of Mecanum wheels. Because of these properties, Mecanum wheels can provide movement on three axes. It consists of cylinders attached to its periphery and can rotate freely around its axes in cylinders. The cylinders have a rotation axis of 45° that passes through the center of the cylinder, parallel to both the plane of the wheel and the axis of rotation of the wheel. The wheels in this structure are called Mecanum wheels. The Mecanum wheel was designed and invented by Ilon Bengt of Mecanum AB Company in 1975. [1] Afterwards, The United States Army purchased this patent and was in development work in Panama.

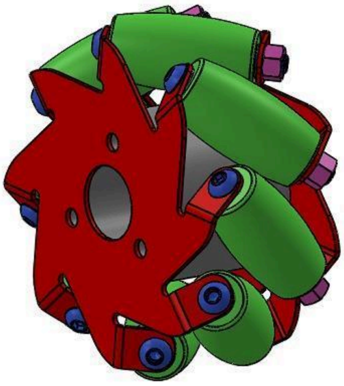


Figure 1: 3-Dimensional View of Mecanum Wheel

1.2. Problem Statement

Nowadays, forklift is used in many areas such as warehouse, factory interior and exterior. As the forklift is not maneuverable enough, a specific area of movement is required for it to operate. Conventional four-wheel forklifts maneuver it becomes quite difficult to maneuver in a narrow space. In this case it greatly increases occupational accidents. We want to minimize this space by using the forklift in our design.

Figure 2: Standard Wheels Forklift

1.3. Solution

We wanted to find a solution to increase the efficiency of this situation and as a result of our research we planned to use a wheel called "Mecanum" on the forklift that allows the vehicles to move at 3 degrees of freedom. As a result of research, we learned that these wheels increase the vehicle's maneuver. In this thesis, we used these wheels in our model we designed. In this way, we have proved that when we compare our designed forklift with the forklift used in simulation environment, it increases its maneuver.

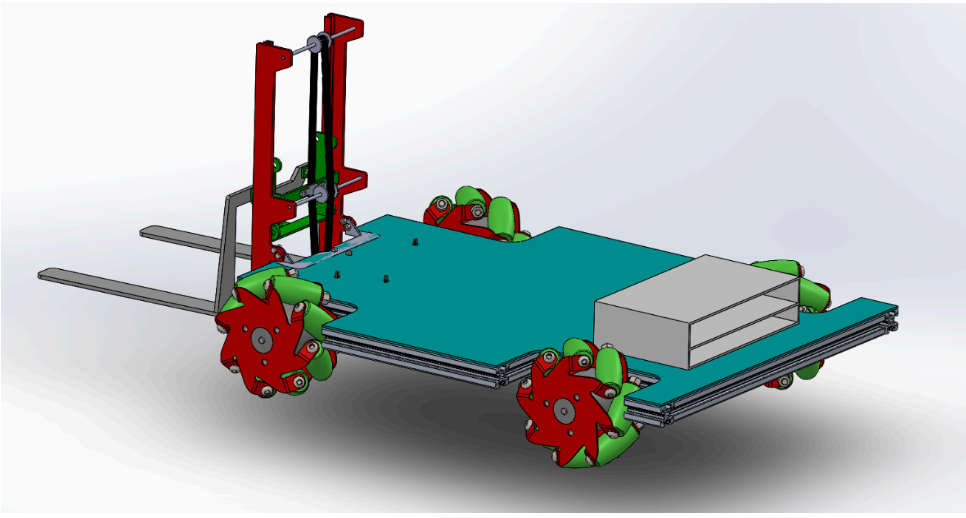
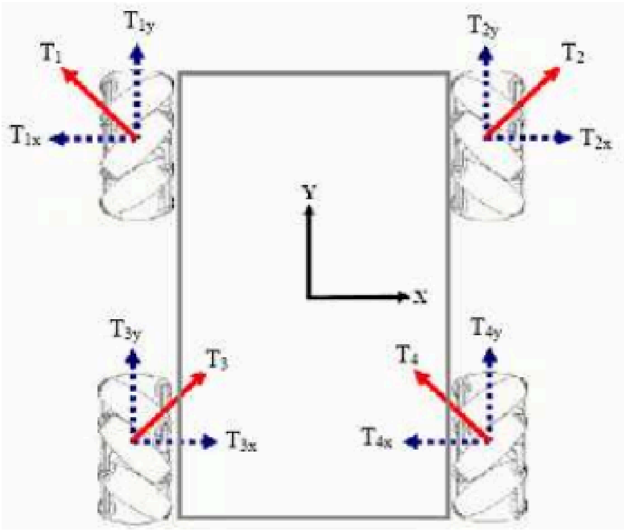


Figure 3: The Vehicle Which We Designed

1.4. How it Works?

The angled peripheral rollers translate a portion of the force in the rotational direction of the wheel to a force normal to the wheel direction. A vehicle using four of these wheels has an omni-directional movement without needing a conventional steering system. In the omni-directional wheel, its velocity can be divided into the components in the active direction and in the passive direction. The active component is directed along the axis of the roller in contact with the ground, while the passive one is perpendicular to the roller axis. [3] Depending on each individual wheel direction and speed, the resulting combination of all these forces produces a total force vector in any desired direction, thus allowing the platform to move freely in direction of the resulting force vector, without changing the direction of the wheel. By a simple control of each wheel rotation, the robot moving direction can be changed instantaneously.



