Prototyping Autonomous Grid Car Group B8

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***Abstract*—The purpose of this article is to make a small introduction to the operation of an autonomous car as well as prototypes to help a better development of a vehicle, this will show difficulties in the development of the logic, as well as the design, all subject to analysis and testing environment to reach a good performance and serve as an example for other developments on the same subject in the future.**

I. Introduction

In the coming decades, significant changes will occur, particularly in the area of driving, that will imply a before and after not only for the automobile industry, but also for any vehicle that currently cannot operate without human intervention. The rise of self-driving cars at the expense of those that require human driving will have far-reaching implications on our lives and society. Some experts predicted that, at these altitudes, the autonomous car would become part of the everyday landscape of our streets five years ago. However, many of these prognoses remain unfulfilled, owing to a series of unfortunate events that have drew negative media attention, Despite this, the use of Smart objects has been made public, whereby functions can be performed autonomously with just one click, reducing user engagement even further [1]. One of the most notable examples has been the use of autonomous cars, in which their movements and reactions are determined by their own interaction rather than by the actions of a driver. This is the concept behind this project, in which not only a vehicle is developed autonomously, but it is also a vehicle that can follow the direction of a map using coordinates and thus be able to pick up and deliver objects to another location however also there's a concept for a welcoming design, whether futuristic or traditional, and it's the first steps toward understanding how autonomous cars work and what their benefits and drawbacks might be.

II. Objective

A grid was created in a surface, consisting of 4 colors for the lines and white circles in the middle, in theory it resembled a field. The entire development process revolved around navigating the grid, and staying on the lines that created the grid, autonomously. A secondary task at the beginning of the project, was obstacle detection and "movement", meaning finding an obstacle (haybale), and moving it to a drop off area, however this later changed and was no longer necessary. The car would have to maintain its coordinates and navigate through the grid, from a starting position, to a secondary position and after that to a third position. The process would start with understanding the tasks, choosing an approach, and based on this approach designing a car through solidworks, either laser cutting on wood or 3d printing, and finally assembling the different components and writing the code. Another important part of the project was color detection, which could prove useful considering the grid was made of lines of different colors. To summarize the requirements, a vehicle was to be designed and constructed, capable of navigating a predefined grid through autonomous pathing and reaching certain destinations.

III. Materials

Considering we were to create the entire car from scratch, the university provided us with certain materials, necessary for achieving the objective. The materials used composed of: 1. A wooden chassis made of separate pieces, designed by us, laser cut at the university and assembled by us, the actual chassis had a compartment for the motors and motor driver, and space in the back for the rest of the components.

1) Two IR sensors
2) Two DC motors
3) A motor driver circuit
4) An ultrasonic sensor
5) One RGB color sensor
6) Arduino UNO
7) A battery and basic electronics elements such as jumper cables and a breadboard
8) Two wheels and a ball bearing "wheel"

IV. Limitations

The only noticeable limitations were due to the hardware being used and the influence from the environment. The first noticeable problem were the motors, one of them turned out to be much more powerful than the other, thus the speed varied and struggled to keep up with the other. In order to solve this problem, we used different speeds for both motors until the car was able to maintain a relatively straight line over short distances. We also tried changing an engine for a new one but the problem persisted, so we decided to stick with the software implementation. Another problem arose after assembly during testing in the labs. Our car was designed with the wheels in the front, close to being in the same line as the color and IR sensors, thus when we ran it on the track (not the grid) the car would wobble and go out of the line. The fix we found that worked was moving the wheels a bit back. The reason behind the wheels being in the front was to have a better turning angle in tight corners. The final major limitation was the light coming from the environment and color sensor, it would disrupt the IR sensors, which would pick up the lights reflections and not detect the black lines, in response to this limitation we disconnected the color sensor and only used the IR sensors for navigation.

V. System Engineering

A. Requirement Diagrams

In order to successfully build an effective and efficient system certain requirements must be met. The requirement diagram below shows the general requirements of the project. The project is divided into 3 major requirements: dimension, vehicle navigation system and programming requirement. The dimension entails the detail of the size of the vehicle and the test environment. the system size will be on a scale of 1:10 and the test environment on an x value that ranges from 3.5-7.5 meters. As for the vehicle navigation system, the vehicle coordination will be described by the line (x, y) and involve four steps namely: determination of current coordinate, route calculation, route navigation and stop position. The last requirement is the programming type that the system will be run on. Finally, for the smooth running of the system, C programming language will be.

