Control autónomo de un vehículo eléctrico mediante visión artificial aplicada al proceso de enseñanza-aprendizaje

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Autonomous Control of an Electric Vehicle by Computer Vision Applied to the Teaching-Learning Process

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Abstract. The electric vehicle is an attractive tool for the study of autonomous vehicles. In education, it can provide students with concepts on the hardware and software aspects of mobile robotics; therefore, this paper proposes the autonomous control of a low-cost car-like vehicle based on real-time image processing. The vehicle is developed to implement an autonomous control algorithm using image processing, detection of horizontal and vertical traffic signs on the road. In the design of the vehicle, the transmission and steering are modified to resemble the behaviour of an electric vehicle. The implementation of artificial vision uses low-cost elements and free software such as Raspberry Pi with its respective camera module and an Arduino. The Haar Cascade classifier is used to classify the vertical signage, which consists of fast object detection based on automatic learning.
Keywords: Education, Image Processing, Traffic Signal Detection, Image Classifier, Computer Vision.

1 Introduction

In recent years, robots have been widely used in industry for process automation to improve productivity; however, the big challenge for robotics today is to move from the industrial area to service robotics [1], *e.g.*: *a) Tourism*, which points to a new revolution brought about by the introduction of robots and artificial intelligence using them in a collaborative way, e.g. waiter robots, cooks robot and even robots to support hotel reception and room service [2, 3]; *b) Health*, where the use of medical robotics is employed to examine patient care through diagnostic and treatment tools [4], contribute to therapies requiring neurological rehabilitation for patients with functional disorders or cerebral palsy [5, 6]; *c) Agriculture,* where robots are mentioned as possible solutions to improve efficiency and robustness of jobs, through multi-robot approaches. Swarm robotics emphasises aspects such as flexibility, scalability and robustness in solving complex tasks, and is considered highly relevant for precision agriculture, computer vision weed control and large-scale agricultural applications [7,8, 9, 10]; *d) Transport;*

technological innovation is a key driver for the development of the automotive industry and mobile robotics [11,12]; therefore, its study continues to increase, developing technologies such as: robots that are used cooperatively; either for manipulation or for moving objects through structured environments; [13] *e) Education*, robots are used as alternatives to develop and improve programming skills, hardware and software architecture, e.g.; Mona is an open source, low-cost robot used in the development of swarm robotics; it allows for flexibility in both teaching and learning processes and research [14, 15]. Consequently, its study continues to increase through the development of technologies to support teaching and learning processes in different environments and applications.

Educational robotics is applied in different environments depending on the needs, however, the study of robotics emphasises the development of its structure in two areas of interest: *a) Hardware*; robots with modular control architecture built on the basis of industrial prototypes maintain the balance between low-cost devices compared to the performance of industrial robots [16]. There are LEGO robots, where the manipulation of the pieces allows users to design geometric and mechanical structures, among others; in order to involve students in the teaching of mathematics and physics [17]. Tthey are also applied in inclusive education; *e.g.* students with cultural and socioeconomic differences, gender balance, special abilities; including people with problems of "colour fading" building LEGO robots with emphasis on colours [18]. The construction of robots allows the incorporation of new sensors in order to monitor the environment in real time and in turn acquire information to process it [19]; *b) Software,* the use of mobile devices in education through applications that present influence and understanding to students. They are used to understand the inner workings of robots [20], including training applications based on augmented reality [21] and virtual reality, as well as applications based on artificial vision. Computer vision systems allow learners to manipulate the robot based on visual object detection, tracking and pattern navigation [22], as well as enhance interaction with the robot through learning tools by visualising geometric figures, numbers, and other mathematics-related topics [23]. Educational robotics emphasises the use of open source and low-cost robots in both hardware and software, as this ensures affordability for learners and can enhance their learning processes [24].