By varing the individual wheel speed we can achieve driving direction along any vector in X-Y aixs

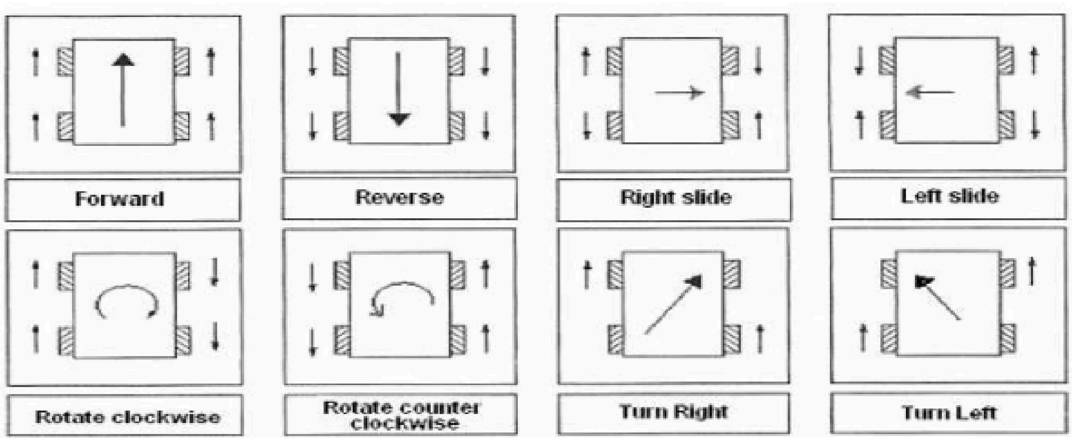


Table 1: Mecanum Wheel Robot DOF

1.5. Forklift Application of Mecanum Wheel

It is possible to see this wheel as very common, which is not very common today but provides considerable convenience for places where movement restrictions are below expectations in the future. The versatile wheel system is now being used in the next generation of unmanned load transport vehicles, load transmission lines, medical vehicles, industrial robots, military and defense industries as seen in Figure 5 and has already become a commercial product. [3]

Figure 4: Kuka Transporting Mecanum Platform

Advantages of multi-wheel driven fork loaders over conventional fork loaders.

* The front of the user is completely open, as there is no need for a steering system.

* It offers the possibility of moving long loads from one area to another while crossing doors at once.

* Reduces the number of maneuvers the user makes during loading and unloading operations in tight spaces by about 70%, resulting in serious time savings.

* Since it is controlled only with control arms, the feet are not needed, it offers the possibility to be used for disabled users who do not hold or are not below the waist.

Disadvantages.

* The floor surface should be smooth and flat.

* 50% more expensive than conventional fork loaders.

* Wheels wear and tear twice as fast as normal wheels.

1.6. Modeling

This is a top view looking down on the drive platform. Wheels in positions 1, 4 should make X-pattern with wheels 2, 3 (Figure 5). If not set up like shown, wheels will not operate correctly. Directions can be determined according to wheels rotations. Desired movements of this system and wheel rotations are listed in Table 2.

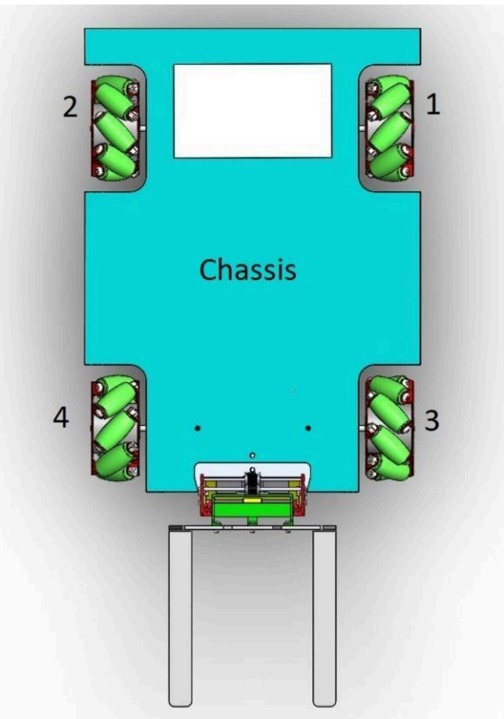


Figure 5: Forklift Top View

Direction of Movement	Wheel Actuation
Forward	All wheels forward same speed
Reverse	All wheels reverse same speed
Right shift	Wheels 1,4 forward 2,3 backward
Left shift	Wheels 2,3 forward 1,4 backward
Right forward	Wheels 2,3 forward 1,4 stop
Left forward	Wheels 1,4 forward 2,3 stop
Right backward	Wheels 1,4 backward 2,3 stop
Left backward	Wheels 2,3 backward 1,4 stop
CW Turn	Wheels 1,3 forward 2,4 backward
CCW Turn	Wheels 2,4 forward 1,3 backward

Table 2: Directions according to wheels rotation

2. MOTOR TORGUE CALCULATION

The output torque of the motor is the quantity of force where its output shaft can rotate. The output of the motor shaft may stall, or even stop turning if torque is over applied to it. Torque is relating to force and distance, which is:

$$T = F \times d$$

$$F = m \times a$$

where T is torque, F is the force, and d is the distance which from the centre of the turning axis to the outside of the wheel is the radius of the wheel R, m is the mass of vehicle, and a is the acceleration. [5]

As Mecanum wheel with diameter 120mm is chosen, and the vehicle acceleration is assumed to 1 m/s^2, 10kg as general vehicle weight.

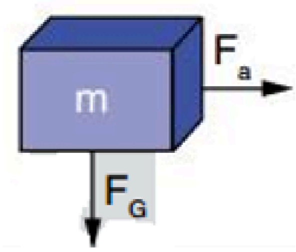


Figure 6: Component of Axis

$F_G = m \cdot g = 10\ kg \cdot 10 m/s^2 = 100\ N$
$F_a = m \cdot a = 10\ kg \cdot 1 m/s^2 = 10\ N$
$T = F_a \cdot R = 10\ N \cdot 0.060\ m = 0.6\ N \cdot m$

where F_G is the force of gravity, g is the acceleration of gravity in this situation where the value is 10 m/s^2. F_a means the force produced by the assumed acceleration a. T is the whole torque of the four wheels. Torque of each wheel on the flat ground:
$T_i = 1/4 \cdot T = 0.15\ N \cdot m$

2.1Motor Speed Calculation

The output speed of the motor is the rotating velocity where the output shaft revolves. There is the output speed reducing when the payload of the motor rises.
Speed in motor is proportional to the voltage applied to the rotor. The following equations show the relationship between the power produced by the motor P, voltage V and current I.

$$P = V \times I$$
$$P = T \times \omega$$

Where T is torque, ω is angular velocity in radians per second. It can increase the voltage rating or current to increase the power output, but the more voltage rating increases, the more dangerous the operator will be. Thus, in this case, 24- or 48-volts motor which is commonly used for medium mobile robots is preferred to use. As seen from equation, the motor selection is also mainly based on rotation speed and torque. Motor torque turns the vehicle wheels and drives the vehicle. And the vehicle speed depends on the rotation speed of the motor shaft and the diameter of the wheels. [4]

After visiting some worldwide motor websites and consulting to some robot makers, A nema23 stepper motor is selected.

