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RESEARCH ARTICLE

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A SIMPLIFIED APPROACH TO AUTONOMOUS CARS

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ABSTRACT

Checking the data in December 2018 present in the “Global status report on road safety 2018”, we can see that there is an increase in the number of deaths caused by vehicular accidents reaching an average of 1.35 million deaths every year due to traffic accidents. The document also reveals that injuries caused by traffic are now the main cause of death for children and young people between 5 and 29 years old. Although many safety measures adopted by governments around the world helps to reduce such accidents, the biggest risk factor still persists, which is precisely human driving. To circumvent this factor, much is being studied about self-driving vehicles, where a vehicle can travel on public roads along with the normal traffic flow without the need for human intervention. In this paper we will explore the characteristics of an autonomous car, represented by line-following robots, in an accident-prone situation and study the behavior of vehicles in face of an imminent collision. The robots will follow an infinite loop track, equipped with sensors to detect their position and objects that represent obstacles or cars in front of them. We aim to prove the safety provided by an intelligent locomotion system when communicating with the environment and contribute to the advancement of autonomous vehicle mobility technology.

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INTRODUCTION

Due to the population concentration around large commercial centers, present in metropolitan regions, the daily traffic of vehicles has reached critical proportions in the Brazilian scenario. The search for comfort and the ease of acquisition, especially in the financial aspect, through credit and financing, contributes to the increase of individual vehicles in circulation (Neis, L. F., 2019). It should be reiterated, also, that due to the current conditions of public transportation, this displeases most of the population, leading those who can afford it to opt for individual motorized transportation. Such changes, however, favor the emergence of problems related to mobility. In Brazil, according to Cni & Ibope (2019), 47% of the inhabitants own a private vehicle and use it as a means of transportation.

The high concentration of vehicles on the streets makes accidents more likely. The driving of the vehicle by human beings brings with it several problems, among them the risk of collision by human failure especially where there are crossing roads. It is in this scenario that opportunities for automating vehicle driving open up. Autonomous vehicles are integral elements of the concept of "Mobility 4.0" which, according to M Azmat (2015), is described as "intelligent mobility in the fourth industrial revolution". This mobility will focus on complete automation, high reliance on artificial intelligence and high-tech equipment on board the vehicles. Before entering the city traffic, autonomous vehicles were already seen in industries and establishments that carry cargo indoors; these vehicles, however, need auxiliary elements to work.

The AGV or Autonomous Guided Vehicle is an older technology that is guided by tracks, guides or magnetic tapes (KAR, Aniket K. et al., 2016). In this paper, we will address the concept of autonomous cars driving on roads with intersections and interacting with other vehicles. For this, we will make use of AGVs, which allow us, at a low cost, to simulate a decision making situation by an autonomous vehicle without human input. According to Campbell et al. (2010), when it comes to autonomous cars, speed control, lane obedience, notion of space and preference rules can all be programmed and incorporated into the car itself. The conditions necessary for a society without human driving are still far from being met, however, in this paper we will address in a simplified way, the concept of an intersection of roads solely with autonomous vehicles.

REVIEW LITERATURE

Autonomous Vehicles: Although ideas for autonomous cars date back to the 1920s, the first concept of an autonomous car dates back to Futurama, an exhibit at the 1939 New York World's Fair. General Motors created the exhibit to showcase its vision of what the world would look like in 20 years, and that vision included an automated road system that would guide autonomous cars. Although a world filled with robotic vehicles is not yet a reality, cars today contain many autonomous features, such as assisted parking and braking systems (Fotsch, 2001). The presence of these features within a vehicle, can currently be classified into 6 levels (Koopman, 2017; Pereira, 2018), these being:

Level 0: Automation present in elements of the car that do not assist in driving directly. In this category are models equipped with systems such as autonomous braking and blind spot monitoring. Examples: Hyundai HB20 and Chevrolet Onix.

Level 1: Automation present in elements of the car that slightly assist in steering, but the vehicle is still dependent on the driver. This category includes vehicles equipped with adaptive cruise control or lane keeping assist. Examples: Volkswagen Nivus and the Jeep Compass.

Level 2: Automation that interchanges the car's steering with the driver, currently the most commonly seen launches. In safe scenarios, the vehicle can accelerate, brake, and stay within lanes. But the driver must remain aware of the roadway at all times to take over steering in emergency situations. Examples: Volvo XC40 SUV and Mercedes-Benz E-Class.

Level 3: Present only in the Honda Legend model, it is currently the most advanced offered in a production car. The autonomous system is capable of steering the vehicle alone in traffic jams. But the driver must remain ready to take control of the vehicle when requested.

Level 4: Autonomous system capable of taking over all the driver's functions. However, in adverse situations, such as weather changes, the vehicle may ask the driver to take over.

Level 5: Dispense with drivers and manual controls altogether, allowing orders to be given to the vehicle by voice command, for example.

As De Souza Pissardini (2013) portrays in his paper, several components work together to ensure that an autonomous car has the perception and orientation necessary for safe driving. Cameras, sensors, and radars act as the vehicle's eyes, detecting obstacles, traffic signs, traffic lights, pedestrians, terrain, etc. The data received by this equipment is sent to a control unit, a kind of brain in the system. It is responsible for transforming this data into actions, controlling the braking, acceleration, and steering of the vehicle. According to Devi & Rukmini, (2017), a vehicle has several ways to communicate with the outside or inside of the case, adopting communication technologies such as wi-fi, bluetooth, and even Zigbee.

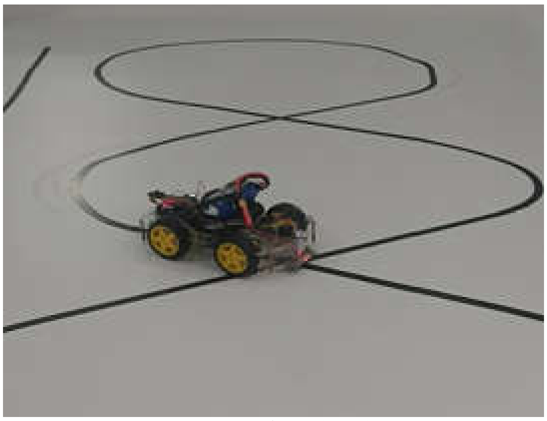
At the same time that the car becomes able to identify and avoid possible accidents, the driver is alerted of everything going on around him through the monitoring system, as Wang et al. (2017) well elaborates, the human in possession of the monitoring system has the most diverse information, and is able to act if he deems necessary. The safety measures provided in the regulations of countries whose use of autonomous cars is more advanced, such as the United States and Germany, determine that autonomous cars must run only with some skilled driver (Uzair, M., 2021). In this way, the driver can take control of the car when there is some kind of safety risk, as in the case of non-parameterized situations or even if there is a system failure. According to a survey by Canalys, one of the world's largest technology communicators, in the last four months of 2020, more than 3.5 million passenger cars were sold with level 2 automation; this number makes up about 30% of the fleet sold in the United States and about 20% in Japan, followed by some other countries in Europe and China. Even though several countries are investing in this system, the transition from human to autonomous driving will not happen overnight, according to Jung et al. (2005): It cannot be predicted, however, whether vehicles will be completely autonomous in the future. Different directives, which go in opposite directions, must be discussed and established by society. If, on the one hand, the basic guideline is total safety on the roads, then the human factor should be minimized and vehicles should autonomously follow their paths. Still according to Jung et al. (2005) there are some impasses connected with this technology, such as the definition of responsibility in case of accidents, optimization of sensors for a better perception of traffic and environmental conditions, adaptation of the infrastructure of cities (e.g.: badly painted traffic lanes).