Control algorithms in robots or vehicles are oriented towards autonomous and assisted driving, either for parking or for tasks that demand coordinated or fleet work [25, 26]. The different control techniques implemented in autonomous vehicles present solutions such as: *a) Geo positioning*, consists of the navigation and location of the vehicle in real time. The study includes the Extended Kalman Filter, which consists of indirectly fusing measurements from low-cost inertial sensors with GPS measurements and thus estimate the position and speed of the vehicle [27]; *b) Navigation and guidance algorithms*, have autonomous navigation algorithms; supported by noise measurements obtained from sensors present in the vehicle. It has a control system to follow a predefined trajectory [10]; *c) Laser technologies*, there are simulations of successful path-following algorithms applied to a commercial vehicle, which is controlled by nodes and sensors that determine the lanes mapped, curves present and points to be moved [28]; *d) Computer vision*, image processing techniques are applied to handle complex tasks;

they receive the environment, identify objects on the road and allow appropriate commands to be sent to the vehicle [29]. Controls and navigation of ground vehicles exist for global tasks; many of them with local and wireless positioning systems for optimal tracking and navigation, as well as search and location applications for centralised, distributed and autonomous mission execution. Thus substantially maintaining the well-being and progress of modern transport and society. Therefore, the development of autonomous vehicles is seen as a great potential to achieve improvements in quality, efficiency and safety for the benefit of people.

In line with the above, this article presents the development of a low-cost autonomous vehicle by means of artificial vision focused on the teaching-learning process. For the implementation of the control algorithm, a car-like autonomous vehicle was designed based on an HPI Trophy buggy. The autonomy of the vehicle is based on real-time image processing; specifically oriented to horizontal traffic signals and vertical signals such as: stop, yield, traffic lights and obstacle detection on the road.

2 Problem Formulation

There is currently a growing interest in the development of technologies that benefit teaching and learning processes through the use of low-cost, Open Source programmable robots. Autonomous driving technologies are growing in order to obtain easily interpretable algorithms that limit human intervention and improve real-time autonomous navigation [4]. Furthermore, one of the main goals of introducing robotics in education is to maximise knowledge through the theoretical and practical application of programmable models.

On the other hand, most land vehicles are internal combustion vehicles where human intervention is required to move from one place to another. However, there are electric vehicles with navigation and autonomous driving systems, but their study is limited due to the high costs involved in their acquisition and even the lack of experience in handling vehicles with autonomous driving [5].

Computer vision control algorithms for autonomous navigation consider image processing techniques in order to identify horizontal, vertical traffic signs, e.g. stop, yield, left or right turns, traffic lights and road obstacle detection, as shown in Fig. 1.

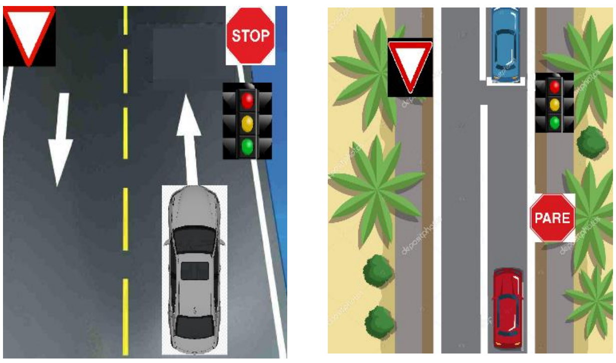


Fig. 1. Autonomous vehicle context.

In this context, the present work considers the mechanical-electrical construction of a prototype vehicle with car-like typology; considering the autonomous control of the transmission for the linear speed and the steering for the steering angle, in order to implement intelligent control algorithms for autonomous navigation. The prototype must be accessible to the learner for manipulation and modification.

3 Construction of the Prototype

This section describes the construction of the prototype of the car-like autonomous electric vehicle. Fig. 2 shows the building block diagram of the electric vehicle, consisting of the main sections: mechanical, electrical, communication and control.