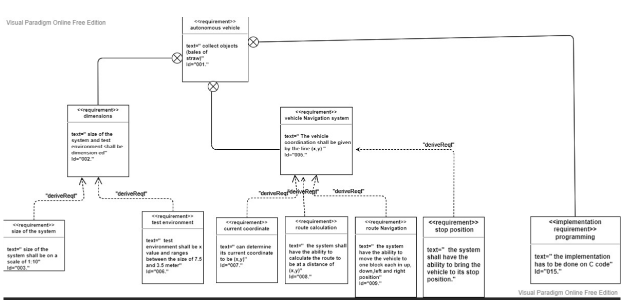

Fig. 1. Class Diagram

B. Use case Diagram

For the Use Case Diagram, we have 1 actor and others are the possible use cases. The actor is the autonomous vehicle that will move from one position to another. For our actor (autonomous vehicle) to perform its function of moving from its initial position to another location, it has to obey the use cases. The vehicle navigation has four use cases. Firstly, the it checks its current coordinate, calculate the route to know the next route to move to and then moves to the route. After the calculation if it has gotten to it final destination the vehicle stops. During route navigation the vehicle have four cases, it can only move one block up, down, left or right. Moreover, it follows the line during navigation and it uses black detector to determine its present position.

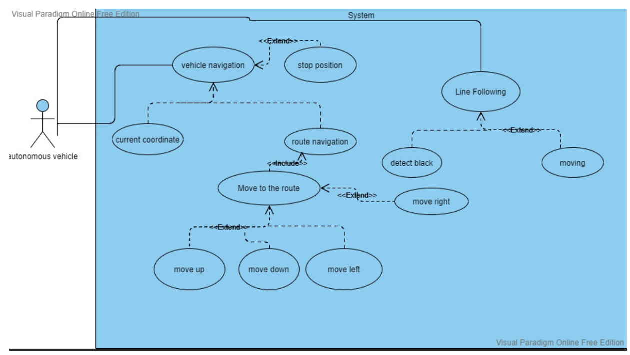

Fig. 2. Use Case Diagram

C. Sequential Diagram

As its name imply sequence diagram is a type of interaction diagram that shows how and in what order a group of objects works together. Sequence diagrams can also be called an event diagrams or event scenarios. We used it in our project to show more details interaction between the actor and the use cases.

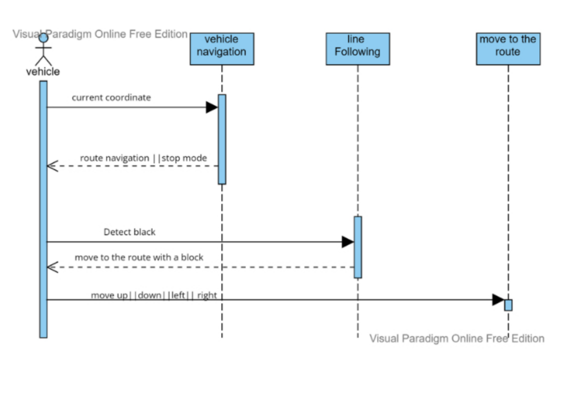

Fig. 3. Sequential Diagram

VI. Design Approach

A. Functional Approach

1) Objective, Initial Idea and Modelling with SolidWorks: As discussed earlier, our aim for the project is to design a vehicle that can navigate to a location in a pre-designed environment to practice precision farming systematically. Regarding the design perspective, this included making an optimal arrangement of the hardware components in the vehicle, so that the car follows a line, makes turns, and stops when facing an object to collect.

