PROJECT REPORT

TABLE OF CONTENTS

SECTION TITLE **PAGE NO.**

ABSTRACT

The recent change in industrial dynamics because of the Covid 19 has resulted in a great amount of unemployment. The industries all over the world are operating with fewer worker employees than ever before and it will take a long period of time for industries to recover and to offer the same amount of jobs they had earlier. As per statistics the United states lost almost 23 million job opportunities just in the year 2020 because of the global pandemic the world is facing to this date.

This recent phase of industry has brought an increase in demand for automated systems to perform daily routine jobs and simple tasks. One of the main tasks that has been faced is difficultto complete by the industries is the transportation of goods and materials from one warehouse to another. Also the loading and unloading of the individual components and complete assemblies from different warehouses and assembly lines within an industry coming from various vendors. This problem raises an idea of an autonomous operating machine that can load transport the material from one station to unload it on another.

The project idea is to bring a team together to build an autonomous operating goods transporting robot. keeping all the above mentioned ideas, figures and requirements we build a prototyperobot that can transport 3 different objects at a time and drop them at their designated stations. The prototype model is built to be in a size of one cubic foot and sustained enough to hold a considerable amount of load in one single run. After considering a few design ideas we decided to make a line following a robot with mark detection to identify the pickup and drop points.

To achieve this task total 8 infrared sensors were installed in which 4 are being used to follow the line two for mark detection and 2 for obstacle detection. An RF module was also added to send a signal to operate a solenoid actuator which was placed in position to open the door. For the drop mechanism an inclined surface was fabricated on the end of which 3 servo motors were attached. Each servo has an arm horn which acts as a gate for the objects. Each time the mark sensor detects a drop mark it will operate a servo motor to unload the object and move further on the path until it detects another mark.

The concept behind this project is to help the industries to overcome the shortage of employers and to have a safer and reliable working environment with no errors in the process. Our prototype is considered capable of transporting goods to its designated stations while bringing noharm or damage to any obstacle in its path and it performed all the necessary deliverable so it is good to say that it has been a successful product to achieve the goal of industrial transportation.

OBJECTIVE

An autonomous material transporting robot whose job is to pick things up and drop them at some specific marked areas has been fabricated and coded. The main goal of this project is to serve humankind through the field of mechatronics and have work done more efficiently and conveniently. The idea was to complete this task with a simpler design which has to be cost efficient and easy to program. The system that was designed is supposed to be generalized and completely autonomous.

INTRODUCTION

The very first design consideration for the robot was the microcontroller for which we use an Arduino mega 2650. The whole robot was divided into the categories mentioned below:

1. Frame
2. Drive system
3. Line following and mark detection
4. Pick and Drop system
5. Obstacle detection
6. Autonomous Door opening

The very first stage of any project is the design consideration and brainstorming of multiple ideas to choose between them and have them put on the table to pick a final design then comes procurement, fabrication and all the rest of the steps. The initial design consideration was a robotic arm which later concluded to be very difficult to integrate and installed on our one cubic foot robot so an alternate design was taken into the consideration which was based on a sliding mechanism on an inclined plane and 3 servo motors attached at the end of the plane with each motor connected to a servo horn acting as a gate.

For line following we used 4 sensors on the front 2 on right and 2 on left of the black line to be followed. The two sensors were used to have a better feedback system for the robot for line detection and to make a better decision on hard turns. In the same manner 2 IR sensors were also used for the mark detection and obstacle avoidance.

For the frame an aluminum alloy sheet was used of 3mm thickness. This sheet was specifically used for the base frame. The mid frame and the top inclined plane was also fabricated using an aluminum metal sheet of thickness 2 mm and 0.7 mm respectively. Water jet machine was used to fabricate the sheet metal to have frames dimensionally accurate and aligned.

The door opening system was based on operating an actuator through nRF24 module which is a radio frequency module and it was operated through the robot. There were some issues integrating it but later on with debugging it was fixed and calibrated. The second door opening system was based on operating a servo motor with arm through an IR sensor detecting an object in front of it to send a signal and run the servo motor.

Every component was procured separately and tested before integrating them on the final assembly. Every system has its own code for debugging. Later on when all the systems were running perfectly fine they were assembled on the main frame and a complete circuit was made to integrate every system. A main switch was added to the robot to supply power to the whole circuit in case of emergency stop the switch can be turned off.

IMPLEMENTING METHODOLOGY

FRAME

The first and of utmost important task in our project was to make a base frame. The first consideration that was taken into the design was the material. We came up with different ideas and the 3 options that we had on the table were aluminum sheet metal, wood and acrylic sheet. The final decision was made and we decided to go with an aluminum alloy sheet metal of 3mm (⅛ inch) thickness. It's a 6061 T651 Aluminum sheet covered with protective film. The reasonfor choosing this specific material for the base frame is that its tensile strength is very high and it's strong enough to sustain a great amount of load. The size of the base frame is 220mm x 280 mm. A Cad file was generated for the fabrication of the base frame which was later converted into DXF format in order to upload on the water jet machine.

For the second frame that comes above the base frame an aluminum metal sheet of 2 mm thickness was chosen. The sheet metal is strong enough to withstand the load and to have the perfect thickness to be fabricated with a bunch of holes and slots into it. The second frame consists of 4 slots and around 30 holes of 3mm and 4 mm dia. The reason for giving extra slots and holes was the easy passage of wires. The size of the second frame is about 210mm x 280mm.The third and top frame is made by using a 0.7 mm aluminum sheet with two slots at each side and it is bent at a 30 degree angle. The length of the above plate meant to be maintained at 270 mm after bending so a plate of total length 300 mm and width of 220 mm was cut and bent at 30 degree angle.

Each plate was fabricated at a waterjet cutting machine to have precise and dimensionally accurate holes and length so no issue arises in alignment while assembling. The CAD files of the frame are attached in Appendix A along with the DXF files that were used for the water jet machine.

DRIVE SYSTEM

After the fabrication of the base frame the second task was to have a drive system. To have a stable drive system we considered that a reduction motor will be the right choice to go with. We procure 4 reduction motors but the issue we faced in starting was the rpm of the motor was too high and instead of procuring high speed drive we decided to go with high torque reduction motors hence reducing the value from 300 rpm to 100 rpm.

Figure 1 : Shows a 100 rpm 12V DC motor procured for the drive system.