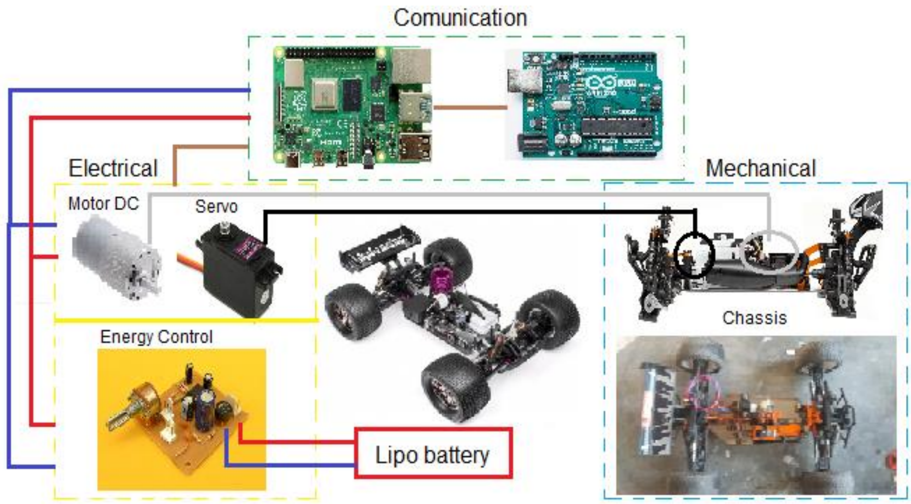


Fig. 2. Diagram of vehicle construction blocks

A. Mechanical System

For the mechanical design, relevant information was gathered in terms of the vehicle's autonomy and the load to be transported. The main systems are analysed with CAD software and then the structural stress of the material is determined using the Von Mises stress. The mechanical system analysis consists of three sets: *i) Transmission system*, the traction of the system is taken into account to transmit the power to the rear wheels. The system consists of a set of gears geometrically adapted in order to avoid power losses in the linear displacement as shown in Fig. 3; *ii) Steering system*, consists of an aluminium steering rack and robust steel tie rods to guide the wheels, steel bolts, self-locking nuts, steel tie rods and four sealed ball bearings for precision steering; *iii) Chassis*, be able to withstand the weight incorporated on it, e.g. gears, motors, battery, screws and other components.

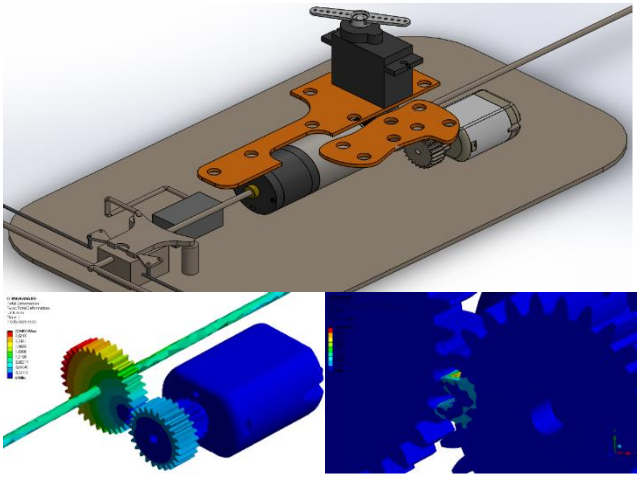


Fig. 3. Mechanical design analysis (Transmission)

B. Electrical System

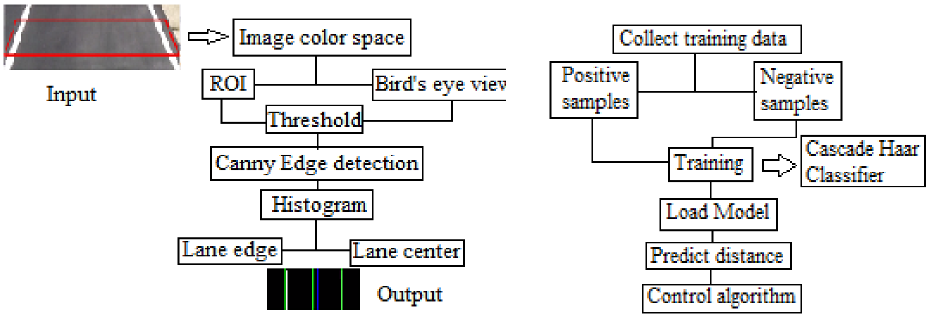
The electrical system describes the following stages: *i) Power*, which is composed of the autonomous vehicle power supply consisting of an 11.1V Lipo Battery with a capacity of 5000mAh, and the transmission motor with a nominal voltage of 12V, with a no-load current consumption of 900mA and a load current of 1300mA; *ii) Power regulator*, voltage regulating circuit is considered which provides 5V output and a current of 3A. It has a servo motor with a voltage range of 4.8V to 6V and a torque of 6.5 kg/cm; and *iii) Protection*, consists of protecting the electrical system and actuators in the presence of an electric shock, consisting mainly of a fuse and heat sinks.

C. Control unit

A 5V powered Raspberrry Pi is implemented as the control unit where the different external peripherals are connected, e.g. the camera which allows to determine the environment where the robot is going to navigate or the internal sensors of the platform. Using the Raspberry Pi and the OpenCV library, real-time image processing is carried out in order to execute the maneuverability commands. The commands are sent through a master-slave protocol to an Arduino board to activate the different actuators and provide movement to the robot.