Source: Ryan, (2018).

Figure 1. Frame from a video presentation of an autonomous car

Line follower is the name given to the mobile robot that has the ability to determine its trajectory through a strip placed on the ground made of material of a contrasting hue to the ground surface. The most common way to determine the shade of the ground, is through an infrared sensor, positioned close to the ground. Each sensor consists of an LED and a photodiode, both infrared. The light emitted by the LED hits the surface and is reflected back to the photodiode, which then generates an output voltage proportional to the reflectance of the surface.

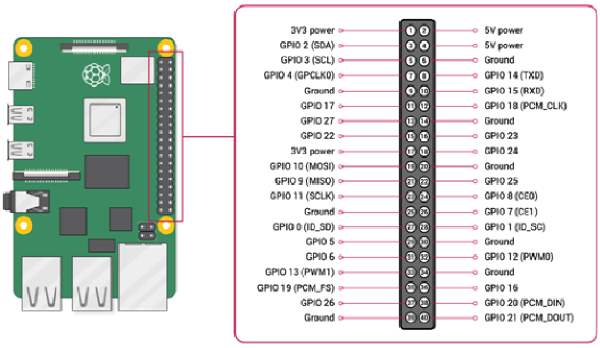
Considering that the trajectory will at some point have a curve, or even the vehicle will deviate from the trajectory by itself, using a sensor array becomes more effective in keeping the vehicle following the desired path.In a case of a circular track, or shapes where the end meets the beginning, a line following robot can continue to move automatically along its path for a period of time determined only by the duration of its power supply, thus approaching an autonomous vehicle. Line-following robots are used in a variety of ways, from pedagogical use, assisting in teaching robotics to all age groups, to large-scale business use and automation. letters, snacks, and various objects within an office. In the dissertation, the robot can be called by a button attached to each employee's desk, it then traces its trajectory following the lines marked on the floor and completes the requested task automatically.



Source: Authors, (2022).

Figure 2. Line-following robot.

Raspberry Pi 4: The Raspberry Pi Foundation in the UK has developed a series of small computers at a low cost where all the hardware is on a single board, called Raspberry Pi, just like a desktop, they have outputs for standard peripherals such asmonitors, keyboards and mice. The foundation's goal was to promote accessibility to computing and technology to low-income people (Raspberry Foundation, 2022). One of the features of the Raspberry Pi is the presence of a row of 40 GPIO (general-purpose input/output) pins. As the name suggests, the pins can be used for Input or Output, thus allowing a range of options for using the feature. The Raspberry Pi contains a vast collection of connections that can be used for many different activities, such connections include: USB ports, SD Card Slots, Ethernet port, Audio out, HDMI port, Micro USB source connector, and GPIO ports.

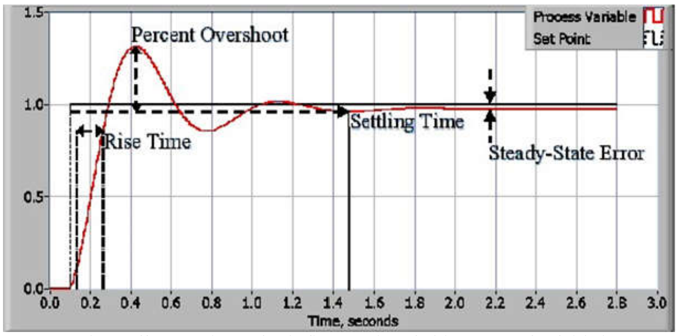


Source: https://docs.microsoft.com/pt-br/dotnet/iot/tutorials/blink-led. Accessed on Jan/2021.

Figure 3. Pinning GPIO Rapsberry Pi

PID Control (Proportional, Integral and Derivative): Proportional-Integral-Derivative (PID) control is the most widely used control algorithm in industry and has been used worldwide for industrial control systems. The popularity of PID controllers can be attributed in part to their robust performance over a wide range of operating conditions and in part to their functional simplicity, which allows them to be operated in a simple and straightforward manner. As the name suggests, the PID algorithm is composed of three coefficients: Proportional, Integral, and Derivative, which are varied to obtain the optimal response (GILLARD, George, 2018).

Definition of Control Terminologies: The control design process starts with the performance requirements. The performance control of the system is usually measured by applying a step function defined as a setpoint command, then the response of the process variable is measured. Generally, the response is quantified by the characteristics of the response waveform. The rise time is the time it takes for the system to go from 10% to 90% of the steady state, or final value. Percent Overshoot is the amount that the process variable exceeds the final value, expressed as a percentage of the final value (Shamsuzzoha, Mohammad; Skogestad, Sigurd, 2010). Settling time is the time required for the process variable to get within a certain percentage (usually 5%) of the final value (Jantzen, Jan; Jakobsen, Carl, 2016). Steady-State error is the final difference between the process variables and the setpoint. In some cases, the system response to a control output may change over time or with respect to some variables. A nonlinear system is a system in which the control parameters produce a desired response at one operating point and do not produce a satisfactory response at another operating point. For example, a chamber partially filled with a liquid will exhibit a much faster response at the outlet of a heater than when it is more filled with this same liquid. The robustness of the control system is understood as the extent to which the system will tolerate disturbances and non-linearities. Some systems exhibit an undesirable behavior called deadtime. Deadtime is a delay between the time a change in the process variable occurs and when the change can be observed (Fong-Chwee, Teng; Sirisena, H. R, 1988). For example, if a temperature sensor is placed away from a cold water inlet valve it will not measure the temperature change immediately if the valve is opened or closed. Deadtime can also be caused by a system actuator or slow output taking time to respond to the control command. For example, a valve that is slow to open or close. A common source of deadtime in chemical plants is the delay caused by fluid flow through pipes. Loop cycle is also an important parameter of a closed-loop system. The Loop cycle is the time interval between calls to a control algorithm. Systems that change rapidly or have complex behaviors, require faster control loop rates (Torres, 2020).



Source: https://www.ni.com/pt-br/innovations/white-papers/06/pid-theory-explained.htmlni.com, 2020. Accessed on Jun/2021

Figure 4. Response of a closed-loop PID source.

Proportional Response: The proportional component depends only on the difference between the setpoint and the process variable. This difference is referred to as the error term. The proportional gain (Kc) determines the output response rate for the error signal. For example, if the error term has a magnitude of 10, a proportional gain of 5 would produce a proportional response of 50. In general, increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the process variable will begin to oscillate. If Kc is increased further, the oscillations will get larger and the system will become unstable and may even oscillate out of control (Ahmad, Adizul et al, 2017).

Integral Response: The integral component adds up the error term over time. The result is that even a small error will cause the integral component to slowly increase. The integral response will increase over time unless the error is zero, so the effect is to drive the steady-state error to zero. The Steady-State error is the final difference between the process and set point variables. A phenomenon called integral windup occurs when integral action saturates a controller, without the controller adjusting the error signal to zero (Mazari, Funda Buyuk et al, 2018).