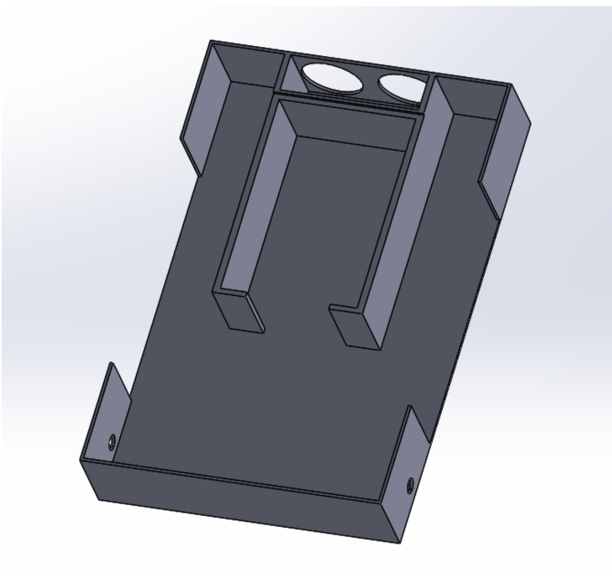

Fig. 4. Initial Design for the Frame

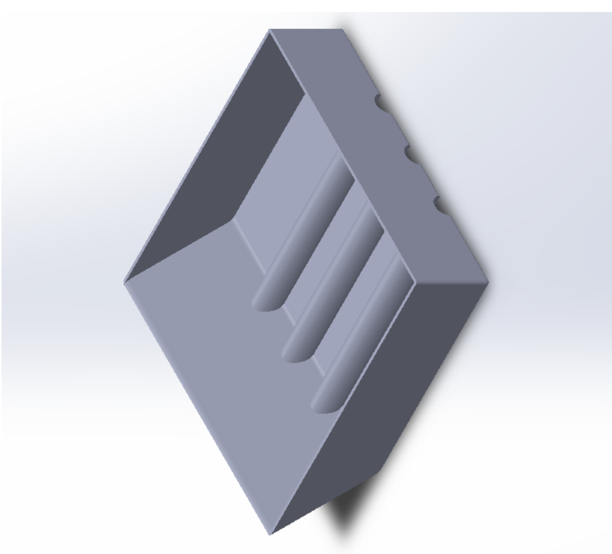

Fig. 5. Initial Design for the Clamp

The 3D Modelling of the vehicle was applied on computer-aided design(CAD) software, SolidWorks. Initially, we have divided the overall design into two parts: grabbing parts and the frame of the vehicle. When designing the clamp, the dimension of the object that the vehicle should carry was considered to be a box of 5 x 5 x 5 plywood. Also, the frame of the vehicle had space for its two wheels responsible for the car turning situated at the back of the car. Note that we have a special compartment for an ultrasonic sensor for detecting objects in the front of the car and it is separated from the place for other hardware components by a wall.

2) First Prototyping: We went further on the design after studying some UML diagrams and the necessary hardware components to do an activity or the required performance that the vehicle had to make. Based on what they do for the system, we finalized the necessary hardware components with certain design requirements. To make the vehicle move, we had two wheels and one front wheel, to enable the movement of the vehicle, and two motors, a motor controller, and a lipo battery to turn electric power to engine power. We decided to have an Arduino Uno module with a breadboard connecting all the components to the Arduino so that it can run the motor controller and be used to program the vehicle. Two sets of the infrared sensors will help in line following functions and an ultrasonic sensor will be used to detect the object to collect and stop accordingly.

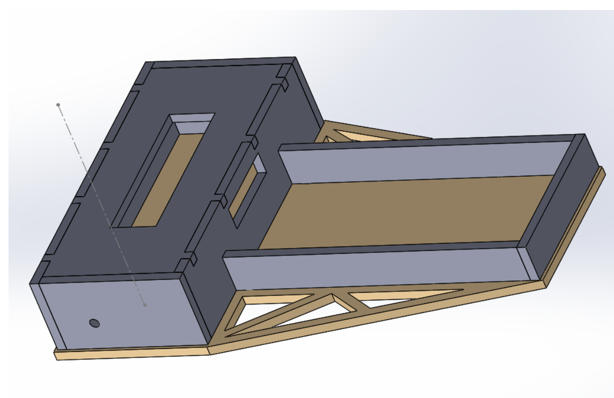

Fig. 6. 1st Prototype Assembly of the walls

Consider the above figure. This is the design of the first prototype. We have designed the entire frame or the chassis of the car by designing 9 blocks to be put together like lego. In more detail, we have a part called the bottom frame into which all other parts are fitted like walls. We decided to use plywood of 6 mm thickness by utilizing the laser cutting technique to physically cut out these walls and put them together to make a proper chassis of the vehicle.