4 Image Processing and Control Algorithm

In this section, we describe real-time image processing using the OpenCV library, process horizontal and vertical traffic signs and train a cascade classifier. Fig. 4 describes the block diagrams for the two-stage image processing: (a) the control algorithm for horizontal signalling and Fig. 4 (b) the Haar Cascade image classifier for vertical signalling.



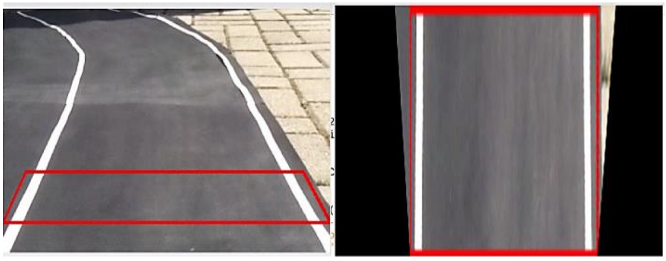
a) Horizontal signage diagram b) Cascade classifier diagram

Fig.4. Stages for image processing

4.1 Horizontal Signage Processing

This subsection details real-time image processing by configuring a camera with the Raspberry and calculating the frames per second (FPS) through the ctime function of c++.

The image processing for lane detection (horizontal signalling) consists of the stages presented in Fig. 4 (a); *i) Colour space of the image*, the initial frame is presented in the BGR (Blue, Green, Red) colour space considered an incorrect colour image; therefore, the image is converted to the RGB colour space in order to give colour accuracy to the image; *ii) Region of interest (ROI) and Bird's eye view*, from the real time image a particular box called ROI is extracted; where four different vertices are considered, it must be ensured that the horizontal signage is part of the box. In this case, the region of interest belongs to the lower part of the frame Fig. 5 (a). The processing for the bird's eye view consists of obtaining the top view of the ROI, transforming the perspective indicated by the camera using the “warpPerspective()” function until the final result is obtained as shown in Fig. 5 (b).



a) Region of interest, ROI b) Bird's eye view

Fig. 5. Processing of the desired frame.

iii) Threshold and edge detection, in order to extract the region determined by an appropriate threshold value; the three-channel RGB image is converted to a one-channel grey image; where the background pixels must be varied from 0 the black colour to 255 the white colour to obtain a frame as shown in Fig. 6 (a). For lane edge finding, the Canny algorithm is used, which aims to obtain a low error rate, i.e. good detection of only existing edges in the signage. Finally, the threshold image is matched with the edge detection to obtain the final image result presented in Fig. 6 (b); *iv) Histogram*, starting from the edges found in the frame, a histogram is generated to verify areas of the image that have high concentrations of white pixels and to trace the edges of the lane

a) Noisy frame threshold b) Final processed image

Fig. 6. Processing of the desired frame.

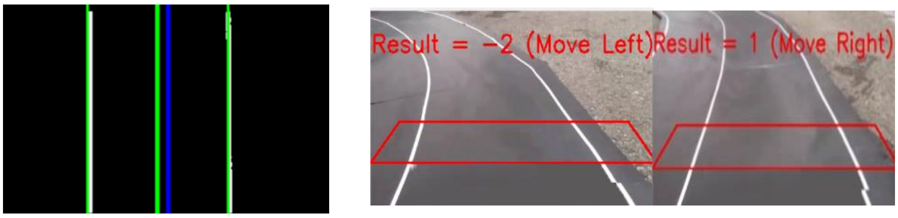
v) Lane edge and lane centre detection, it is necessary to find the exact position of each line with respect to the left side of the image edge in order to obtain the exact centre of the ROI; as it supports the control of vehicle movement. From these two edges, the position of the centre line (L_c) (green colour) is found, which is determined by the position of the right side of the frame (P_{LD}), and the position of the left side of the frame (P_{LI}). It is represented by the following expression:

$$L_c = \frac{P_{LD} - P_{LI}}{2} + P_{LI} \tag{3}$$

.

It is also required to indicate a frame centre line (L_F) (blue colour) to determine the centre of the vehicle, and it must also be framed in the centre of the frame as shown in Fig 7 (a). To properly define the central position of the autonomous vehicle (L_c) is superimposed on (L_F); since the displacement of (L_F) towards either edge indicates that the vehicle is moving either to the left or to the right side as shown in Fig. 7 (b). The vehicle positioning error for which the control of the steering commands is generated is defined by the following expression:

$$Error = L_c - L_F \tag{2}$$



a) Frame line and centre line b) Shift left and right

Fig. 7. Real-time image processing

4.2 Image Classifier

This subsection details the classification of vertical signage such as stop, traffic lights and obstacle detection using the Haar Cascade classifier and OpenCV.