Response Derivative: The derivative component causes the output to decrease if the process variable is increasing rapidly. The derivative of the response is proportional to the rate of change of the process variable. Increasing the derivative time parameter (Td) will cause the control system to react more strongly to changes in the error parameter by increasing the speed of the overall control response of the system. In practice, most control systems use very small derivative time (Td), because the response derivative is very sensitive to noise in the process variable signal. If the sensor feedback signal is noisy or if the control loop rate is too slow, the response derivative can make the control system unstable (Anwar, Md et al, 2017).

Adjustment: The process of optimal setting for the gains P, I and D to obtain an optimal response of a control system is called tuning. There are different tuning methods, the "guess and check" method and the Ziegler Nichols method, which is the most common error correction method in PID (Reis, 2020). The gains of a PID controller can be obtained by the trial and error method. In this method, the I and D terms are set to zero and the proportional gain is increased until the loop output begins to oscillate. When the proportional gain is increased, the system becomes faster. Once P has been set to obtain a desired fast response, the integral term is increased in order to stop oscillations. The integral term reduces the steady state error, but increases the overshoot. A certain value of overshoot is required for a fast system so that it can respond to changes immediately. The integral term is again adjusted to achieve a minimum steady state error. Since P and I have been set so that the control system is fast with minimum steady state and constant, the derivative term is increased until the loop is acceptably fast relative to its reference point. Increasing the derivative term decreases overshoot, increasing gain, maintaining stability and still making the system highly sensitive to noise (Graham C. Goodwin, 2020). The Ziegler-Nichols method is another popular method of tuning a PID controller. It is very similar to the trial and error method, where I and D are set to zero and P is increased until the cycle begins to oscillate. Once the oscillation begins, the critical gain Kc and the period of oscillations Pc are noted. The P, I and D are then adjusted according to tabulated values (Åström, Karl Johan; Hagglund, Tore, 2004).

Wireless Technology: Devices commonly used for wireless networking include laptop computers, desktop computers, cell phones, and others. Wireless networks work similarly to wired networks, however, wireless networks must convert information signals into a form suitable for transmission over the airborne medium (Harder, Patrick, 2011). Wireless networks serve many purposes. In some cases, they are used to replace the cable network or when the infrastructure does not allow for their installation, while in other cases they are used to provide access to corporate data from remote locations. Wireless infrastructure can be built at a very low cost compared to wired networking (Davis, Harold, 2004). Wireless networks provide people with cheaper access to information. The time and effort saved by having access to the global network of information translates into wealth on a local scale, as more work can be done in less time and with less effort. Wireless networks allow remote devices to connect without difficulty, regardless of whether those devices are a few meters or several kilometers away. This has made the use of this technology very popular, spreading rapidly (Gast, Matthew, 2005). There are many technologies that differ in the transmission frequency used, speed and range of their transmissions. On the other hand, there are some issues related to the regulation of emissions within the electromagnetic spectrum.

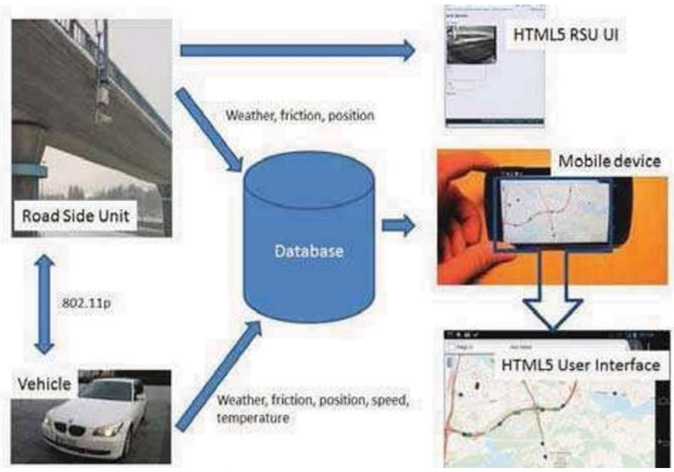
Electromagnetic waves are transmitted through various devices, but eventually these devices are subject to interference during transmission / reception. For this reason, all countries need regulations that define the frequency ranges and permitted transmission power for each technology. Wireless sensor networks (WSN) are in growing development and their use has been increasing in several sectors of society due to the ability to monitor and control environments without the need for a physical connection between their devices (Loureiro, Antonio AF et al, 2003). Wireless communication (or wireless) is used in networks such as WPANs (Wireless Personal Area Network), WLANs (Wireless Local Area Network), WMANs (Wireless Metropolitan Area Network) and WWANs (Wireless Wide Area Network), where each classification varies according to the application area and signal range (Salazar, 2017). The WWAN consists of wireless networks capable of covering a large geographical area, from antennas or satellites. Wireless Metropolitan Area Network (WMAN) allows connecting different locations in a metropolitan area (e.g. office buildings in a city), using fiber optic or copper cables and dedicated lines. Wireless Local Area Network (WLAN) covers only a limited area, equivalent to a room or offices (Park, Byeong-Yong; Jeong, Myung-Hun; Park, Seong-Ook, 2014).

Wifi: Wifi technology allows connection between different points without the need for wires, through devices that use radio frequency or light such as infrared. Among the main wireless technologies we have: (ENGST, Adam; FLEISHMAN, Glenn, 2003): IrDA - (Infrared Dada Associations) - Transmission bus through infrared light. By means of light signals emitted from an infrared LED (light emitting diode), data transmission is made. These signals are captured by a sensor present in the device, the receiver (Williams, Stuart; Millar, Iain. The IrDA Platform, 1999). Despite being a cheap interface, its data transmission speed is low, reaching up to 115 kpbs. Its mobility is also limited, since it has a range of no more than 2 meters and needs line of sight, without obstacles, i.e., the devices need to be pointed at each other for data transmission. This system is commonly used in TV remote controls (Januszkiewicz, Łukasz et al, 2016):

IrDA-D - Oriented to connection between devices for data transfer;
IrDA-C - Oriented to command and control.

Wifi - (Wireless Fidelity) - Licensed by the Wi-Fi Alliance to describe the technology for on-board wireless networks (WLAN) based on the IEEE 802.11 standard. WiFi, based on the IEEE 802.11 standard, operates in the ISM (Industrial, Scientific and Medical) bands with the following ranges: 902 MHz - 928 MHz; 2.4 GHz - 2.485 GHz 8 and 5.15 GHz - 5.825 GHz (depending on the country, these limits may vary) (Matos, 2017). The access point transmits the wireless signal over a short distance, usually up to 100 meters, but if the network is of the IEEE 802.11n standard the distance can reach up to 400 meters.

Internet of Things: Internet of Things or I.o.T. (Acronym in English) is the interaction of various objects connected to the same network, the possibility of controlling various physical elements at a distance and allowing these elements to control others that are connected to them (Faccione Filho, 2016). The concept was created in the late 1990s at MIT, and has been adapting as technology advances. The concept of I.o.T. can be applied even for communication between vehicles, according to Oraibi et al. (2017), the vehicle-to-vehicle communication still presents divergences as to the desired ideal, making the desirability of a server as a mediator of communication, but the tests are promising and will advance every day more.