These parts are assembled together to make space for the motors and the battery in one section and other parts in the

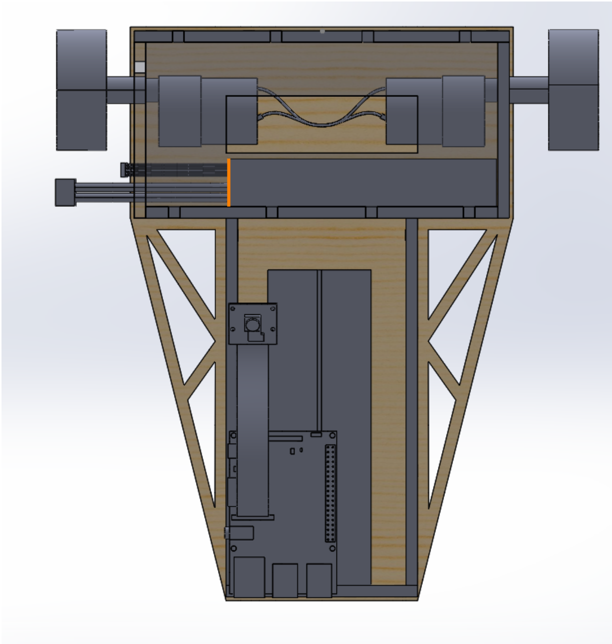

Fig. 7. 1st Prototype Assembly of all

other. We separated these components in this way to separate space for the mechanical part from the part for controlling the vehicle. We had a technical limitation to having our ultrasonic sensor which we neglected when working with the first prototype. Also, another technical limitation set the distance between two infrared sensors to be 30 mm. This is due to the thickness of the black line the car should follow being 3cm while we are implementing the line detecting technique based on the premise that the infrared sensors are situated right outside the black line, trying to adjust its direction by avoiding sensing black.

Note that we have changed our design to a front-wheel-drive (FWD), not a rear-wheel-drive (RWD) like before. We have decided to put the wheels as closest as possible to the front of the body. To simply put, for FWD, the vehicle is pulled forward whereas RWD pushes the vehicle forward. The main reason why we have decided to have FWD was for implementing a simpler turning control. It will make a much sharper turn or be faster and stronger to make the turn when needed. Since FWD has the engine located close to the wheels at the front, it is usually heavier in the front, giving better traction and making the setup more simple, thus providing a better economy. [4]

3) Second Prototype with Grabber: What we did not take into account when designing the first prototype was the grabber and two important sensors: an ultrasonic sensor and a color sensor. The system calls for color sensors for navigation purposes. The map on which the vehicle will be driving has four different colors alternating with a certain pattern. The color sensors will be used to figure out how many blocks the vehicle traveled. One technical limitation will be that it is ideal to place the color sensor behind the IR sensors.