In order to control every motor and tire separately we decided to use two L298 motor drivers. The left front and rear motors were connected to one L298 and the right front and rear motors were connected to the other L298. The L298 were powered through a ZEEE Lipo battery of 11.1V and 5200 mAh capacity. The circuit connection for the motors and L298 is added in the section Appendix A. Arduino mega 2650 was used to build this whole circuit. Both the components are shown below:

Figure 2 : L298 Motor Driver

Figure 3: ZEEE battery 11.1v, 5200 mAh

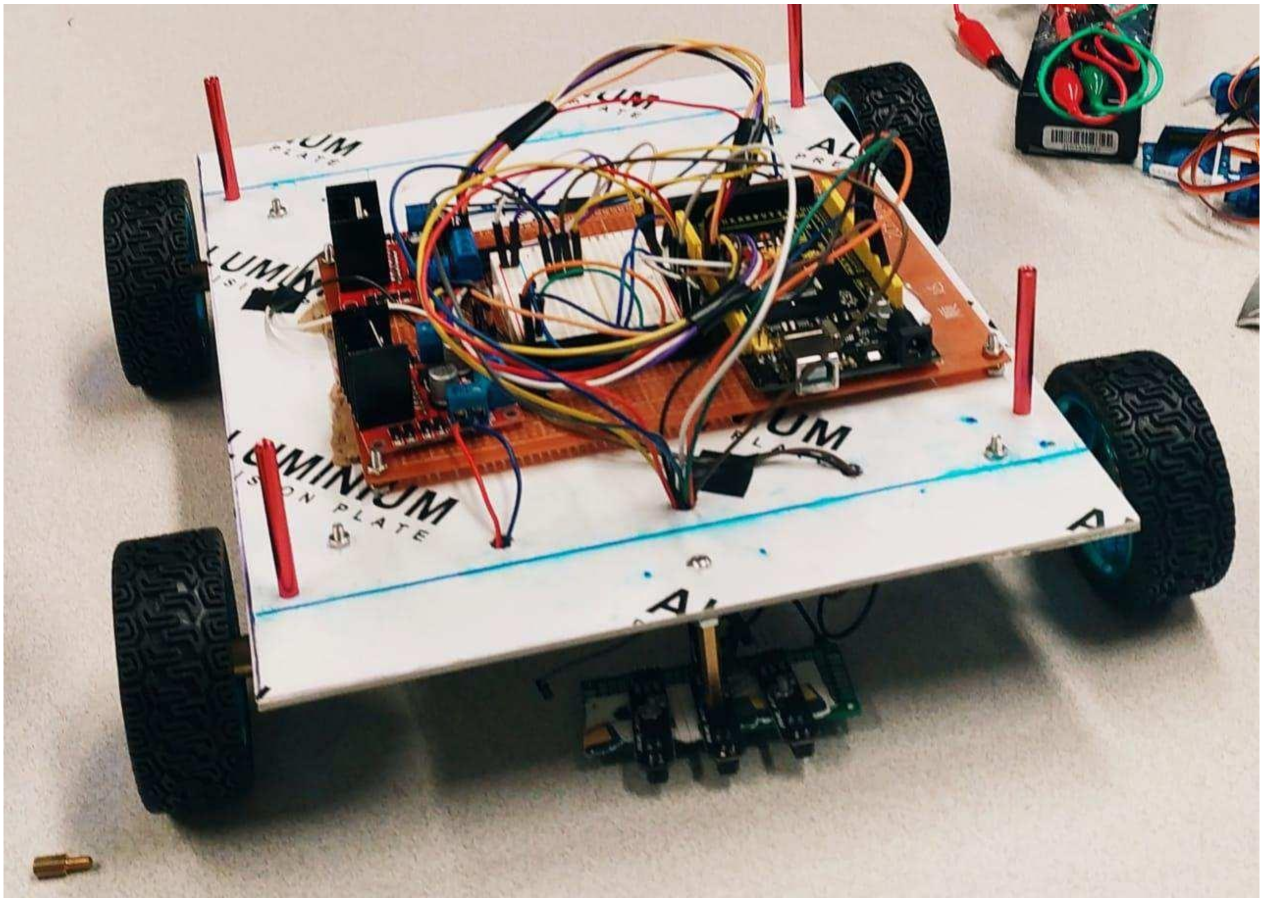

Figure 4 : An assembled drive system on the base frame.

The picture shown above is representing a drive system at very early stages of the project. Later there were multiple tests that were performed on the drive system and its alignment was calibrated. All the tests performed will be discussed in further upcoming sections.

LINE FOLLOWING AND MARK DETECTION

After the assembly of the drive system it was necessary to have our logic of line following forthe robot for which multiple IR sensors were procured but we ended up using an LM393 comparator reflectivity sensor. These sensors are specifically designed for line following and highly efficient in detecting and differentiating the black from other surfaces.

In the earlier stages of the line following total 3 sensors were used to fulfil the purpose based on the logic that the middle one will detect the black line and follow the part and the right and left sensors will remain on non-black platform and only will notify when either of these sensors detect any black path on the floor on the basis of which the robot will take a turn to its respectivedirection to keep it self on the line. The working with three IR sensors resulted in favour and the tests were a success. The test code with 3 IR sensors was based on if and else condition which is added in the Appendix A section.

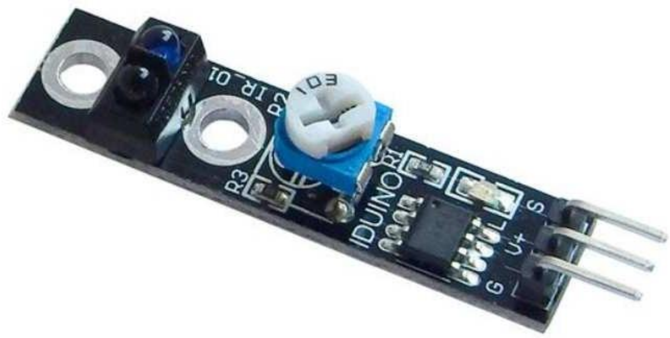

Figure 5 : LM393 Comparator reflectivity sensor

For the line following however in next stages the logic was changed from 3 sensors to 4 sensors. The new logic was based on the idea that two sensors were placed on the right side and two sensors were placed on the left side. A plate with the dimension of 100mm x 40mm of stainless steel of thickness 1.25mm was fabricated to hold the front sensors for line following. A CAD filewas made for the plate later converted in DXF file to be fabricated through a water jet machine. The logic is based on the idea that the areas in between the left and right sensors will be on blackline and until the sensors on both sides are not sensing any black line on the path the robot movesstraight. If the sensors on the right senses a black line it means the robot is going in the left direction hence it is supposed to take a right turn and if the sensors on the left senses a black line the robot will take a left turn which means the robot was moving in the right direction. Adding two sensors on each side has a purpose of sending better feedback to the controller, just in case ifone sensor misses the reading the other sensor will detect the black path and provide thenecessary feedback to the controller.