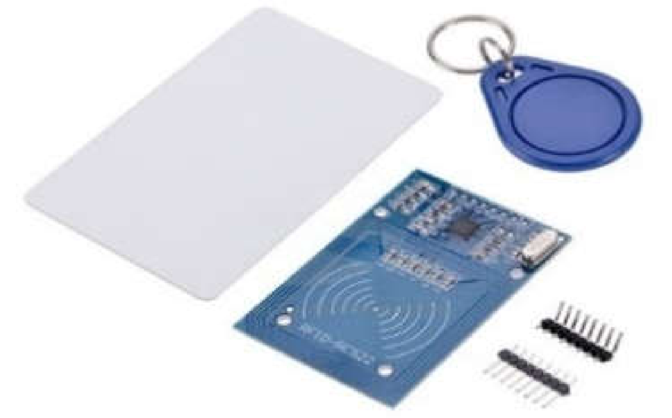


Source: Oraibi *et al.,* (2017).

Figure 5. I.o.T. invehicles

SSH Protocol: The SSH (Secure Shell or Secure Socket Shell) protocol was created to provide more security than other existing protocols when users need to control and modify their remote servers on the internet. It is a protocol that offers users, especially system administrators, a secure way to access a computer on an open network, such as the Internet (Barret, 2001). Using the client-server model, this protocol connects a Secure Shell client application, which is where the session is displayed, with an SSH server, which is where the session is executed, by creating secure tunnels to other protocols, i.e. it uses different combinations of technology to ensure communication between two points through a tunnel (Butler, 2000). Network administrators use SSH to manage systems remotely because they rely on its encryption, known as the strength of the protocol. In addition, it is also the encryption that allows them to connect to another computer on a network, execute commands, and move files from one computer to another.

MQTT Protocol: When thinking about a structure for message transmission in an I.o.T network, the standard is to use MQTT, which consists of sending and receiving short messages in two-way (publisher/subscriber) for all connections. According to Singh et al. (2015), MQTT is data-centric, so it is simpler and lighter because its messages are in binary format and its header has a maximum of two bits. It follows the publish/subscribe model, which makes the message arrive at the server and not wait for a reply, being able to send several times without any errors. The broker is responsible for receiving and sending the messages received from the publishers to the subscribers. The publisher is responsible for connecting to the broker and publishing the messages. The subscriber is responsible for connecting to the broker and receiving the messages he is interested in, these messages are separated by a "topic", which consists of a path determined by the programmer. The publisher sends the message to the broker on a given topic. The broker is responsible for receiving the message from the publisher and pre-filters the messages and sends them to the subscribers that are registered on the given topic.RFID. The term RFID (Radio Frequency Identification) is used for radio frequency data capture technologies. One of the most widely used technologies is the insertion of a serial number on a microchip to identify a certain person or object. To do this, the number is recorded on an element to which the microchip is allocated, commonly called a tag, by a recording equipment. And at the other end, we have a reader equipment to identify the existing number on the tag and confirm it as valid data, associating it to the person or object registered. In practice, an RFID system is basically composed of an antenna, a transceiver, which reads the signal and transfers the information to a reader device, and also a radio frequency tag, which should contain the information to be transmitted. According to Domdouzis et al. (2007) the applications for RFID are wide-ranging precisely because they identify items, making them traceable.



Source: https://www.arduinoeeletronica.com.br/produto/kit-leitor-rfid-rc522-tag-cartao/, Accessed Mar, (2021).

Figure 6. Kit RFID

MATERIALS AND METHODS

The materials and methods discussed in the research, are distributed according to sequential determinations.

Materials list:

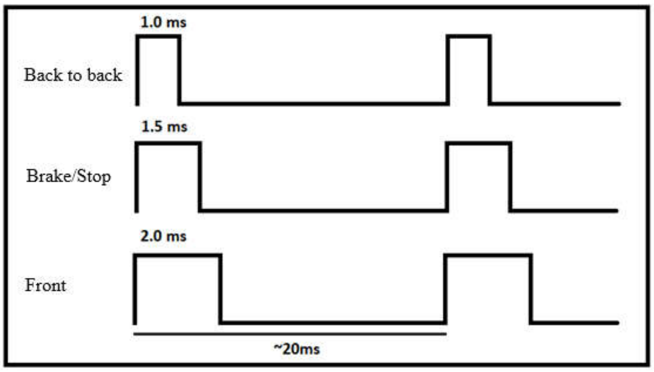
Line-following robots: The robot chosen for the work to be presented to the board is composed of Raspberry Pi 4 model B controllers, where two sensors on the same robot (infrared and RFID) will act separately, showing that there can be interaction of devices regardless of the hardware configuration, H-bridge motor for better speed control, five infrared sensors responsible for identifying the suggested path, an RFID reader sensor for locating the robot on the model, and use of MQTT and SSH protocols for communication between project elements.

Tabela 1. Lista de Materiais

Item	Quantity	Description
Battery Charger LIPO (Lipo/Life Balance Charger)	1	Charger for Lithium Batteries
LIPO Turnigy 2200mAh Batteries	3	Lithiumbattery 2200mAh/11.1V
Raspberry Pi4	3	Single board computer used to control the vehicle miniatures
Tcrt5000 5-Channel Line Tracking Module	3	Infrared sensor capable of detecting color variation
Motor Driver: Driver Ponte H Double L298n	3	Driver for clockwise or counter-clockwise motor drives
Wheel with Tire + DC 3 to 6v Motor with Reducer for Arduino	12	Wheel and motor set for moving the miniatures
Converter DC/DC Buck Boost 2 Em 1 Step Up E Down Xl6019	3	Voltage regulator, for the correct power supply to the circuit
Sensor RF ID: RC522	3	RFID code reader sensor for TAG card identification
Card TAG RFID	8	RFID Encrypted cards with single identification
Board MDF (1.90x2.80m)	1	Structure for simulation and validation of the research project

Source: Authors (2022)

Motor tuning: Four servos were used in continuous mode. These servos will rotate at a given speed depending on the pulse width they receive on their input. For this particular servo, the pulse width varies from 1.0ms to 2.0ms. The 1.5ms pulse will command the servo to stay in its neutral, or "stopped" position. A 1.0ms pulse will command the servo to run at its maximum speed (about 70 RPM) in one direction, and 2.0ms in the opposite direction.Pulses between 1.0 and 1.5ms, or 1.5ms and 2.0ms, will cause the servos to rotate at intermediate and proportional speeds.



Source: Authors (2022).