Step Accuracy	±5%
Resistance Accuracy	±10%
Inductance Accuracy	±20%
Temperature Rise	80℃ MAX
Ambient Temperature Range	-20◦C~+50◦C
Storage Temperature Range	-30◦C~+60◦C
Insulation Resistance	100M Ω MIN 500V DC
Dielectric Strength	500v AC 1 MIN
Radial Play	0.02 mm MAX (450g Load)
End Play	0.08 mm MAX (450g Load)
Max Radial Force	75N
Max Axial Force	15N

Table3: General Specifications of Nema 23

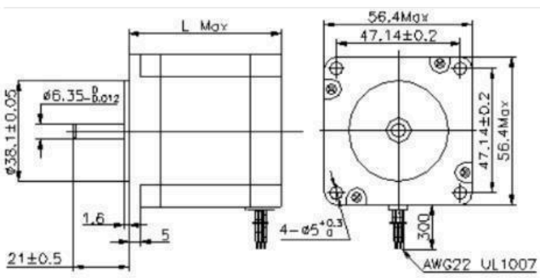


Figure 7: Mechanical Dimensions

3.FORKLIFT DESIGN

The Forklift prototype generally consists of 4 main elements.These are as follows in order.

1. Main motion modules: includes chassis and wheels

2. Leverage module: tabs and support parts on the front

3. Control unit: Arduino, electrical parts such as batteries

4. Weight module: vehicle weight stabilizer

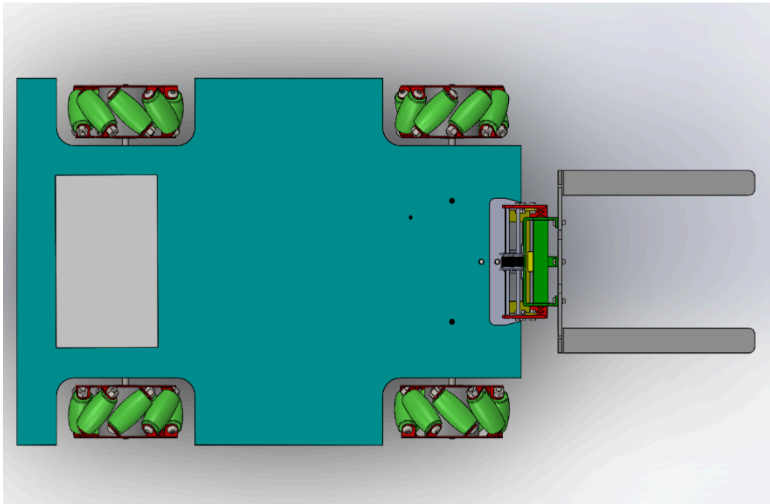


Figure 8: Forklift Top View

The biggest challenge in the design of the cylinder is the requirement that the rolls form a full circle when viewed in line with the center axis of the wheel, as seen in Figure-2. The rollers are fixed with pins by adding bearings to the wheel rim. In this case the cylinders can be replaced in case of any deformation or damage.Rollers have been selected as polyamide where the material is more flexible. [5]

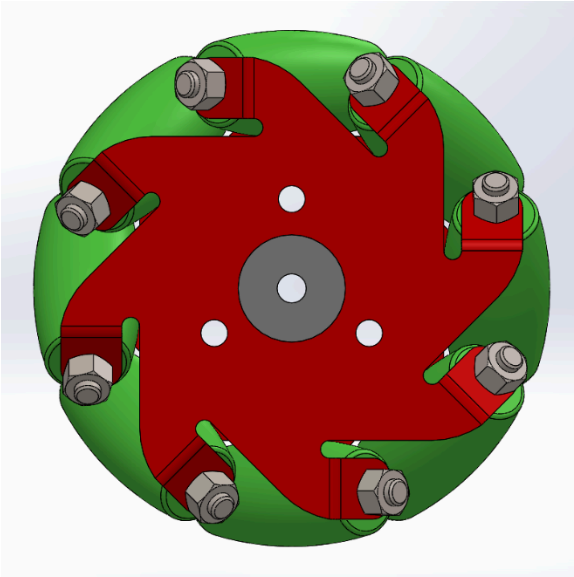


Figure 9: Mecanum Wheel

3.1.Lift and Fork Module

The maximum load we want to remove has been determined.Torque calculation was made for stepper motors that could operate under these loads. The fork and lever section were designed to fit this engine. Primarily the leverage portion is formed by side walls consisting of two main parts. Part of the forks to these side walls and Shashe connection holes have been opened. The decal plate was used to connect the fork to the tower. The reels and belt system provide the movement of the fork up and down.

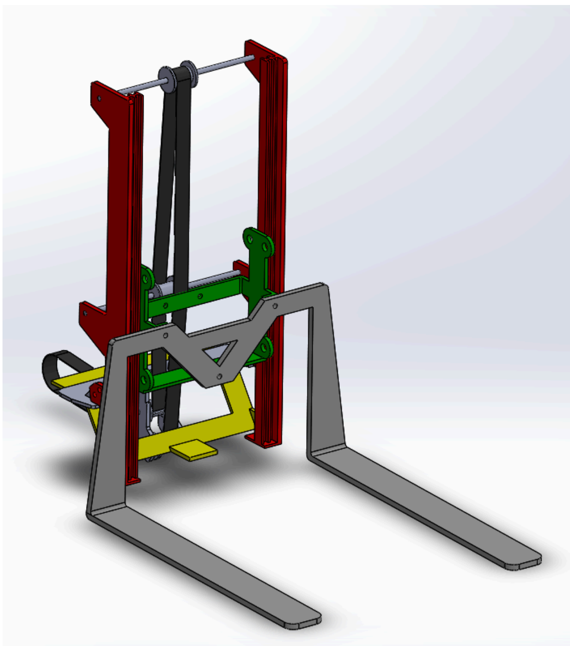


Figure 10: Lift and Fork View

3.2. Control Panel

The Arduino Mega 2560 is powered from USB and can be powered by an external adapter or battery. The Arduino Mega card needs power between 6-20 V volts to operate in a balanced way. The car has 1 12 V 3A battery. The capacity that this battery provides us is 12000mpa. This power is supplied by our chosen battery. This battery is used for 5 step motors in this project we used 5 motors and defined one driver for each engine. These engines were used for 4 wheels and one lever.