For mark detection two separate IR sensors were added on the right side of the robot between the right front and rear tires. if any of these sensors read a black mark the robot will move to its respective stop, drop, pickup or door opening state. A counter is added in the FSM to monitor the state transition of the robot. marks were added on the right side of the path at proper distance to ensure the mark reading.

Figure 6 : TCRT5000 IR sensor used for mark detection.

PICKUP AND DROP SYSTEM

The robotic arm initially used was a 6-degree of freedom, but due to complexity of using the servos and power .we decided to convert into a 3 degree of freedom. But the arm did not meet the given considerations, the arm is able to pick and drop the objects but it was 43cm long which is 12cm long than the given condition and the gripper can open its wings only up to 80cm that is less than the given object. So we changed our mind and decided to drop only.

Components used :

1.35kg torque servo
2. 30kg torque servo
3.gripper

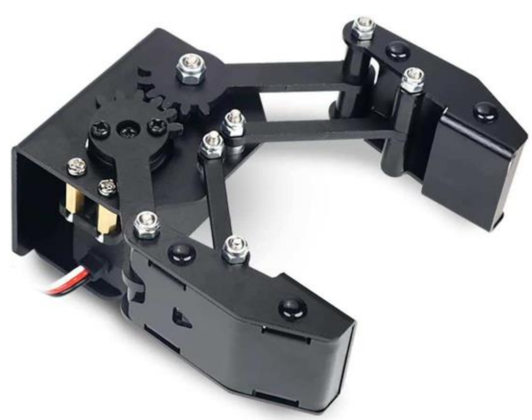

Figure a : Servo used for Robotic arm.

Figure b : The clipper installed at hand.

After considering the design and implementation complications of the robotic hand an alternate drop mechanism was designed that was added in the final assembly of the robot. The final drop mechanism design is based on an inclined surface at 30 degree and 3 servos attached at the end of the inclined plane. The servos were attached to the second frame of the final assembly. Servo horns were attached to the servo motors which acted as a gate for the loaded material.

The logic of the three servos was that the right servo was holding the container consisting of a tennis ball which had to be dropped on 1st drop mark detection. The servo on the left was considered to be numbered as 2nd and was holding the cubes container only to be operated at the second drop mark detection and the servo in the middle was identified as the 3rd servo and was holding the container with rebar and to be operated at last. All three servos were initialized at zero position at the start point before loading the material on the inclined plate. The gates attached to the servo were 3d printed through a CAD file converted in the STL format.

Figure 7 : SG90 Servo motors

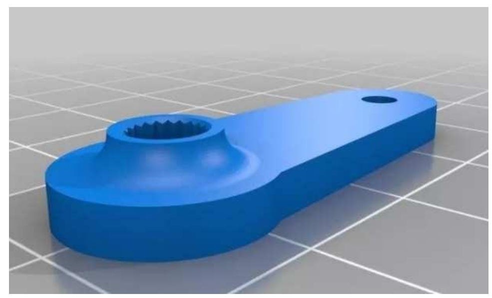

Figure 8: Servo horn (ref: 3Dmixers.com)

The alternate pickup method was based on a dragging mechanism. The design was completed and was based on low rpm dc motors to which a plate is attached on front such that if the motor rotates it drags the material in forward direction without any path deflection. To ensure its straight movement two guiders were added on each side. The whole system is to be set on a separate station so that the robot will come under it and receive the products and then will move on further to follow its own path. Unfortunately the pickup mechanism is still under manufacturing phase and was not presented during the demonstration.

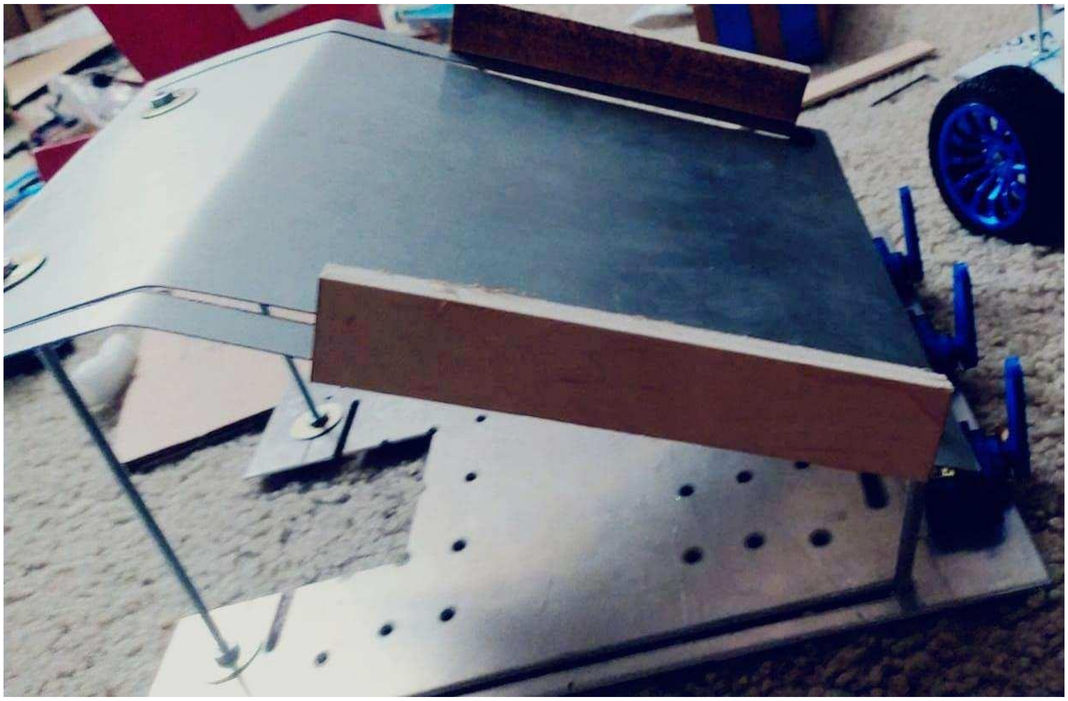

Figure 9 : Assembled Drop mechanism with servos attached at the rear end of the second frame.