The present work uses a shape-based approach, hence Haar feature-based cascade classifiers are used for object detection. Since each object requires its own classifier and follows the same training and detection process, the project focuses on the detection of stop signs, traffic lights and obstacle detection, and consists of the following stages; *i) Training data collection*, is done by Raspicam, the set of samples are collected randomly and at different angles; they should be classified into two groups: positive samples containing the target object and negative samples which are those that do not contain the target object. In particular, 100 positive samples were taken from stops and obstacles; however, the traffic light samples contain 200 positive images for both red and green traffic lights. The negative samples contain 300 images and are part of the training set; *ii) Training*, a Haar Cascade Classifier is used to extract features from the images using a type of filter, similar to the concept of the convolution kernel. These filters are called Haar filters, and are used to inspect one portion or frame at a time. For each window, all pixel intensities of the black and white portions are added together, the value obtained by subtracting the two portions is the value of the extracted feature;

iii) Load the Model, XML files are created during the different stages of training which is used in the main Raspberry algorithm; *iv) Distance prediction*, in order to determine the distance between the vehicle and the object, the scheme presented in Fig. 8 shows a geometrical model of distance detection to an object based on a monocular camera [30].

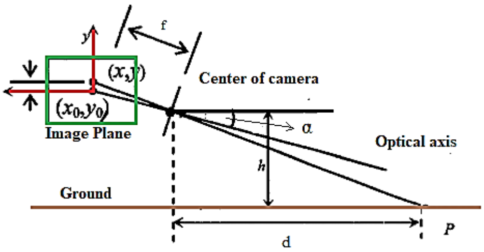


Fig. 8. Geometric model for detecting distance in the image

where, P is a point on the target object; d is the distance from the optical centre to point P, f is the focal length of the camera; α is the tilt angle of the camera; h is the height of the optical centre; (x_0, y_0) refers to the point of intersection of the image plane and the optical axis; (x, y) refers to the projection of point P on the image plane. Assuming that O_1 (u_0, v_0) is the camera coordinate of the point of intersection of the optical axis and the image plane, also the physical dimension of a pixel corresponding to the x-axis and the y-axis in the image plane are d_x y d_y; then it follows that:

$$d = \frac{h}{tan\left(\alpha + arctan\left(\frac{y - y_0}{f}\right)\right)} \tag{3}$$

$$u = \frac{x}{d_x} + u_0 \quad v = \frac{y}{d_y} + v_0 \tag{4}$$

Equating $x_0=y_0=0$, desde (3) and (4) we obtain:

$$d = \frac{h}{tan\left(\alpha + arctan\left(\frac{v - v_0}{a_y}\right)\right)} ; \qquad \left(a_y = \frac{f}{d_y}\right) \tag{5}$$

v , are the coordinates of the camera on the y-axis and can be returned from the object detection process. All other parameters are intrinsic camera parameters.

Considering the vertical transistor signals, the vehicle motion control detects the traffic signals set out in Fig. 9. within a certain distance; it sends the necessary commands from the Raspberry Pi to the Arduino. The Arduino manipulates the vehicle to stop for a set time for the stop sign and then move forward in its lane; in the case of the traffic light the vehicle observing the red light stops until the light changes to green. If the vehicle detects an obstacle in front of it, it changes to the opposite lane, moves forward a distance and resumes its lane automatically.

Fig 9. Traffic signs

Finally, the detection of obstacles on the road is considered; in which the cascade classifier is modelled and implemented for a particular object. The model allows identifying the obstacle on the road in order to generate stopping manoeuvres for the vehicle. The control is performed by means of a determined distance where the vehicle identifies the obstacle and proceeds to stop for a certain time until the object is removed from the road.

5 Experimental Results

This section presents the results obtained during the performance tests, for which the construction of the prototype, the mechanical and electrical characteristics of the prototype are considered. A Raspberry Pi with a 1.5 GHz quad-core processor and 4 GB RAM is used. The processed image is in the RGB colour space; its size is 320*240 pixels at a speed of 30 frames per second.