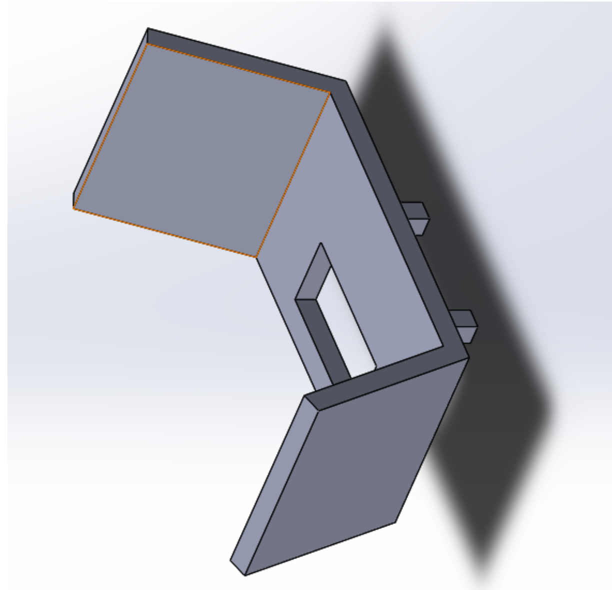

Fig. 8. 2nd Prototype Grabber

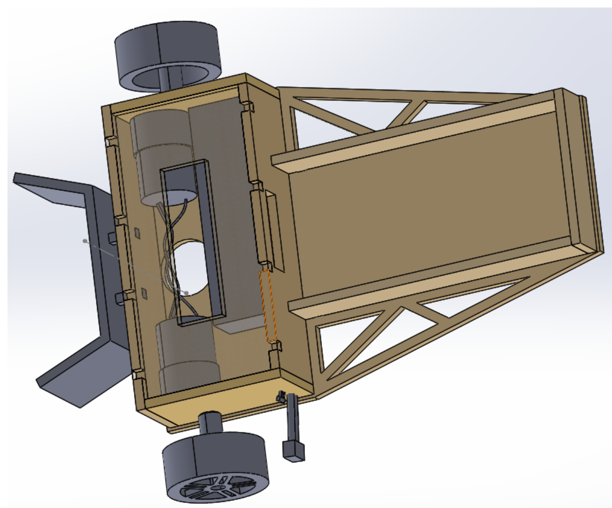

Fig. 9. 2nd Prototype Assembly of all

The ultrasonic sensor will be used for detecting the object to collect and giving a condition for a stop. The technical requirement emphasizes it to be situated at the front of the vehicle or with the clamping part so that it can detect the object with no other components blocking the sensor. We decided to build the ultrasonic sensors into the clamp. For time management, we avoided using 3D printing when printing the clamp. We laser cut some parts to put the clamp and the frame fixed together and detach them easily for experiment purposes.

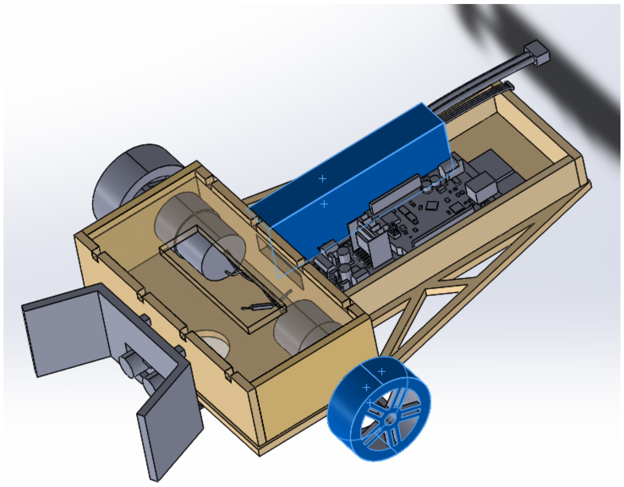

Fig. 10. Final Prototype Functional Assembly

4) Final Design with all parts together: Eventually, we have come up with the 3D modeling of the final prototype after considering all the system engineering perspectives. Consider the above design. All of the hardware components are assembled together with the frame of the car as well as the clamp of the car. You can notice a couple of changes are made in the design for valid reasons we came up with. First of all, the wheels are situated a little bit further back from the front. This is because we decide to place our infrared sensors closer to the front. The system will command the vehicle to make a turn or goes straight only after the infrared sensor detects the change in color. At this point, the wheels are situated before the point of the intersection, and they will make the turn more easily.

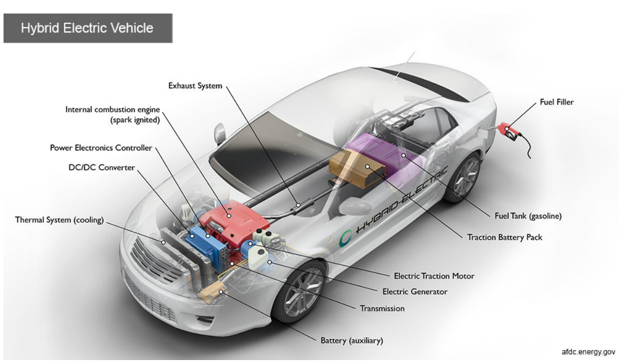

Fig. 11. Example of an Overview of a Hybrid Electric Vehicle

Also, note that the lipo battery is now situated in the compartment at the back. By designing in this way, we avoided having too much weight in the front and separated the battery, the power source, from the engine. Another figure shows an architectural overview of a hybrid electric vehicle. [5] In the figure 11, the traction battery pack is situated at the back apart from the engine. This was why we thought this would be more optimal.

B. Style Approach

Fig. 12. Exemplar Style of a vehicle

1) Design Motivation: From the beginning of the project, due to the juvenile nature of our group members, we were inclined to design our vehicle in a sports car style with a minimalistic approach. In terms of technical perspective, we wanted to have a shield for each wheel and spoilers to manage the aerodynamics of the vehicle. In terms of design perspective, we made the edges of the car smooth to implement a streamlined design by filleting those edges. On top of these, we wanted our car to be robust and not easily damaged. In conclusion, we decided to deliver these characteristics by making a cover frame that fits the car perfectly with the right dimension. By taking a minimalistic approach, we tried to discard unnecessary but possible change and keep it simple. An exemplary design in figure 12 was used in our style approach.