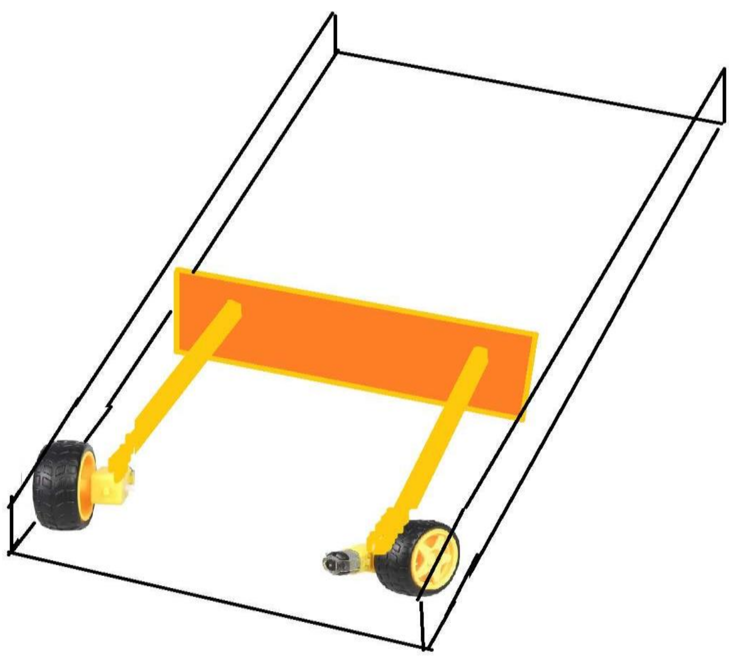

Figure c : A rough sketch of the load drag station for pickup point.

OBSTACLE DETECTION

In order to avoid any possible obstacle in front of the robot two ir sensors were added on the front end of the robot. The IRs were set on the logic that their reading when not detecting any object remains HIGH, that is 1 and whenever they detect any object in front of them the value turns to 0 and the controller sends the robot to a stop state. The robot will not move any further until its reading is 0 which means the` object is still in front of the robot. Once the object moves after a considerable amount of delay the robot will continue on its path. The IRs were calibrated to detect an object at a distance of 6 inches before the robot runs into it.

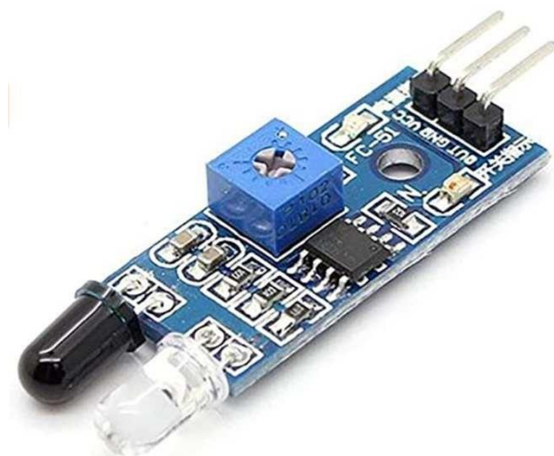

Figure 10 : Infrared obstacle avoidance sensor.

AUTONOMOUS DOOR OPENING MECHANISM

The task associated with the project was to follow the assigned path and there were two doors that came into it which are supposed to be operated through the robot. The idea was to make a generalized door opening mechanism not just for this particular case only and considering this point in mind the idea of a radio frequency module came to mind. Since there were two doors, two different methods were implemented to open the door. On the first door we used an RF module and on the second door we used a servo motor and an IR sensor.

The RF module we chose is nRF24L01. The module has a total 8 pins which includes GND, VCC, CE, CSN, SCK MISO, MOSI and IRQ. The MISO, MOSI and SCK pins of the module have designated pins on the arduino microcontroller, if they are not attached to those pins the module will not work.

	MOSI	MISO	SCK
Arduino Uno	11	12	13
Arduino Nano	11	12	13
Arduino Mega	51	50	52

Figure 11 : Represents designated pin connections for RF module.

The nRF24 module operates at 3.3V. The CE pin ensures the transmission and receiving of the signals while CSN ensures the proper working of the chip. The pin identification chart ismentioned below:

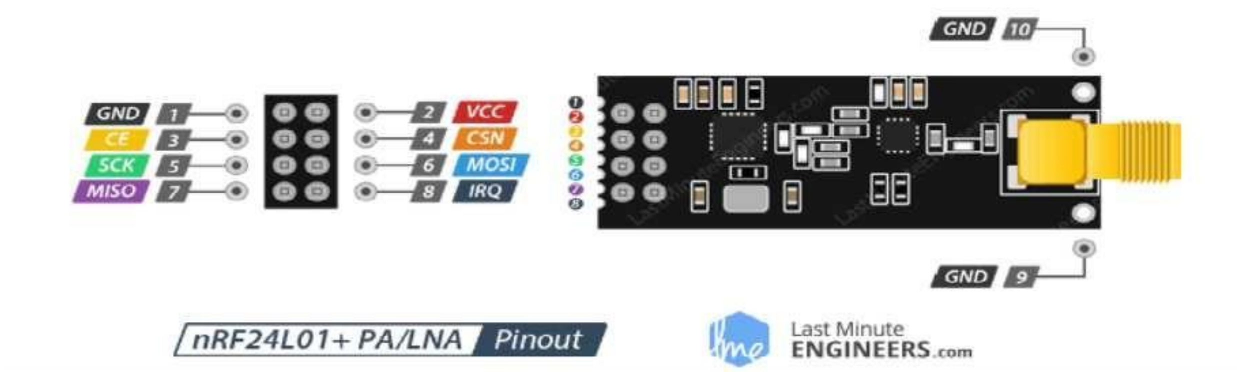

Figure 12 : Shows nRF24 module pin connections. (ref : Lastminuteengineers.com)

CE (Chip Enable) is an active-HIGH pin. When selected the nRF24L01 will either transmit or receive, depending upon which mode it is currently in.

CSN (Chip Select Not) is an active-LOW pin and is normally kept HIGH. When this pin goes low, the nRF24L01 begins listening on its SPI port for data and processes it accordingly.