For each movement command given to the vehicle, the signals that the engines load on the wheels must be different. Our forklift has 12 mobility. In order to perform these movements, each wheel and lift were individually programmed. [6]

Figure 11: Ardunio Mega Top View

Microcontroller	ATmega2560
Operating voltage	5V
Supply voltage (recommended)	7-12V
Supply voltage (Limit)	6-20V
Digital I / O pins	54 (14 PWM output)
Analog Input Pins	16
Current of I / O pins	40 mA
3.3 V Pini current	50 mA
256 KB of Flash memory	256KB (of which the bootloader uses)
SRAM	8 KB
EEPROM	4 KB

Clock Frequency	16 MHz

Table 4: Arduino Mega Features

It is programmed via Arduino IDE. It comes on the Bootloader (the piece of code that allows you to install software on the card). You can skip the bootloader and program the microcontroller directly via ICSP.

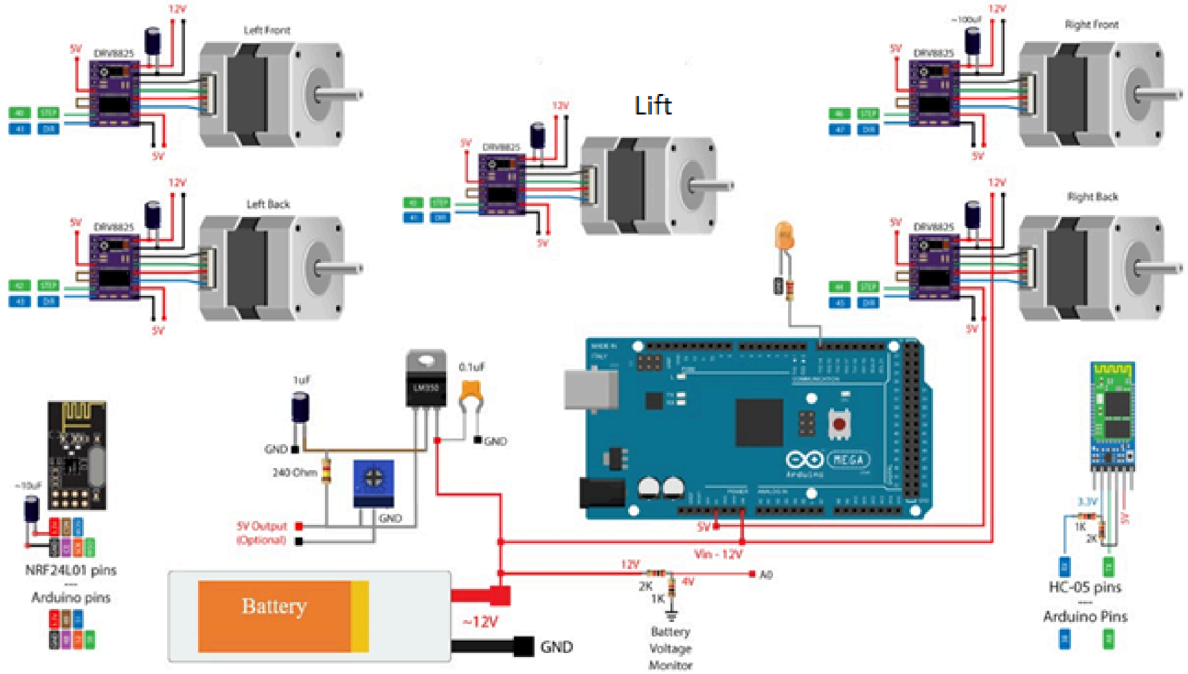


Figure 12: Control Circuit Diagram

3.3. Weight Module

Our forklift has a mass of 5 kg. The Forklift can be left behind when we get extra load. To prevent this, we have developed a weight system that we can add manually. The goal is to add a plaque that will prevent the forklift from lying on the back when the extra load is lifted. This plate weight is 2.3 and 5 kg respectively. By making this system, the forklift remains in balance.

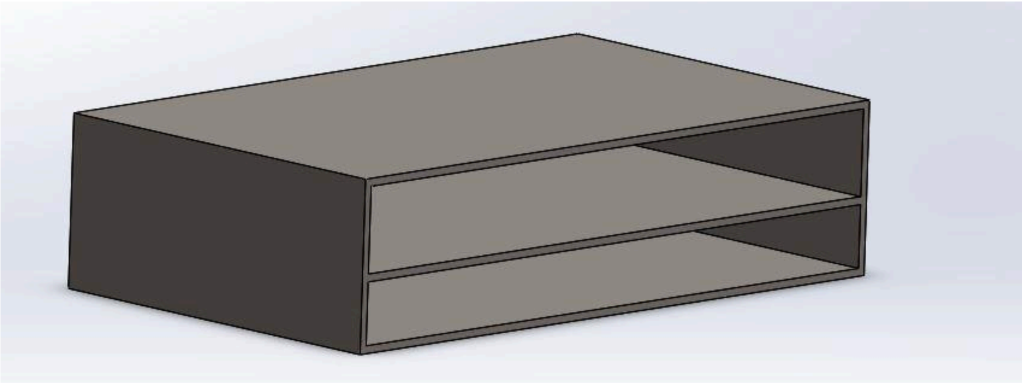


Figure 13: Mass Balance

4.MECHANICAL DESIGN

The design of Forklift is needed to consider three fundamental characteristics which is maneuverability, controllability and stability based on both wheel types and configuration. As mentioned before, omnidirectional wheels are selected because it has better maneuverability and mobility to move in any direction. This part introduces some information about Mecanum wheel and the mechanical design of this type of wheel. [7]

The most important aspect of this thesis and its backbone is the mechanical design of the Mecanum wheel. The Mecanum wheel has certain design features and some parameters must be considered. Not all our designs may be efficient, and trial and error Cannot be blindly relied on. We decided to design our own Mecanum wheeled forklift truck in such a way that its dimensions are useful. There are some basic points to consider in the design. These are as follows in order.