Fig 10. Defined route for the vehicle route

In order to evaluate the described task, a defined route is considered as shown in Fig 10. We proceed to verify the control of the vertical signalling; where the vehicle must follow a straight trajectory maintaining a constant speed in the transmission. A more difficult task is to stay within the lane in curves, where the steering is actuated by the servomotor by varying its angle as the radius of curvature of the track increases or decreases. Fig. 11 shows the route of the autonomous vehicle on different sections of the track with their respective image processing.

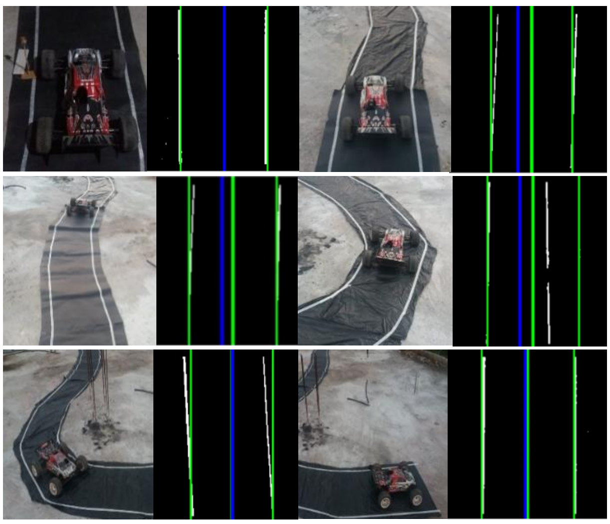


Fig 11. Evolution of the vehicle's route

For image classification, a pre-trained model such as Haar Cascade is used, an ROI is considered to delimit the object to be analysed. Gaussian blur is applied within the ROI in order to reduce noise present in the photograph. Within the ROI the model locates the brightest point and according to its position determines the status of the traffic light; either green or red.

On the defined route, the vertical signage Fig 12 is implemented, in addition to an obstacle on the road. The autonomous vehicle identifies the stop signal, stops for 5 seconds and then activates the transmission to continue its route. On detecting a red traffic light, the vehicle stops until the light turns green and the transmission is activated again. When the vehicle detects the presence of an obstacle, it stops, changes lanes, moves forward in a set time and finally returns to its lane.

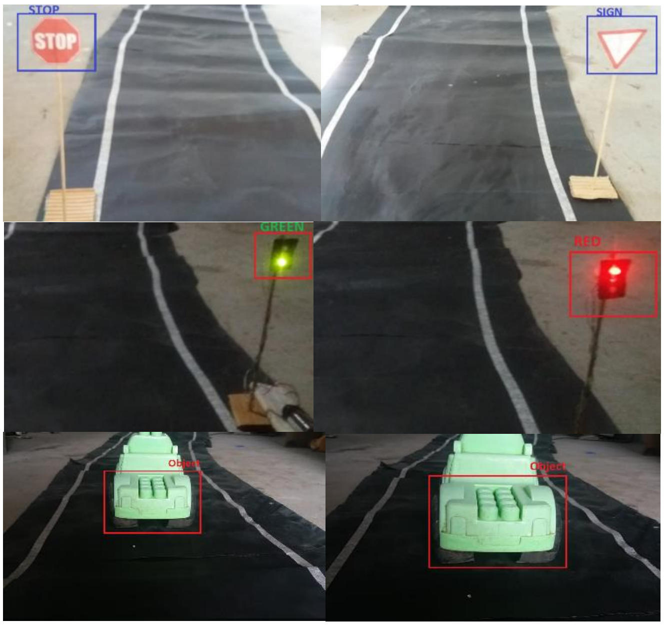


Fig 12. Identification of vertical signage.

6 Conclusions and Future Work

In this work we proposed the development of a control algorithm to be implemented in a low-cost, open-source, kart-like electric vehicle. The control algorithm, is based on image processing and focused on the detection of horizontal and vertical signals in real time. The different experiments carried out show the behaviour of the vehicle whose objective is to travel the route defined by the user and the detection of vertical signals. It should be noted that the construction of the scaled vehicle allowed the study and affordability to students through the implementation of mechanical and electrical systems, its programming uses free operating systems such as Raspbian and Arduino, and the prototype will serve to implement new advanced control strategies. Future work is planned to implement the algorithm in unstructured and real environments taking into account the luminosity of the environment, as well as the implementation of a neural network to identify a greater diversity of vertical traffic signals, as well as segmented horizontal signals. The development of autonomous vehicles helps technological growth by providing efficiency in future transport systems, and making people's lives easier.

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