SCK (Serial Clock) accepts clock pulses provided by the SPI bus Master.

MOSI (Master Out Slave In) is SPI input to the nRF24L01.

MISO (Master In Slave Out) is SPI output from the nRF24L01.

Figure 13 : shows the pin functions of the nRF24 module. (ref : Lastminuteengineers.com)

Two RF modules were used, one at the receiving end and one on the robot with final assembly which acted as transmitter. When a mark detection sensor reads a mark and gives a counter setfor door opening state the transmitter sends a signal to the receiver to operate an actuator which will press the push button for the door. Both the sensors were set at a particular address and weregiven a bool number which helped in debugging the process. The RF modules were not operatingso they have to be fixed. A library was updated and fewer more libraries were added to make them work; the address was corrected as well.

The module at the receiving end was connected to an arduino UNO microcontroller which after receiving a signal from the RF module transmits a signal to a relay which operates the actuator connected to a 7.4 v battery. A circuit diagram is added in the appendix section. The debugging code and the receiving code is also added in the Appendix A section.

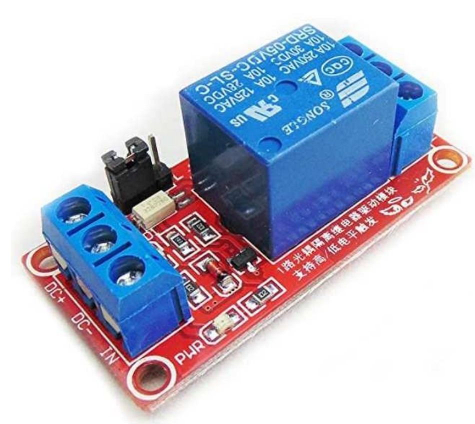

Figure 14 : nRF24L01 + PA + LNA

Figure 15 : HiLetgo 5V relay

Figure 16 : Linear Solenoid Actuator.

COMPONENTS AND LOGIC TESTING

In order to make sure that all the components are working properly, they all need to be tested and calibrated separately. There were numerous tests that were performed to ensure the component quality which includes motor alignment and polarity testing, IR sensor testing, servo testing and RF module testing.

MOTOR ALIGNMENT AND POLARITY TESTING

In order to make sure that all the motors are working properly and their polarity is connected right to the L298n motor driver a code was drafted to test it. The code was based on the logic that all the motors first rotated in the forward direction then in reverse direction and then the robot took a right turn and then it took a left turn. If the behavior of the robot differs from the logic mentioned it means that either the motors are not running properly or their connections have been made wrong. The test code is added in the Appendix A section and the flowchart is mentioned below:

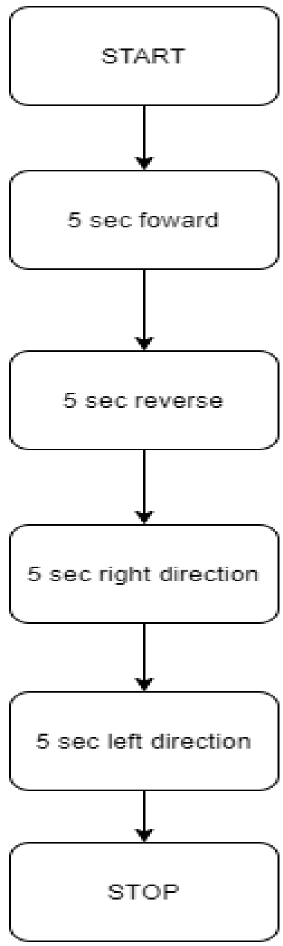

Figure 17 : Flow diagram of motor testing code.

INFRARED SENSOR TESTING

In order to test and calibrate all the IR sensors a test code was drafted to monitor their value at both analog and digital pins using an Arduino Uno serial monitor. This test helped us to calibrate the sensors for line following , mark detection and obstacle avoidance. All three objectives have different kinds of Infrared sensors (LM393, TCRT5000, obstacle avoidance) for which they all were installed at different heights and orientations. Using this test the obstacle avoidance sensor was calibrated up to 6 inches of distance to detect objects. The test codes used are mentioned in the appendix section.

SERVO TESTING

The servo motors are a delicate component to work with. They are very sensitive to operate hence needed to be code very carefully and a test code was required to observe their behaviorand to identify their zero position. The servo testing code helped us to learn about operating servos and identifying their zero position. The code was later integrated with the main code to have the servo set at zero position before having them operate at a 90 degree angle. The code logic is that first servo moves to their zero position then 1st servo after a delay moves to 90 degree angle and then returns to its original position and same for the rest two servos only the delay differed and observed. The code used for the servo testing is mentioned in the appendix section.

RF MODULE TESTING

In order to operate the RF module several points were taken into consideration. The first problem that was faced was that the library was not updated. All the necessary files needed to be in the library section were added through gitthub.com. Later the address was corrected and after all these considerations a debug code was used to test the receiving and transmitting of the module. Later another code was drafted to make sure that the module only operates when an IR sensor detects a black mark. All these codes are mentioned in the appendix section and the references are also given. Later the codes were integrated with the main code.

FINITE STATE MACHINE

Every system was programmed and tested separately and we had a model code for each running system it was just the matter of integrating it now but before we began our integration we needed a flowchart to follow, a path , a truth table and an FSM that indicates the our input and outputs and the state transition and the possible outcomes. To achieve this purpose we first drafted a flow chart that would need to be followed before we start defining our inputs and outputs. The drafted flow chart is given below:

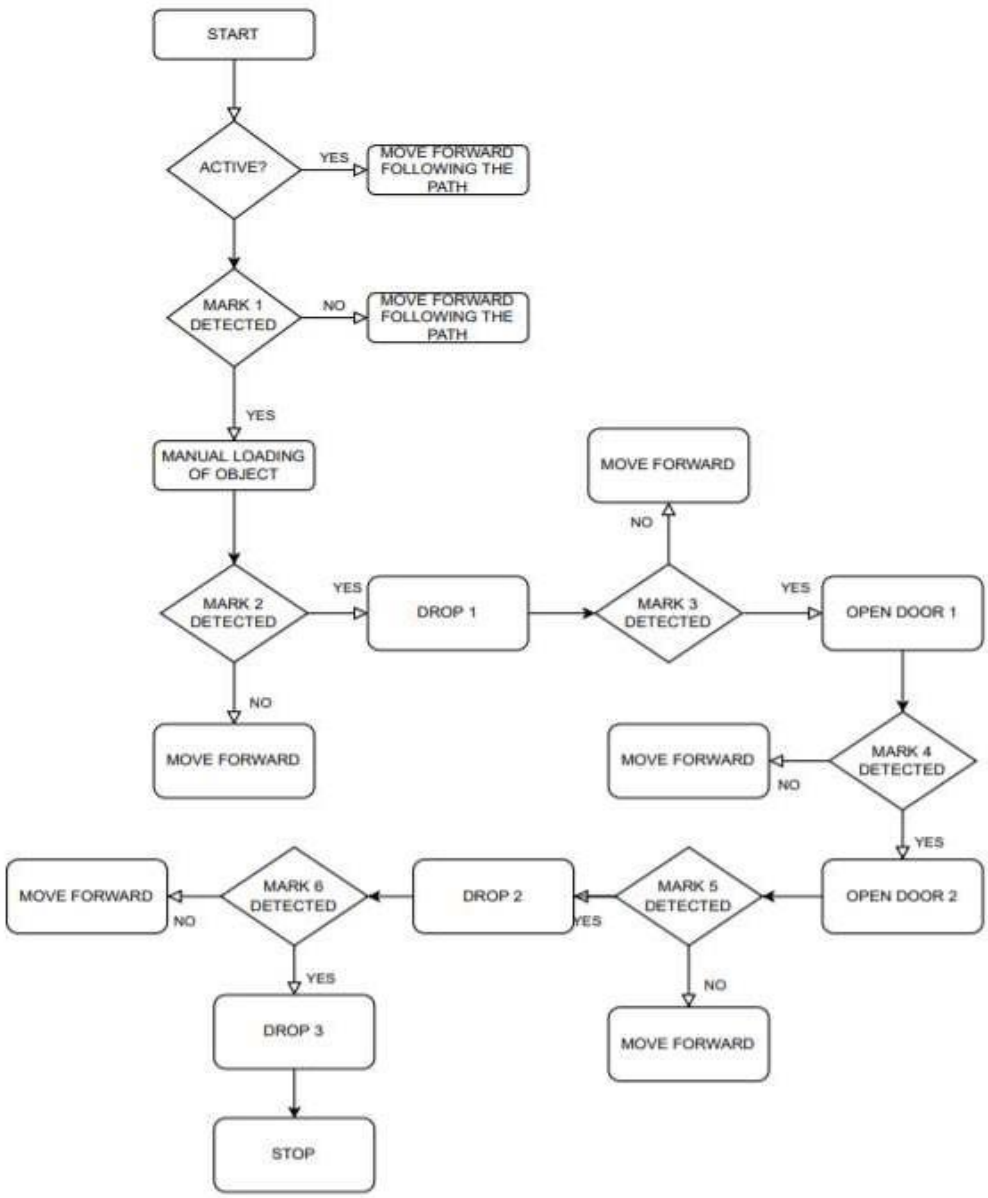

Figure 18 : Autonomous pickup and drop robot flow chart.

The first task we had was to pick up the load which needed to be placed within 6 feet from the starting point after which we moved towards our second mark detection point that is our first drop off point. At this point we drop a container with a tennis ball and proceed on path to detect the third mark of the right side of the track on which the RF module sends a signal from transmitter to receiver only to operate the actuator which will push the switch to open the door. Now the robot proceeds to the second door and the IR sensor that is placed on the right edge of it will detect an obstacle only to send a signal to an arduino UNO controller which will operate the servo to which an extended wood arm is connected to push open the door. The robot now moves on its path to mark detection 5 and mark detection 6 to have the drop 2 containing cubes and drop 3 containing rebar respectively. After dropping the third load the robot moves to a stop state until programmed any further or the cycle restarts.

The second step is now to have our inputs and outputs defined for which we have a total 4 IR sensors for line following 2 IRs for mark detection and 2 IRs for obstacle avoidance. All these IRs are our system input and components and 4 DC motors controlled by L298 driver and 3 servos and 1 RF module are our robots' outsout components. The all are listed below:

Inputs
IRR1 - Right IR sensor 1
IRR2 - Right IR sensor 2
IRL1 - Left IR sensor 1
IRL2 - Left IR sensor 2
MS1 - Mark IR sensor 1
MS2 - Mark IR sensor 2
OBS 1 - Obstacle IR sensor 1
OBS 2 - Obstacle IR sensor 2

Output
FR - Front right motor
RR - Rear right motor
FL - Front left motor
RL - Rear left motor
S1 - Servo drop 1
S2 - Servo for drop 2
S3 - Servo for drop 3
RF - nRF24L01 module for door

After defining all these inputs and outputs we can start mapping our FSM. The final draft of the FSM is given below:

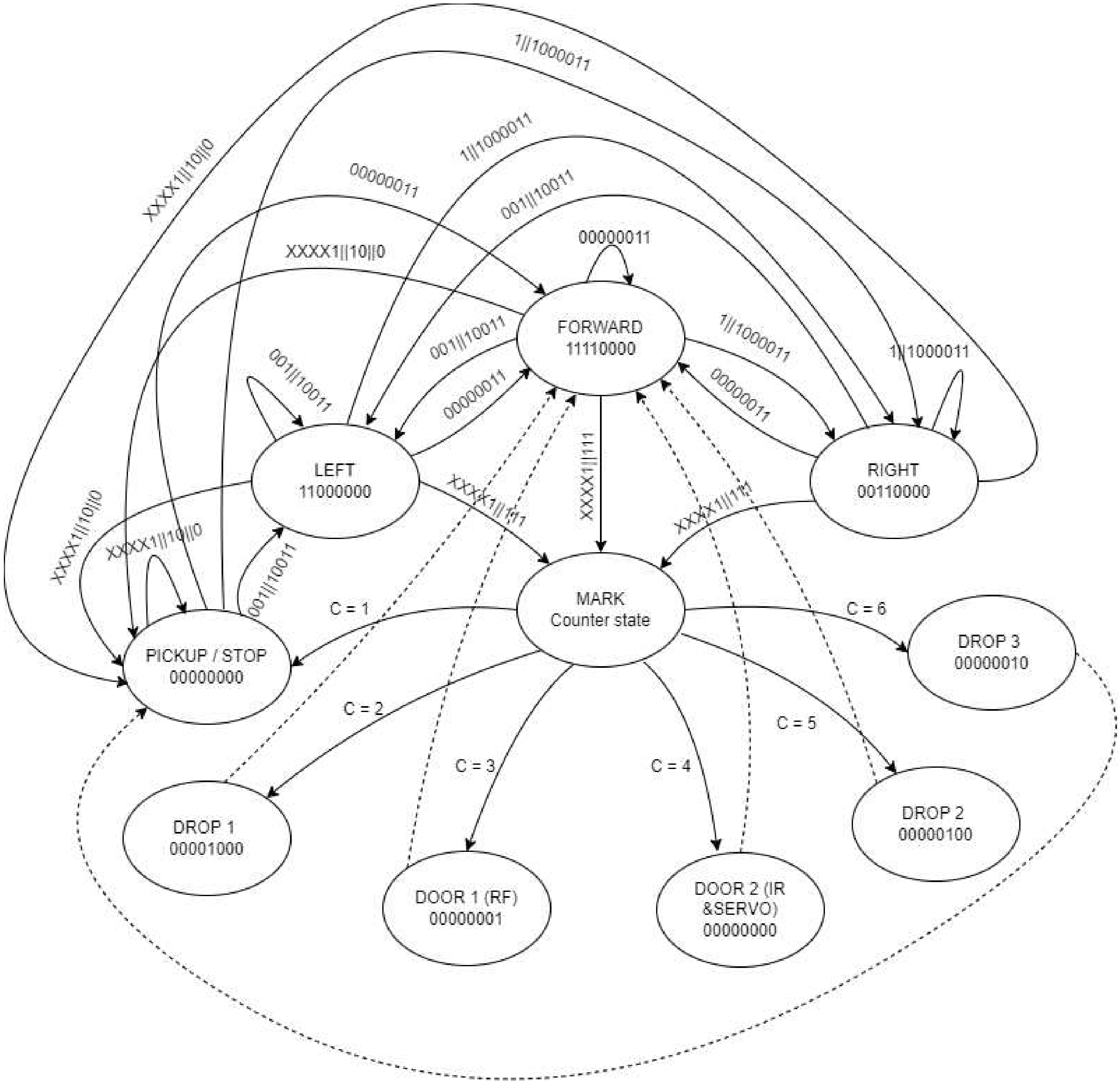

Figure 19 : Finite state machine diagram of an Autonomous line following robot.

To understand the state transition better in the above given model , the table below can be refer:

INPUTs								Counter	STATE
IRR1	IRR2	IRL1	IRL2	MS1	MS2	OBS1	OBS2		
0	0	0	0	0	0	1	1		Forward
1 |	| 1	0	0	0	0	1	1		Right
0	0	1 |	| 1	0	0	1	1		Left
X	X	X	X	1 |	| 1	1	1		Mark
X	X	X	X	X	X	1 |	| 1		Stop/Pickup
X	X	X	X	1 |	| 1	0 |	| 0	1	
X	X	X	X	1 |	| 1	1	1	2	Drop 1
X	X	X	X	1 |	| 1	1	1	5	Drop 2
X	X	X	X	1 |	| 1	1	1	6	Drop 3
X	X	X	X	1 |	| 1	1	1	3 & 4	Door
1	1	1	1	1	1	1	1		Impossible State

Table 1 : Outputs state conditions based on the Inputs.

As per the table above it is understood that if all the sensors read 0 except the obstacle avoidance because it works the other way, the robot goes in forward direction. If any of the right sensors read 1 that is black the robot takes a right turn but the condition here is that the left sensor must read 0 while in right state. In the same manner if taking a left turn the right sensor must be reading 0 and either of the left sensor is HIGH that is 1. If any of the mark sensors reads HIGH that is 1 the robot will go into mark counter state and add a +1 in counter reading to perform the respective function the counter will take the robot into. If any of the obstacle sensors reads then the reading will turn to 0 which means there is an obstacle in front of the robot and the robot will go into a stop state. The robot will face a delay and after that it will again take a reading. If the obstacle is still there the robot will stay at its position until the obstacle has been removed from its path. All the drop and door states depend on the counter reading as shown in the FSM and table above.

RESULT

Overall, our robot was successful in achieving the goals mapped out by the project guidelines. Our robot was able to follow the line and go to its designated drop stations, stop when there is any obstacle in its path and then continue to move when the path is clear. At the pick station, the robot stops and after loading the material it continues its path towards the drops and stops when the stop mark is detected. In our path there are two doors, and the robot was successful in opening one door using an RF module and the second door using a digital IR sensor.

The drop mechanism did work properly, only we could not implement the pick-up mechanism due to wrong motor selection. The whole prototype of the robot was designed on the university campus and the frames were made in the fabrication lab and wood shop. Following outcomes canbe notified after the prototype testing:

FUTURE SCOPE

In today's era transportation is the main work in every field, this prototype when well manufactured and released in industry it would act as a helping hand for industry or factory workers, drawback in this prototype is that it does not return to its original point, but that can be developed. Medical equipment which are small in size but way too heavy to be lifted and can be transported from one building to another.

In industries this transportation car can be utilized to transport materials from one building to another. Not only the in industries and factories but also in mall store house where materials are transported in bulk and forklifts are operated by people, which have led to many accidents, instead of human intervention if a robot can do these things it would be very helpful and quick, let it be human directed as we cannot directly rely on robots it can malfunction. Installing a barcode system near the door opening mechanism can be more efficient as the entry for the robotwill be noted if it enters any room. Smooth and quick pick-up mechanisms can be made so that objects should not be damaged as well as safer and better drop systems which are more autonomous can be designed to avoid accidents or damaging the objects that are to be delivered. Using alarms and LED light that can be used as the signal for other workers that the transporter car is on the field.

DISCUSSION

The main objective of the robot was to follow the track given and transport the objects to its designated positions (which in this case was 2 Tennis balls, 2 boxed and 1 rebar) allotted across the builds in the university campus. There were tasks that provided 3 objects to be picked up and dropped, open two doors in the path, halt at the designated stop points and detect obstacles in the path. To go to the drop stations there were various methods. The method our team chose was following a line using a line follower IR sensor.

The robot was designed to get through all these difficult tasks, which it magnificently cleared. The drawbacks that we faced throughout the project was late approach for correct motors, batteryhas been utilized a lot by connecting 3 servo motors directly to it, which led to frequent battery drop, mistakes in connecting the motor driver which have blown off the 2 Arduino mega. Also it was observed that the servo was not operating properly when combined with the main circuit so to resolve that issue a separate circuit was built with a 6V power supply through 4 AA batteries.