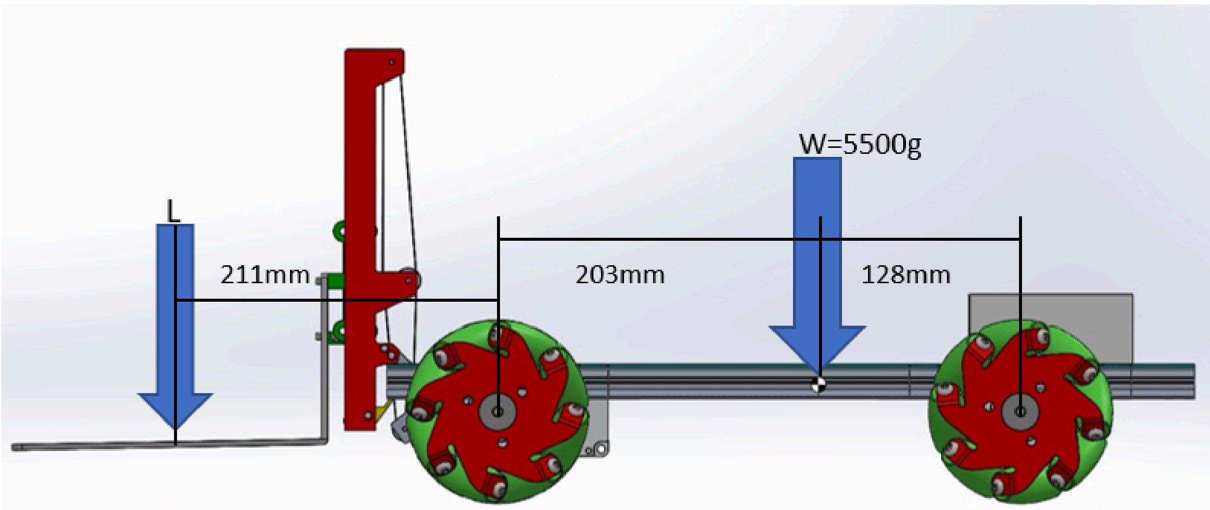


Figure 14: Forklift Side View

$$N_1 = N_2$$

$$N_1 + N_2 = 5500 + L$$

$$0 = 203 \times 5500 - 330 \times N_2 - 211 \times L$$

$$L = 800$$

$$L_{max} \times 211 = 5500 \times 203$$

$$L_{max} = 5290$$

According to the dimensions most load will be on the rear wheels when unloaded and on the front when loaded above 800g load. And the load on the back wheel becomes 0 when lifting any weight above 5290g, which means the vehicle will tip over.

The critical weight and the critical wheel are known the stress on the rollers will be:

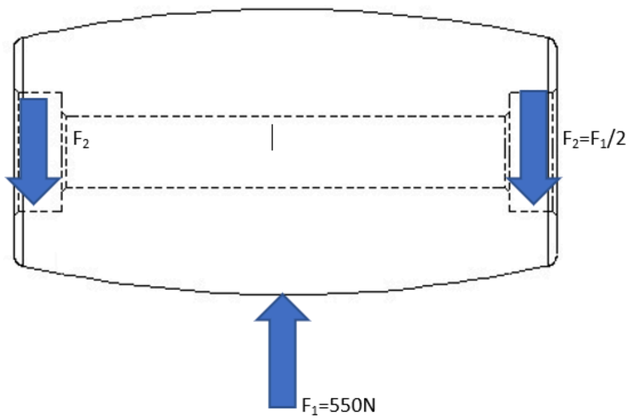


Figure 15: Rollers Technical Drawing

$$\tau = \frac{550}{\pi(0.01^2 - 0.0005^2)}$$

Maximum shear stress due to forces is calculated to be $\tau = 1,167 MPa$ which is much less than the material we are using has, Delrin at 53MPa maximum shear strength.

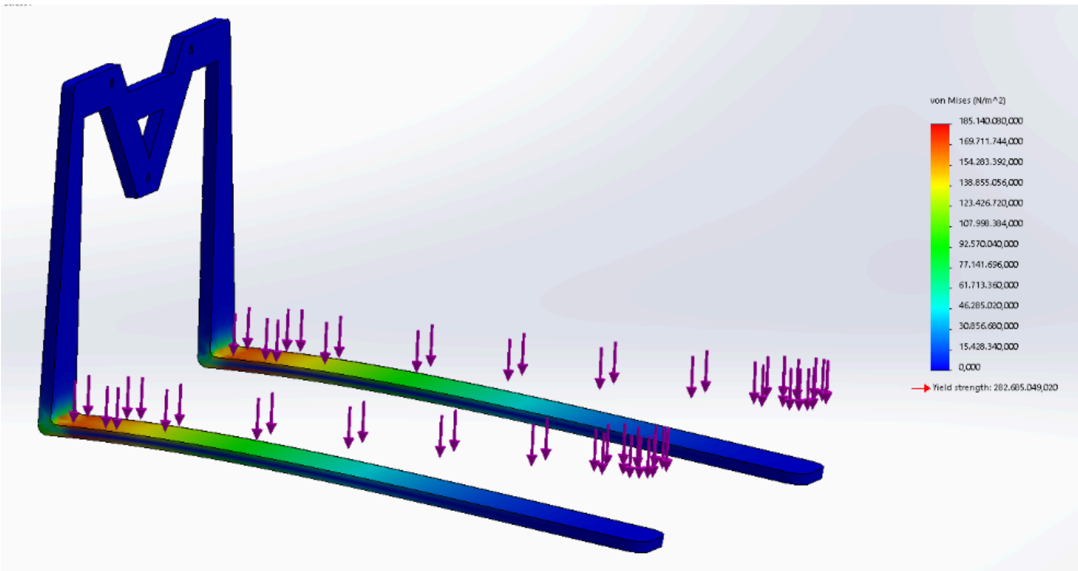


Figure 16: Fork Analysis

Also, another strength analysis was conducted using on the fork using SolidWorks and it passed easily on a much higher load test.