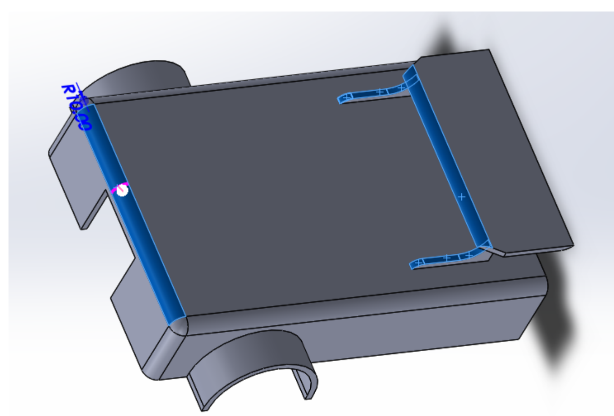

Fig. 13. Cover Style Approach 1

2) Distinguishing Features: The first design criterion, to begin with, is a streamlined design. A streamlined design of a car indicates that the shape of the car makes it possible to move efficiently and quickly through the air by minimizing

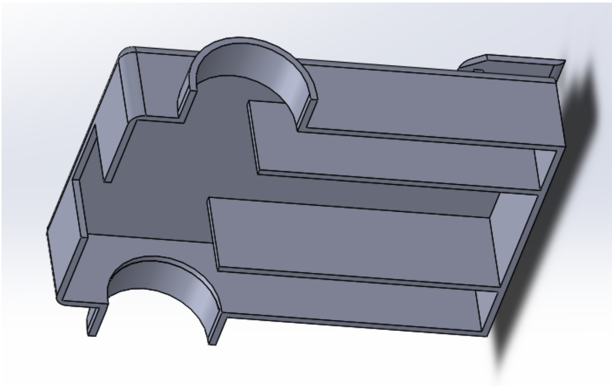

Fig. 14. Cover Style Approach 2

air friction. In modern days, most design procedure for cars considers streamlined design a necessity. It has a number of positive effects. It has better efficiency in fuel consumption, better control, better performance, and less vibration and noise. To have these characteristics, we have filleted the edges of the car to make the contour smooth. [6]

The second criterion to discuss is the spoiler and aerodynamics of the vehicle. The spoiler and the wing are often interchangeably used but they are in fact different devices and have distinct behaviors in aerodynamics. A spoiler is a device used for reducing the lift and improving aerodynamics by disrupting an airflow flying over the vehicle. An example of a spoiler can be seen on the wings of an airplane. By adjusting a blunt angle of the spoilers to an acute angle to disrupt the pressure difference, the airplane can move down in altitude. It is true that our car will not experience any drastic change in aerodynamics or the sense of getting lifted because the maximum speed of the car is relatively low. However, we have implemented this feature to show that our style approach is based on that of a sports car. [7]

Below, we have our final design implementation of all the parts and cover assembled together

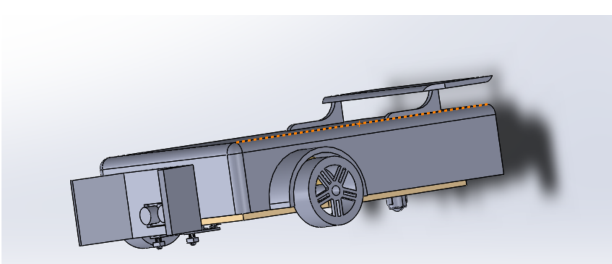

Fig. 15. Final Design

VII. Programming

A. Line Detection

The approach taken to meet the line detection and following requirement was to give all control over movement on a straight line to the IR sensors (model ST1140). Whenever the car would try to move in a straight line, it would read in the values of both IR sensors and decide through IF statements whether to go forwards or adjust to the left or right. The IR sensors were placed on the left and right side of the car, a bit ahead of the wheels and in the very front of the car, at a distance from each other not much bigger than the thickness of the line we were trying to follow.