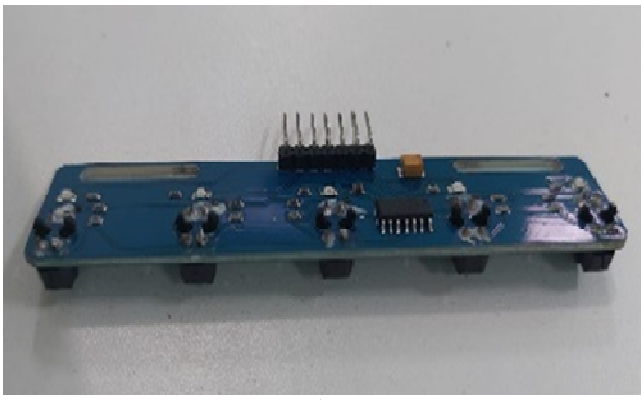
Figure 7. Pulse for motor control

The code below, using the C language for Raspberry, was used for the setup:

```
void motorDir_frente(void)
{
digitalWrite(IN1,HIGH);
```

```
digitalWrite(IN2,LOW);
}
void motorDir_freia(void)
{
digitalWrite(IN1,HIGH);
digitalWrite(IN2,HIGH);
}
void motorEsq_frente(void)
{
digitalWrite(IN3,LOW);
digitalWrite(IN4,HIGH);
}
void motorEsq_freia(void)
{
digitalWrite(IN3,HIGH);
digitalWrite(IN4,HIGH);
}
```

Adding the line sensors: When considering a larger number of sensors for better accuracy regarding the positioning of the vehicle in the lane to be followed, we opted to place five sensors for each vehicle. If unit sensors were used, the connections with the microprocessor, wiring and coupling in the miniature, would be much more complex than using a complete module with the desired number of sensors, so we chose to use a single board that integrates five infrared sensors



Source: Authors (2022).

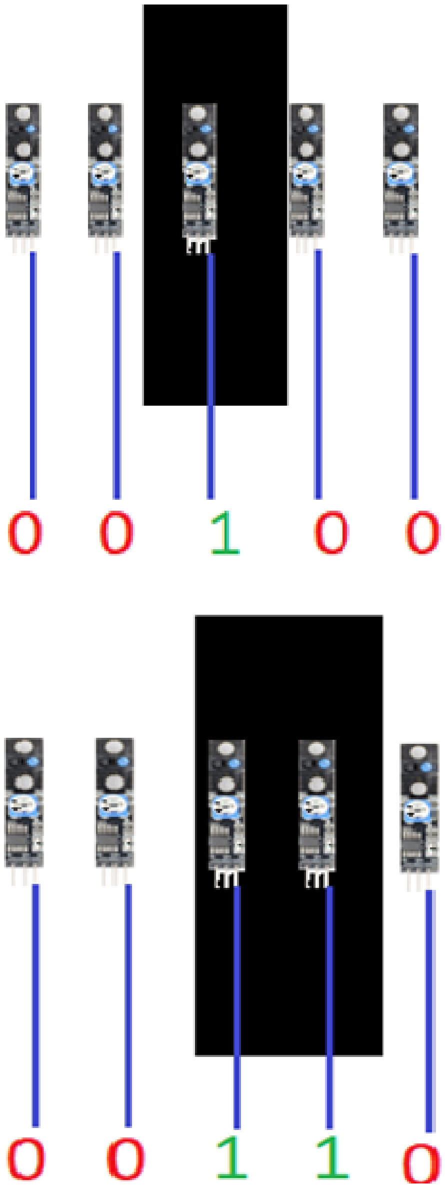
Figure 8. Infrared Sensor

Implementing the logic of line sensors: For the sensors used, an integrated circuit in the module generates a simple digital output signal (HIGH: dark; LOW: Light). To obtain a more approximate result of the robot's position in relation to the track (black insulating tape) an integrated module with 5 (five) sensors was used, being the sensor located in the center, when in "HIGH" value, the ideal position indicator of the cart. For better position adjustment, the space between the sensors allows two sensors to identify the black line simultaneously, thus producing a double "HIGH" signal input.

The possible output combinations of the sensor set are:

- 0 0 0 0 1
- 0 0 0 1 1
- 0 0 0 1 0
- 0 0 1 1 0
- 0 0 1 0 0
- 0 1 1 0 0
- 0 1 0 0 0
- 1 1 0 0 0
- 1 0 0 0 0

Working with five sensors, allows the generation of an "error variable" that will help control the position of the robot on the line. We adopt the matrix [0 0 1 0 0] as zero error.If the robot drifts to the left, the error should increase and with a positive sign. If the robot drifts to the right, likewise, the error should increase, but with a negative sign.



Source: Authors (2022).

Figure 10. Recognition in infrared sensor array 2

The error variable, related to the state of the sensor, was defined as:

0 0 0 0 1 ==> error = 4
0 0 0 1 1 ==> error = 3
0 0 0 1 0 ==> error = 2
0 0 1 1 0 ==> error = 1
0 0 1 0 0 ==> error = 0
0 1 1 0 0 ==> error = -1
0 1 0 0 0 ==> error = -2
1 1 0 0 0 ==> error = -3
1 0 0 0 0 ==> error = -4

To identify each of the positions it used a sum of the positions of each sensor in base 2 logarithmic scale. It thus tenses an integer number related to each reading of the infrared sensors as shown in the following code:

```
int lerSensor(void){

SeqLinha=0;
 if (digitalRead(S2)==1 ) {
      L[4]='1';
} else {
      L[4]='0';
```

```
}
if (digitalRead(S3)==1) {
      L[3]='1';
} else {
      L[3]='0';
}
if (digitalRead(S4)==1) {
      L[2]='1';
} else {
      L[2]='0';
}
if (digitalRead(S5)==1) {
      L[1]='1';
} else {
      L[1]='0';
}
if (digitalRead(S6)==1) {
      L[0]='1';
} else {
      L[0]='0';
}
 for(i=4;i>=0;i--)
 {
       if(L[i] == '1') {
SeqLinha = SeqLinha + 1*pow(2,i);
      printf("1");
                          }
      elseprintf("0");
       }
printf(" %d",SeqLinha);
returnSeqLinha;
}
```

And so that this value can be of use to the vehicle, the action is selected for each pre-programmed case, using a function that determines the intensity of each servo so that the vehicle returns to the ideal path, as per the following code.

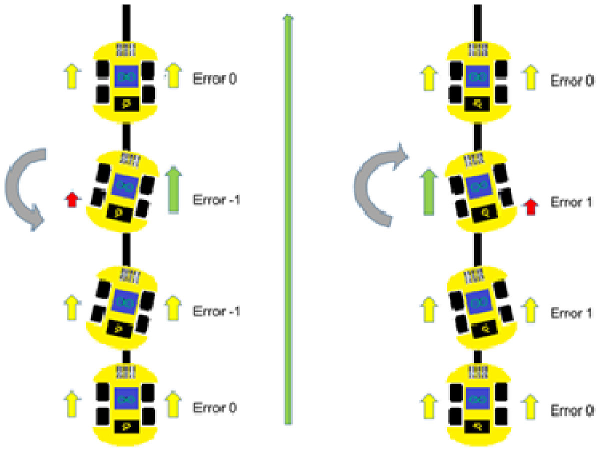
```
switch(lerSensor())
 {
case 1: //00001
      error=4;
      break;
case 3: //00011
      error=3;
      break;
 case 2: //00010
      error=2;
      break;
 case 6: //00110
      error=1;
      break;
 case 4: //00100
      error=0;
      break;
case 12: //01100
      error=-1;
      break;
 case 8://01000
      error=-2;
      break;
 case 24: //11000
      error=-3;
      break;
 case 16://10000
      error=-4;
      break;
default:
      motorDir_freia();
      motorEsq_freia();
pwmWrite (PWM_DIR,0);
pwmWrite (PWM_ESQ, 0);
printf("\nI found the end of the line");
getchar();
      break;
}
usleep(50);
}
}
```

Controlling the Direction (Proportional Control - p): To make the robot walk on the line, a control logic was implemented that will act as the "brain" of the carts. Suppose the robot is "walking" on a line and the output of the Sensor Array is: "0 0 1 0 0". In this case, the corresponding error is "0" and both motors will be pushing the robot forward with a constant speed.