4.1. Kinematics

The vehicle of the Tomation project will use the Mecanum wheels to move autonomously from path to path in greenhouses. To control the vehicle and to take properly advantage of the properties of the Mecanum wheeled vehicle, the kinematics of these wheels should be analyzed. Using the kinematics, a proper model of the vehicle can be created. This section starts with an analysis of the kinematic model of a vehicle with Mecanum wheels. Next, some analytical findings on the kinematics and the rollers of the wheel are discussed. Finally, an experiment for obtaining a practical model by adjustments to the kinematic model is described and analyzed. [7]

5.ASSEMBLY

The assembly of our parts is constructed using computer aided design program (CAD).Mecanum wheel, fork and Tower elements are formed in the installation environment. The model we created was designed as a prototype. First, we designed the Mecanum wheel. the weight of all other parts, including the carrying load, was designed according to the loads coming on top of the Mecanum wheel. Figure 17 as you can see. [8]

5.1 Mecanum Wheel Parts

The Mecanum caster collection consists of six pieces. First, we fixed two wheels which were main trotters and eight cylinders were added to the wheel parts. Then we added the decks. These are bearings, bolts and nuts, respectively. We added bearings to all our cylinders and connected each other to the other body part.

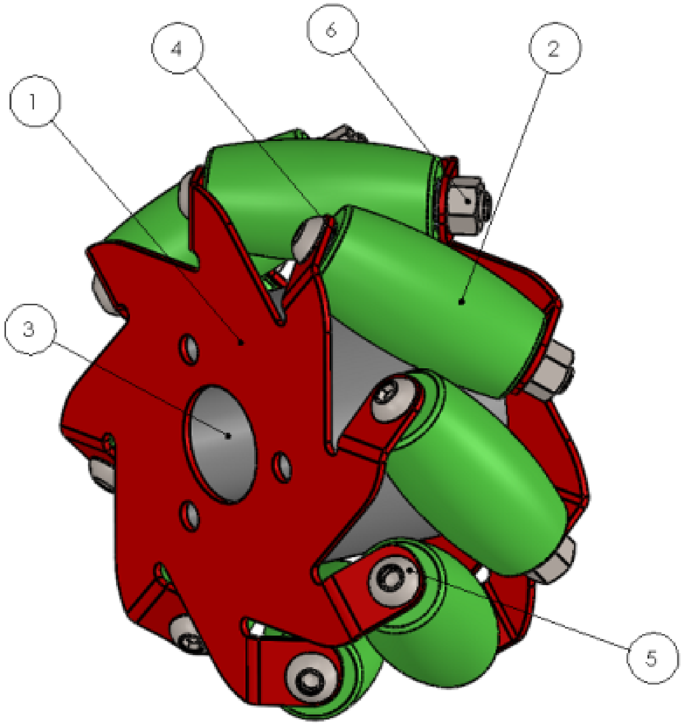


Figure 17: Elements of Assembled Mecanum Wheel

Specifications (for an individual wheel):

- Diameter: 150 mm
- Body Material: Structural Steel
- Load Capacity: 15 kg
- Weight: 1 kg
- Number of Rollers: 8

Element No	Part Number	Piece
1	Rim	2
2	Rollers	8
3	Hub	1
4	Bearing	16

5	Bolt-ISO 738 – M6 x 60	8
6	Nut-ISO – 4034 – M6 - N	8

Table 5: Assembly Part Number of Mecanum

5.2.Fork and Lift Elements

The mechanism is connected to the chassis by points 1 and 2 as shown below.Belt and reel systems were used to facilitate the movement of the system.

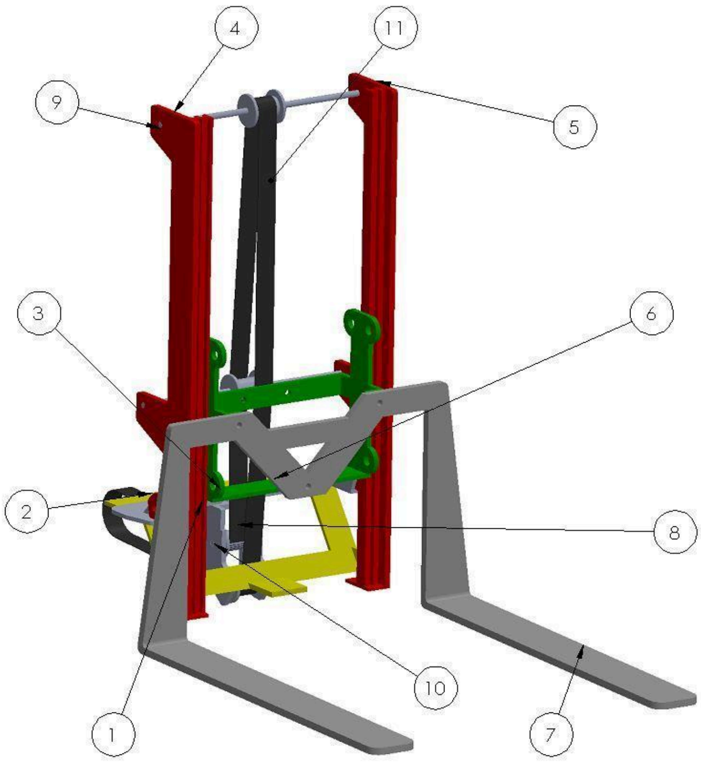


Figure 18: Elements of Assembled lift

Specifications (Fork and lift):

- Working height: 300 mm
- Body Material: Structural Steel
- Load Capacity: 8 kg
- Weight: 2 kg