Mostly this function dealt with the imperfections in the movement, in turning or going straight since the angle at which the car would start at would always be a bit off and any movement would gradually take it off the line. The car would move forward whenever both line sensors picked up the black tape around the grid, and whenever one would detect the color in the middle, the signal would be read and the car would turn towards the direction of the line sensor. For example, if the left sensor picked up a color other than black, the left motor would slow down, giving the car an uneven speed and turning it slightly to the left, until the point when the left sensor would pick up the black line again, and when both sensors would be on black, both motors would move at predefined speeds, moving the car along a straight line. The vehicle was designed to not move unless any of the sensors picks up the black tape. This line detection functionality would only be used to travel between intersections in the grid. Regardless of any imperfections in the forwards function, the line detection was capable of keeping the car on the grid at all times during testing.

Fig. 16. IR sensor ST1140 [8]

B. Object Detection

Near the start of the project, we were planning to use an ultrasonic sensor to detect and pick up objects in the grid, however as the project goals evolved, detecting the object was no longer necessary and simply navigating the grid would suffice. Nevertheless we implemented a method to detect objects, even though the ultrasonic sensor is disconnected from the current prototype and the code has been adjusted around it. The sensor used was of the HC SR-04 model, and was sufficient for detecting objects in a relatively close proximity.

The way this sensor worked was by using sound waves and calculating the distance from the object based on the duration of the pulse reflected by the object. The process is based on the speed of sound being a constant of approximately 343 meters per second, however this is subject to change due to humidity and temperature (it's only 343 m/s for dry air at 20 degrees Celsius). However, considering the environment and scale of the project the speed of sound would not vary much and even if the object distance was off by a few centimeters in reality compared to the calculated distance, this would not affect the outcome at all. The sensor consists of two main parts, the transmitter and receiver, the former emits sound waves which eventually bounce back off the object and are picked up by the receiver. The way it works is by sending pulses through the transmitter and then waiting for the receiver to pick up the reflections, the duration of the wait is measured through a PulseIn function within the arduino IDE. The time is stored in a variable ("duration" in our case) and through a simple calculation the distance to the object is found. Since the speed of sound is taken as a constant of 343 m/s, that leaves us with roughly 29.1 cm/ms for each direction, pinging and returning. So the final distance is found through this equation: Distance = (duration/2)/29.1 cm.

This process has a few delays built into the pinging, because the pinging takes a few milliseconds. So using it would cost a bit of performance if the car was moving, due to the fact the arduino can not execute a line of code while waiting for the delay() function to run its time.

Fig. 17. Ultrasonic sensor HC SR-04 [9]

C. Navigation

After establishing the necessary components, the testing phase was passed, where the logical process was part of it. The main idea was the use of an RGB Color Sensor, which would follow the colored lines placed on the map where it would be carried out. the test, it was possible to calibrate in a way that it could detect in what color it was located and what it should be after, after several days of testing it was not possible to see clearly why when detecting the colors, it did not make any movement or something about it , where it was given that through the use of IR sensor we could use our logic in a more comfortable way, despite not using the RGB sensor, the operating code could be used later in the future for improvements, despite Therefore, the idea of this autonomous car, as already mentioned, is to follow a map (measures mentioned before) where, by means of coordinates, it must reach a given point, pick up an object or make a kind of stop for to then be able to go to another point in an autonomous way, this was achieved with a developed logic where it was thought that making the vehicle every time it crosses an intersection can remember or save the intersection, after the intersection is arrived depending on the other works, it will determine if it should cross to the left or right until it reaches its end point, by means of logical functions and conditions, also as variable calls such as (X,Y) where each variable increases for each intersection.Also by means of a variable called (Direction) we can know in which position we are either up, down left or right, where the vehicle must check where it is and by means of the position it will decide whether to continue, cross, reach an intersection or stop.

D. Coordinates With X Position

```
//XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

void goTo(int x, int y){
  do{
  Serial.print("X =");
  Serial.println(startX);
  Serial.print("Y =");
  Serial.println(startY);

  while(startX < x){                                              //moving up
//oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
    if(direction == Up){                                          //pointed up
      followLine();
      if(sensorValueLeft == white && sensorValueRight == white){
        startX++;
        delay(150);
      }
    }
    if(direction == Right){                                       //pointed right
      if(turned == 0){
        turnLeft();
        turned = 1;
      }
      followLine();
      if(sensorValueLeft == white && sensorValueRight == white){
       direction = Up;
       startX++;
       turned = 0;
       delay(150);
      }
    }
    if(direction == Down){                                         //pointed down
      if(turned == 0){
        turnLeft();
        turned = 1;
      }
```

Fig. 18. Arduino Code X position

Once the first position starts, we must check the increment of our variable StartX together with the Variable X to know how many positions or in this case how many intersections in the range X the vehicle must follow, as you can see in the figure depending on the value that is given to X will determine the driving of the vehicle, if it is determined that the direction is up, the followline function must be called and must check the condition where it is checked that the sensor is checking only the black color otherwise when both sensors check another color that is not the same, it means that it has reached an intersection and must increase the x and then determine whether to cross, follow or stop, always checking the direction in which the vehicle is and the increase of intersections to reach the desired X point.