A code for this condition would be:

```
pwmWrite (PWM_ESQ,VEL+error);
pwmWrite (PWM_DIR,VEL-error);
motorDir_front();
motorEsq_front();
```

Suppose the robot starts drifting to the left, causing sensor 3 too, to be on the line. In this case, the output of the Sensor Array will be: "0 0 1 1 0" and the error = 1. In this situation, the speed of the right Servo should decrease, which means decreasing the pulse width. Also, the speed of the left Servo should increase, which means decreasing the pulse width. To do this, you change the control function of the motor:



Fonte: Authors (2022).

Figure 11. Correcting the robot's trajectory

```
pwmWrite (PWM_ESQ,VEL+error); //positive error, left engine accelerates
pwmWrite (PWM_DIR,VEL-error); //positive error, right motor brakes
motorDir_front();
motorEsq_front();
```

Adding or subtracting only "1" microsecond in the duration of the pulses will not generate the necessary correction, for the correction to become effective, the number to be added or subtracted must be larger, e.g. 50, 100, etc. To achieve this, the "error" must be multiplied by a constant "K". Since the influence of this constant will be proportional to the error, we will call it "Proportional Constant: Kp". Initially, with the value = 50.

The final function for the motors will be:

```
int Kp = 50;
pwmWrite (PWM_ESQ,VEL+Kp*error);
pwmWrite (PWM_DIR,VEL-Kp*error);
motorDir_front();
motorEsq_front();
```

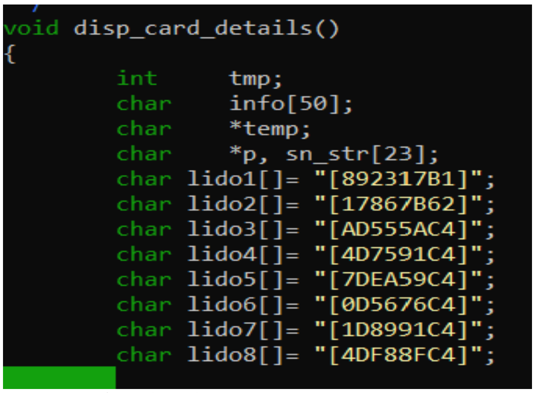
We can summarize what will happen to the engines as shown below:Array de Sensores: 0 0 1 0 0
error = 0
Right Servo: pulse = 1.750us
Left Servo: pulse = 1.250us
(both motors at the same speed)
Sensor Array: 0 0 1 1 0
error = 1
Right Servo: pulse = 1,700us (slower)
Left Servo: pulse = 1,200us (faster)

If the situation is the opposite and the robot goes to the right, the error would be "negative" and the speed of the servo should change:
Sensor Set: 0 0 0 0 1 0 0 0

error = 0
Right servo: pulse = 1.750us
Left Servo: pulse = 1.250us
(both motors at the same speed)
Sensor Array: 0 1 1 1 0 0
error = -1
Right servo: pulse = 1.800us (faster)
Left Servo: pulse = 1.300us (slower).

At this point it becomes clear that the more the robot "slips" to one side, the greater the error (1, 2, 3 or 4) and the faster it must return to the center (values to be added to the pulse width: 50, 100, 150, 200). The speed with which the robot will react to the error will be proportional to it, always seeking to eliminate the error, that is, return to the ideal position "0 0 1 0 0".

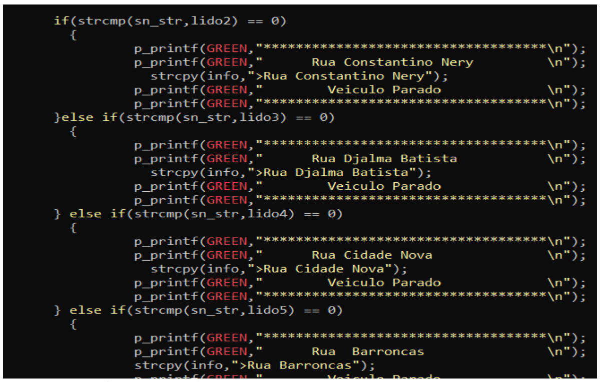
Implementing RFID identification: In order to signal the vehicles when there is an intersection ahead, RFID tags were positioned with names of streets, where each one represents the beginning or the end of an intersection. When passing by the tag, the vehicle sends a message via MQTT to the host, and all the vehicles connected to the protocol topic receive the message of which vehicle passed by which street. To configure each tag the following code was used:



```
void disp_card_details()
{
        int      tmp;
        char     info[50];
        char     *temp;
        char     *p, sn_str[23];
        char lido1[]= "[892317B1]";
        char lido2[]= "[17867B62]";
        char lido3[]= "[AD555AC4]";
        char lido4[]= "[4D7591C4]";
        char lido5[]= "[7DEA59C4]";
        char lido6[]= "[0D5676C4]";
        char lido7[]= "[1D8991C4]";
        char lido8[]= "[4DF88FC4]";
```

Source: Authors (2022).

Figure 12. Registration of RFID card codes

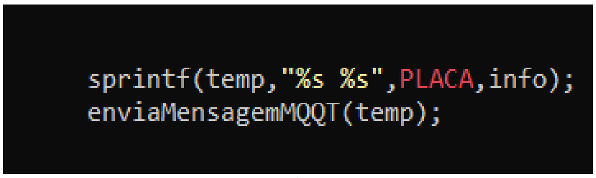


```
if(strcmp(sn_str,lido2) == 0)
  {
          p_printf(GREEN,"***********************************\n");
          p_printf(GREEN,"      Rua Constantino Nery          \n");
            strcpy(info,">Rua Constantino Nery");
          p_printf(GREEN,"        Veiculo Parado              \n");
          p_printf(GREEN,"***********************************\n");
}else if(strcmp(sn_str,lido3) == 0)
  {
          p_printf(GREEN,"***********************************\n");
          p_printf(GREEN,"      Rua Djalma Batista            \n");
            strcpy(info,">Rua Djalma Batista");
          p_printf(GREEN,"        Veiculo Parado              \n");
          p_printf(GREEN,"***********************************\n");
} else if(strcmp(sn_str,lido4) == 0)
  {
          p_printf(GREEN,"***********************************\n");
          p_printf(GREEN,"      Rua Cidade Nova               \n");
            strcpy(info,">Rua Cidade Nova");
          p_printf(GREEN,"        Veiculo Parado              \n");
          p_printf(GREEN,"***********************************\n");
} else if(strcmp(sn_str,lido5) == 0)
  {
          p_printf(GREEN,"***********************************\n");
          p_printf(GREEN,"      Rua  Barroncas                \n");
          strcpy(info,">Rua Barroncas");
```

Source: Authors (2022)

Figure 13. Registration of street names RFID card.