- Fork width: 200 mm

Element No	Part Number	Piece
1	Belt Connection	1
2	Construction.Connection-1	1
3	Construction.Connection-2	1
4	Side Wall Right-1	1
5	Side Wall Left-2	1
6	Construction.Connection-3	1
7	Lift	1
8	Ring.16x17	4
9	Shaft x114xD3	2
10	Shaft x23xD3	2
11	Belt- 96-12	1

Table 6: Assembly Part Number of Lift

6.EXPENDITURE CALCULATION

6.1Purchased Cost

Element No	**Materials**	**Piece**	**Unit**	**Material Cost(Unit)**	**Process Costing**
1	Nema 23 Step Motor	5	Piece	159,77 ₺	798,85 ₺
2	Sigma Profile	3M	Wholesal e	25 ₺	75 ₺

3	Ardunio Mega	1	Piece	328 ₺	328 ₺
4	20 x 4 LCD display with Ramps 1.4 compatible	1	Piece	45 ₺	45 ₺
5	Ardunio Mega	1	Piece	328 ₺	328 ₺
6	USB cable from A to B	1	Piece	4 ₺	4 ₺
7	Jumper Cable	10	Piece	3 ₺	30 ₺
				Total Cost:	1.609 ₺

Table 7:Purchased Cost Table

6.2 Unpurchased Cost

Element No	**Materials**	**Piece**	**Unit**	**Material Cost(Unit)**	**Process Costing**
1	Sigma Profile Corner Fasteners*	10	Piece	2,50 ₺	25 ₺
2	Sigma Profile Hidden Corner Fasteners*	10	Piece	3 ₺	30 ₺
3	Side Pole	2	Piece	30 ₺	60 ₺

4	Fork Plate	1	Piece	30 ₺	30 ₺
5	Side Pole Connection	1	Piece	30 ₺	30 ₺
6	Plate Connection1	1	Piece	25 ₺	25 ₺
7	Plate Connection2	1	Piece	25 ₺	25 ₺
8	Shaft X 114XD3	2	Piece	10 ₺	20 ₺
9	Shaft X 23XD3	2	Piece	6 ₺	12 ₺
10	Reel System	5	Piece	10 ₺	50 ₺
11	Ardunio Mega	5	Piece	29 ₺	29 ₺
12	Battery	1	Piece	60 ₺	60 ₺
13	Driver	6	Piece	68 ₺	408 ₺
				Total Cost:	804 ₺

Table 8: Unpurchased Cost Table

*Labor costs include laser cutting, abkant and cnc operations.

6.3Mecanum Wheel Cost

Element No	Materials	Piece	Unit	Material Cost (Unit)	Employment Cost (Unit)	Process Costing
1	Rim	8	Piece	20 ₺	120 ₺	1.120 ₺
2	Roller	32	Piece	15 ₺	50 ₺	2.080 ₺
3	Hub	4	Piece	20 ₺	15 ₺	140 ₺
4	Bearing	64	Piece	4 ₺		256 ₺

5	Bolt – M6 x 60	32	Piece	1,01 ₺		32,32
6	Nut – M6	32	Piece	0,07 ₺		2,24 ₺
					Total Cost:	3.631 ₺

Table 9: 3Mecanum Wheel Table

6.4 Total Cost

Purchased	1.609 ₺
Not Purchased	804 ₺
Mecanum Wheel	3.631 ₺
Total Cost	6044₺

Table 10: Total Cost Table

7.CONCLUSION

In this way, with the changes made in the direction of rotation of the mutual wheels, movement can be achieved in the desired directions. The Forklift can move in any direction in its position. Each wheel has independent stepper motors. The Forklift is remotely controlled by programmable electronic circuits. With the signals coming from the control system, the motors apply drive to the wheels. With the fork, it lifts the load from the front with the reels and belt system. For extra load lifting, the rear load balancing system ensures that the vehicle is in balance.

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CURRICULUM VITAE

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He was born in Bakırköy / Istanbul on 14.03.1994. After completing his primary and secondary education here, he completed his high school education at Istanbul / Kağıkhane Gültepe Industrial Vocational High School. He then completed the Department of machinery program at Istanbul Aydin University. He started the Department of Mechanical Engineering at Doğuş University in 2016.