E. Coordinates With Y Position

Once arrived to the point X we proceed to review now the points in Y that would be the coordinate of the other point where we want to arrive after having traveled all the points of x, this can be better appreciated in the code where it is observed that X=x and we pass to review the points of Y until arriving equally to the desired coordinate, it is important to emphasize that Y must also be increased after reviewing all the conditions of followline and the location of the direction and if it has crossed or not the vehicle.

```
 while(startX == x && startY < y){                                    //moving right
/oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
   if(direction == Up){                                               //pointed up
     if(turned == 0){
       turnRight();
       turned = 1;
     }
     followLine();
     if(sensorValueLeft == white && sensorValueRight == white){
       startY++;
       delay(150);
       direction = Right;
       turned = 0;
     }
   }
   if(direction == Right){                                            //pointed right
     followLine();
     if(sensorValueLeft == white && sensorValueRight == white){
       startY++;
       delay(150);
     }
   }
   if(direction == Down){                                             //pointed down
     if(turned == 0){
       turnLeft();
       turned = 1;
     }
     followLine();
     if(sensorValueLeft == white && sensorValueRight == white){
       direction = Right;
       startY++;
   delay(150);
       turned = 0;
```

Fig. 19. Arduino Code Y position

Once both X and Y have been checked and if the coordinate conditions are met then we say that the vehicle should stop and wait for 2 seconds.

One of the most important functions also in our code is the function "followline" which is the one that makes the call of the conditionals of the sensors and adjust them at any time they leave the range of the black color, as you can see in the code, all this will be understood more clearly when implementing all the logic of the code with the vehicle.

VIII. Conclusion

After testing the whole environment of the map with the vehicle, you can see a clear picture, where by means of coordinates the vehicle goes from point X to point Y in an autonomous way, this shows that the operation of autonomous vehicles not only for better driving or more comfortable but perhaps for the use for the collection of objects, rescue or emergency vehicles, perhaps also for the implementation in fertilizer farms, there will be many projects where it can be implemented and help in an efficient and fast way for any autonomous task later, in the future with this project could be made improvements in the code adding the functions with the RGB plus perhaps a design where perhaps not only collect objects but also serve as a transfer of people as a rescue mode and also as other accessories that help a closer understanding with the environment as would be the inclusion of a camera.

```
  }while(startX != x && startY != y);                          //At desired coordinates

  vehicleStop();                                               //We stop the car for 2 seconds
  delay(2000);
}

//XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

void followLine(){
     sensorValueLeft = digitalRead(sensorPinLeft);
     sensorValueRight = digitalRead(sensorPinRight);

    if(sensorValueLeft == black && sensorValueRight == white){
      Serial.println("adjusting right");
      rightSlow();
    }

    else if(sensorValueLeft == white && sensorValueRight == black){
      Serial.println("adjusting left");
      leftSlow();
    }

    else if(sensorValueLeft == black && sensorValueRight == black){
      Serial.println("going forward");
      forward();
    }
}

//XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Fig. 20. Follow Line Function

IX. Task Distribution

1) Younsuk Choi : Design Approach
2) Thanas Dushku :Objective, Materials, Limitations, Programming (Line Detection, Object Detection)
3) Raheem Abiola Salam : System Engineering
4) Luis Cabezas Suarez : Abstract, Introduction, Conclusion, Programming (Navigation, Coordinates With X Position, Coordinates With Y Position)

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[7] https://www.youtube.com/watch?v=DYpxcE7rBw8
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[10] https://github.com/luiscab09/Prototyping

Eidesstattliche Erklärung

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I hereby confirm that I have written this paper independently and have not used any sources or aids other than those indicated. All statements taken from other sources in wording or sense are clearly marked. Furthermore, I assure that this paper has not been part of a course or examination in the same or a similar version.

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