As explained by Vogt (2002), the reading of the tags is done in cycles, so to define when the next reading will be done, we assign the value in milliseconds of the last reading to a variable, and we increase this same value with the desired cycle time, in this case, we used one hundred milliseconds. As soon as the reading of a registered card is done, we send a message via MQTT to the vehicle with the vehicle's location, so the vehicle understands if it needs to stop, or can continue its route.

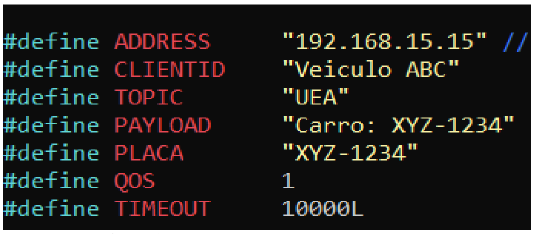


```
sprintf(temp,"%s %s",PLACA,info);
enviaMensagemMQQT(temp);
```

Source: Authors (2022).

Figure 14. Sending the MQTT message

Establishing communication via MQTT protocol: In order for the vehicles to communicate, and even the components of a single vehicle to communicate with each other, we set up a topic with an MQTT Publisher using an external raspberry pi as a host. Initially, we set up the code with the host IP and defined the topic for vehicle communication. We also set a vehicle "license plate" to identify who the message will be sent to.



```
#define ADDRESS     "192.168.15.15" //
#define CLIENTID    "Veiculo ABC"
#define TOPIC       "UEA"
#define PAYLOAD     "Carro: XYZ-1234"
#define PLACA       "XYZ-1234"
#define QOS         1
#define TIMEOUT     10000L
```

Source: Authors (2022).

Figure 15. MQTT client configuration

Field Tests

Line following robot: As a first step, two line-following robots are assembled and tested. Equipped with a 3-cell 11V LIPO battery for vehicle autonomy, infrared sensors to identify the path to be traveled, RFID reader to locate the vehicle on the mockup, WI-FI network access, to use the MQTT protocol, and an H-bridge motor driver for better vehicle speed control. All the vehicle components are controlled by codes inserted in the raspberry pi4 attached on top of the robot. The codes are triggered via SSH from a third raspberry pi that works as a server. Through this server, the files of the two vehicles are accessed, and then the respective codes for RFID reading and movement are started. Through the SSH protocol, one can follow the log of the sensor readings, as if directly accessing the terminal on the vehicle itself.

Robot interaction in an uncontrolled environment: For the simulation of uncontrolled vehicle interaction, two line followers are placed in different positions on the test track in free-motion mode, until, due to a speed difference caused by the curves of the mock-up, an eventual collision occurs. Even if the vehicles were equipped with sensors to avoid a frontal collision, it would result in a change of trajectory which would cause the vehicle to leave the track, preventing it from continuing the path, since the vehicle is programmed to pause the code if it does not find the lane of the track. In this case, a parallel is made with a situation where two drivers with lapse of attention at an intersection are involved in a collision.

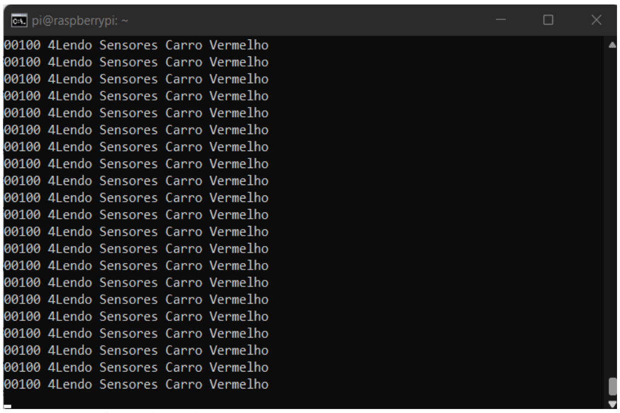
Position tracking of the robots on the mockup: For effective traffic control, it is initially necessary to define a preferred lane and the location of the vehicles in the lane. In a simplified way, we identify each intersection with an RFID tag, so when the robot aligns itself with the card, we will know the approximate position of the vehicle.

With each robot traveling at a different speed because of the curves in the mockup, it is necessary to define the preference following several criteria, such as main road, order of arrival, and preferred vehicle.At this first moment, if a vehicle is located at the beginning of an intersection, it will receive the command to stop the movement and wait for the positive response to resume.

Traffic control performed automatically: For the experiment to be valid, it was necessary that several vehicles pass in a road with collision risk. For this, we used two different robot models and with their components acting in separate codes, which would represent the plurality of brands or technologies found in a predicted situation. The track model was devised to provide an infinite path with two lane intersections. During the experiment, the two vehicles will travel indefinitely through the model, and will make use of communication with an external server, via MQTT to identify intersections and receive orders to stop or authorize resumption of movement, without human interference in decision making.

RESULTS AND DISCUSSION

The Movement: When starting the tests, it can be seen that the vehicle's movement is highly influenced by the charge of the battery attached to the miniature. Since it is a control system that directly influences the engine power, a battery without enough charge is not capable of modifying the power enough to change the vehicle's trajectory efficiently. After some adjustments and using the batteries always above an acceptable charge, the two vehicles travel uninterruptedly along the track, in a free movement without stopping control or obstacle avoidance. Automatically reducing speed during curves and reaching their maximum speed during straights. The sensor is updated every 50ms, which generates an extensive readout list during the entire path of the vehicle, and gives more precision as to the setting of the thumbnail on the desired path.



```
00100 4Lendo Sensores Carro Vermelho
00100 4Lendo Sensores Carro Vermelho
00100 4Lendo Sensores Carro Vermelho
00100 4Lendo Sensores Carro Vermelho
00100 4Lendo Sensores Carro Vermelho
00100 4Lendo Sensores Carro Vermelho
00100 4Lendo Sensores Carro Vermelho
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00100 4Lendo Sensores Carro Vermelho
00100 4Lendo Sensores Carro Vermelho
00100 4Lendo Sensores Carro Vermelho
```
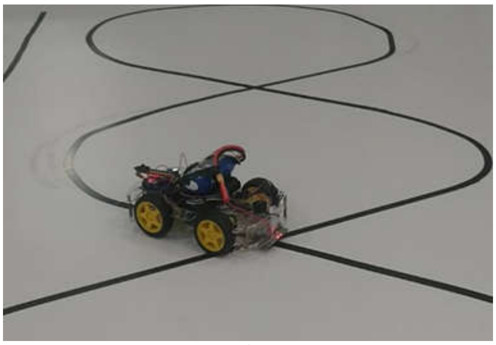

Source: Authors (2022).

Figure 16. Infrared sensor reading in the red vehicle

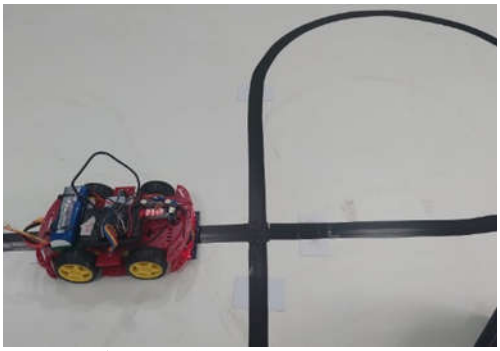
The trajectory: The idealized path was designed to promote two intersections without the need to reposition the vehicles to restart the lap in the lane. Initially, the path provided shallow angle intersections, but to optimize the lane identification by the infrared sensor, the lane was modified to two perpendicular intersections. Thus, allowing the simulation of one main and two side avenues. For the purpose of lane validation, the main lane idea was temporarily suspended, and we adopted all lanes with the same preference lane.