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APPENDIX

```
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
#include <AccelStepper.h>
RF24 radio(48, 49);   // nRF24L01 (CE, CSN)
```

```
const byte address[6] = "00001";
unsigned long lastReceiveTime = 0;
unsigned long currentTime = 0;
// Define the stepper motors and the pins the will use
AccelStepper LeftBackWheel(1, 42, 43);   // (Type:driver, STEP, DIR) - Stepper1
AccelStepper LeftFrontWheel(1, 40, 41);  // Stepper2
AccelStepper RightBackWheel(1, 44, 45);  // Stepper3
AccelStepper RightFrontWheel(1, 46, 47); // Stepper4
AccelStepper Lifter(1, 48, 49); // Stepper5 / Lever, Lifter
int wheelSpeed = 1500;
// Max size of this struct is 32 bytes - NRF24L01 buffer limit
struct Data_Package {
  byte j1PotX;
  byte j1PotY;
  byte j1Button;
  byte j2PotX;
  byte j2PotY;
  byte j2Button;
  byte pot1;
  byte pot2;
  byte tSwitch1;
  byte tSwitch2;
  byte button1;
  byte button2;
  byte button3;
  byte button4;
};
Data_Package data; //Create a variable with the above structure
void setup() {
  // Set initial seed values for the steppers
  LeftFrontWheel.setMaxSpeed(3000);
  LeftBackWheel.setMaxSpeed(3000);
```

```
  RightFrontWheel.setMaxSpeed(3000);
  RightBackWheel.setMaxSpeed(3000);
  radio.begin();
  radio.openReadingPipe(0, address);
  radio.setAutoAck(false);
  radio.setDataRate(RF24_250KBPS);
  radio.setPALevel(RF24_PA_LOW);
  radio.startListening(); //  Set the module as receiver
  Serial.begin(115200);
 }
 void loop() {
  // Check whether we keep receving data, or we have a connection between the two modules
  currentTime = millis();
  if ( currentTime - lastReceiveTime > 1000 ) { // If current time is more then 1 second since we have recived the last data, that means we have lost connection
    resetData(); // If connection is lost, reset the data. It prevents unwanted behavior, for example if a drone jas a throttle up, if we lose connection it can keep flying away if we dont reset the function
  }
  // Check whether there is data to be received
  if (radio.available()) {
    radio.read(&data, sizeof(Data_Package)); // Read the whole data and store it into the 'data' structure
    lastReceiveTime = millis(); // At this moment we have received the data
  }
  // Set speed - left potentiometer
  wheelSpeed = map(data.pot1, 0, 255, 100, 3000);


  if (data.button1==0 & data.button2==1) {
    LifterUp();
  }
  if (data.button2==0 & data.button1==1) {
    LifterDown();
  }
```

```
if (data.j1PotX > 150) {
  moveSidewaysLeft();
}
else if (data.j1PotX < 100) {
  moveSidewaysRight();
}
else if (data.j1PotY > 160) {
  moveForward();
}
else if (data.j1PotY < 100) {
  moveBackward();
}
else if (data.j2PotX < 100 & data.j2PotY > 160) {
  moveRightForward();
}
else if (data.j2PotX > 160 & data.j2PotY > 160) {
  moveLeftForward();
}
else if (data.j2PotX < 100 & data.j2PotY < 100) {
  moveRightBackward();
}
else if (data.j2PotX > 160 & data.j2PotY < 100) {
  moveLeftBackward();
}
else if (data.j2PotX < 100) {
  rotateRight();
}
else if (data.j2PotX > 150) {
  rotateLeft();
}
```

```
  else {
    stopMoving();
  }
  // Execute the steps
  LeftFrontWheel.runSpeed();
  LeftBackWheel.runSpeed();
  RightFrontWheel.runSpeed();
  RightBackWheel.runSpeed();
  Lifter.runSpeed();

  // Monitor the battery voltage
  int sensorValue = analogRead(A0);
  float voltage = sensorValue * (5.0 / 1023.00) * 3; // Convert the reading values from 5v to suitable
12V i
  // If voltage is below 11V turn on the LED
  if (voltage < 11) {
    digitalWrite(led, HIGH);
  }
  else {
    digitalWrite(led, LOW);
  }
}
void moveForward() {
  LeftFrontWheel.setSpeed(wheelSpeed);
  LeftBackWheel.setSpeed(wheelSpeed);
  RightFrontWheel.setSpeed(wheelSpeed);
  RightBackWheel.setSpeed(wheelSpeed);
}
void moveBackward() {
  LeftFrontWheel.setSpeed(-wheelSpeed);
  LeftBackWheel.setSpeed(-wheelSpeed);
  RightFrontWheel.setSpeed(-wheelSpeed);
  RightBackWheel.setSpeed(-wheelSpeed);
```

```
}
void moveSidewaysRight() {
  LeftFrontWheel.setSpeed(wheelSpeed);
  LeftBackWheel.setSpeed(-wheelSpeed);
  RightFrontWheel.setSpeed(-wheelSpeed);
  RightBackWheel.setSpeed(wheelSpeed);
}
void moveSidewaysLeft() {
  LeftFrontWheel.setSpeed(-wheelSpeed);
  LeftBackWheel.setSpeed(wheelSpeed);
  RightFrontWheel.setSpeed(wheelSpeed);
  RightBackWheel.setSpeed(-wheelSpeed);
}
void rotateLeft() {
  LeftFrontWheel.setSpeed(-wheelSpeed);
  LeftBackWheel.setSpeed(-wheelSpeed);
  RightFrontWheel.setSpeed(wheelSpeed);
  RightBackWheel.setSpeed(wheelSpeed);
}
void rotateRight() {
  LeftFrontWheel.setSpeed(wheelSpeed);
  LeftBackWheel.setSpeed(wheelSpeed);
  RightFrontWheel.setSpeed(-wheelSpeed);
  RightBackWheel.setSpeed(-wheelSpeed);
}
void moveRightForward() {
  LeftFrontWheel.setSpeed(wheelSpeed);
  LeftBackWheel.setSpeed(0);
  RightFrontWheel.setSpeed(0);
  RightBackWheel.setSpeed(wheelSpeed);
}
void moveRightBackward() {
```

```
  LeftFrontWheel.setSpeed(0);
  LeftBackWheel.setSpeed(-wheelSpeed);
  RightFrontWheel.setSpeed(-wheelSpeed);
  RightBackWheel.setSpeed(0);
}
void moveLeftForward() {
  LeftFrontWheel.setSpeed(0);
  LeftBackWheel.setSpeed(wheelSpeed);
  RightFrontWheel.setSpeed(wheelSpeed);
  RightBackWheel.setSpeed(0);
}
void moveLeftBackward() {
  LeftFrontWheel.setSpeed(-wheelSpeed);
  LeftBackWheel.setSpeed(0);
  RightFrontWheel.setSpeed(0);
  RightBackWheel.setSpeed(-wheelSpeed);
}
void LifterUp() {
  Lifter.setSpeed(wheelSpeed);
}
void LifterDown() {
  Lifter.setSpeed(-wheelSpeed);
}
void stopMoving() {
  LeftFrontWheel.setSpeed(0);
  LeftBackWheel.setSpeed(0);
  RightFrontWheel.setSpeed(0);
  RightBackWheel.setSpeed(0);
  Lifter.setSpeed(0);
}
void resetData() {
  // Reset the values when there is no radio connection - Set initial default values
```

```
    data.j1PotX = 127;
    data.j1PotY = 127;
    data.j2PotX = 127;
    data.j2PotY = 127;
    data.j1Button = 1;
    data.j2Button = 1;
    data.pot1 = 1;
    data.pot2 = 1;
    data.tSwitch1 = 1;
    data.tSwitch2 = 1;
    data.button1 = 1;
    data.button2 = 1;
    data.button3 = 1;
    data.button4 = 1;
  }
```

*this appendix contains the Arduino codes.