CONCLUSION

By means of this project, we got an opportunity to implement our knowledge of Mechatronic Systems in designing an autonomous robot which performs particular tasks like in our case it was to transport materials to its denoted destination. This type of robot can be used anywhere around the world, let it be any factory, industry, or hospital, these features made me more interested to work on. It reduces human efforts for transportation, so if no human intervention dangerous tasks can also be performed via this robot. Our team tried to perform all the tasks but could not touch some important points, though we learn from our failures. This robot is a prototype but with more accuracy and proper model it can be used in industry, providing great help to humankind.

REFERENCES

https://github.com/maniacbug/RF24
https://lastminuteengineers.com/nrf24l01-arduino-wireless-communication/
https://www.allelectronics.com/item/st-1140/line-following/reflectivity-sensor/1.html
https://www.circuitbasics.com/pull-up-and-pull-down-resistors/
https://create.arduino.cc/projecthub/robocircuits/line-follower-robot-arduino-299bae
https://www.arduino.cc/reference/en/language/structure/control-structure/switchcase/
Free Circuit Diagram Maker with Free Templates - EdrawMax (edrawsoft.com)
https://www.multisim.com/
https://app.diagrams.net/
https://www.quora.com/
https://www.circuit-diagram.org/
https://www.amazon.com/dp/B07B7NXV4R/ref=cm_sw_r_apan_glt_fabc_dl_HAXDJV8Y2FWJRB33DHAZ?_encoding=UTF8&psc=1
https://www.instructables.com/How-to-Continuously-Extend-Retract-an-Actuator-Str/
https://www.google.com/amp/s/www.instructables.com/Line-Follower-Robot-PID-Control-Android-Setup/%3famp_page=true
https://www.youtube.com/watch?v=ZXANgP-q6b4
https://www.tamiyausa.com/shop/educational/
https://www.rcmart.com/omg-25t-aluminum-servo-horn-type-a-black-omg-tg-sa02-bk-00110148
https://www.rcmart.com/r31-house-grk-25t-direct-servo-horn-black-r31s025bk-00108480
https://www.thingiverse.com/thing:4617791
https://www.thingiverse.com/thing:2615098
https://www.thingiverse.com/thing:3814678
https://www.youtube.com/watch?v=BGlUsd7sXMU

Robot electrical circuit Diagram

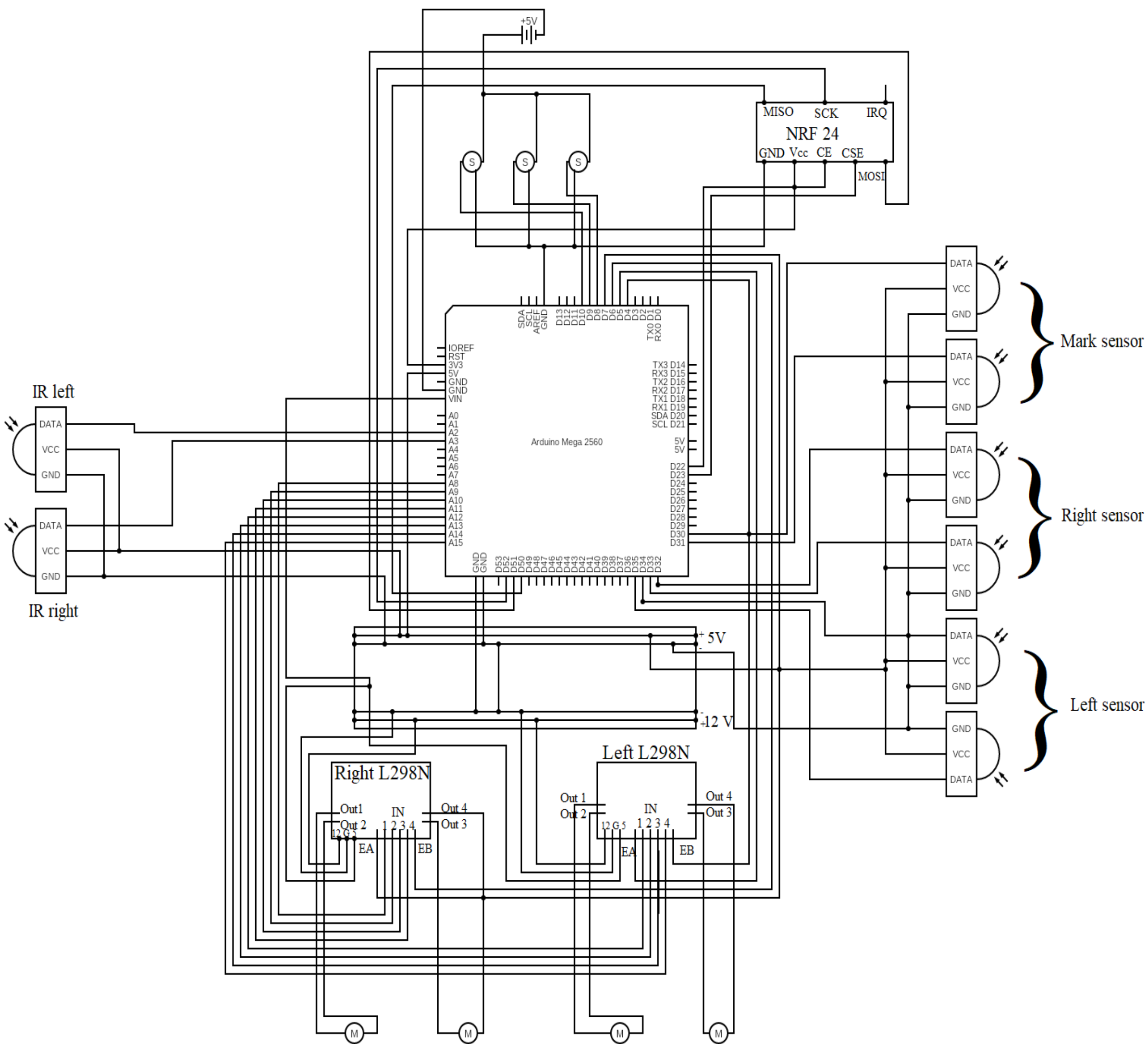

Figure 22 : Final circuit diagram of the Autonomous Pickup and drop line following robot.