RFID reading: Each vehicle, when passing by an RFID card, sends a message to the terminal, confirming its location and sending a message to the MQTT protocol host, where it identifies the license plate and the street it is passing by. If the location is the beginning of an intersection, the message to be sent is that, if the road is busy, the vehicle must stop, and if it is the end of an intersection, it sends the message that it is safe for another vehicle to cross the intersection.



Source: Authors (2022).

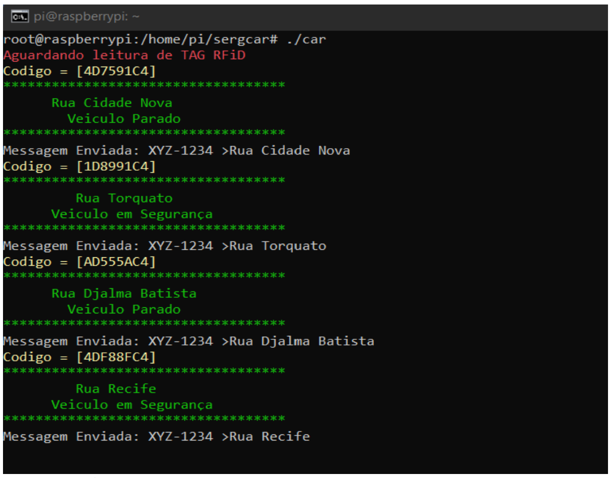
Figurem 17. Test Track, 1st version



Source: Authors (2022).

Figure 18. Test Track, 2st version

Communicating via MQTT: For a vehicle to send the message of its location, it needs a host, which receives the message and sends it to all those connected to the related topic. To keep track of these messages, we use a broker on the raspberry pi terminal that serves as the host and activate the read protocol for all messages received by the host. When messages are passed on, each vehicle identifies, by the license plate at the beginning of the message, whether the message is addressed to itself, or to another vehicle. The vehicle then acts according to the parameters defined by the code: If the path is clear, it proceeds without stopping and blocks the intersection of the competing lane; if the path is blocked, it stops and waits for confirmation to resume; if it passes through the end of the intersection, it releases the competing lane.

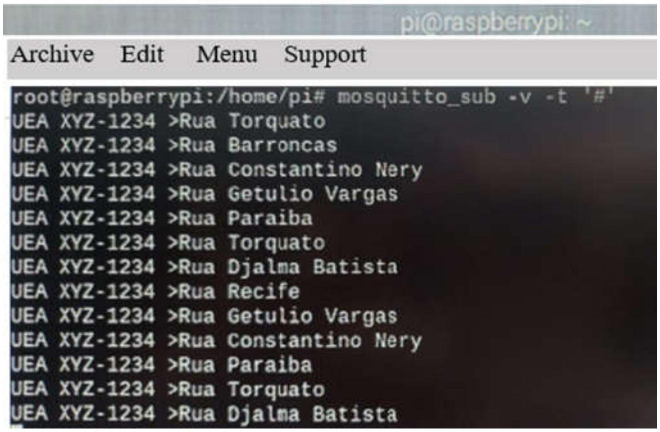


```
root@raspberrypi:/home/pi/sergcar# ./car
Aguardando leitura de TAG RFiD
Codigo = [4D7591C4]
*********************************
      Rua Cidade Nova
        Veiculo Parado
*********************************
Messagem Enviada: XYZ-1234 >Rua Cidade Nova
Codigo = [1D8991C4]
*********************************
         Rua Torquato
      Veiculo em Segurança
*********************************
Messagem Enviada: XYZ-1234 >Rua Torquato
Codigo = [AD555AC4]
*********************************
      Rua Djalma Batista
        Veiculo Parado
*********************************
Messagem Enviada: XYZ-1234 >Rua Djalma Batista
Codigo = [4DF88FC4]
*********************************
         Rua Recife
      Veiculo em Segurança
*********************************
Messagem Enviada: XYZ-1234 >Rua Recife
```

Source: Authors (2022).

Figure 19. Reading RFID cards

The interaction between the vehicles: By running the experiment in automatic mode, one realizes that the harmony between the vehicles depends exclusively on all of their components being in full operation. For everything to occur as expected, the sensor reading time adjustments, the speed of the miniatures, and the size of the mockup had to be in sync.



```
root@raspberrypi:/home/pi# mosquitto_sub -v -t '#'
UEA XYZ-1234 >Rua Torquato
UEA XYZ-1234 >Rua Barroncas
UEA XYZ-1234 >Rua Constantino Nery
UEA XYZ-1234 >Rua Getulio Vargas
UEA XYZ-1234 >Rua Paraiba
UEA XYZ-1234 >Rua Torquato
UEA XYZ-1234 >Rua Djalma Batista
UEA XYZ-1234 >Rua Recife
UEA XYZ-1234 >Rua Getulio Vargas
UEA XYZ-1234 >Rua Constantino Nery
UEA XYZ-1234 >Rua Paraiba
UEA XYZ-1234 >Rua Torquato
UEA XYZ-1234 >Rua Djalma Batista
```

Source: Authors (2022).

Figure 20. MQTT subscriber screen

Throughout the experiment, there was a failure in the reading of some components, however, these failures were corrected and the experiment proceeded without further complications. In an environment where all components performed their functions, the vehicles circulated in a harmonious way, following and stopping as the situation demanded. Without the need for human intervention, the interaction between the vehicles became faster and more effective, thus proving the project's proposal.

CONCLUSION

By allowing traffic flow while ensuring compliance with the traffic rules pre-established in the code, the efficiency of the traffic control system for autonomous vehicles is proven. We can affirm that such a system is one of the solutions to reduce or even eliminate, momentarily, the number of accidents involving vehicles at intersections, since, when well programmed, the system prevents vehicles from advancing without ensuring that the way is clear for crossing. Not leaving aside, an eventual electrical or mechanical error in the vehicle components that will lead the prevention system to failure. For the reduction of accidents to occur optimally, it is necessary that the entire fleet of cars on the road be composed of autonomous cars, or that the prediction technologies installed in the autonomous cars in operation, advance even further, to compensate for an eventual human error. There is still a long way to go before a car with automation level 3 or above is available on the market for the public at an affordable price. Therefore, the optimization of technologies used in vehicles, in order to cheapen costs or promote greater efficiency while driving, is essential to accelerate the migration process from human driving to autonomous driving. The research carried out in this paper, although simple, shows that low-cost technologies that are already commonly used today can be adapted and leveraged for situations that are still little explored involving vehicular traffic both individually and considering the interactions between vehicles. As a continuation, I intend to approach the direct communication between vehicles, thus eliminating the need for totems, or centralized servers for information transfer, as well as concepts of overtaking and path prediction, bringing the project to higher levels of vehicular automation.

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