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Supervisión of a Data Center Using a Fixed Path Robot

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Abstract: The most important areas in the operation and productivity of a data center are the rooms where the computer and telecommunications equipment of clients and users is located. Only identified and authorized personnel who carry out specific preventive and corrective maintenance activities have access to these areas. It is important to always identify people who are in these areas. Although data centers are monitored by mechanisms such as CCTV, there are points that are not covered by video cameras. This paper presents the development of a mobile robot that follows a fixed route to perform presence monitoring in a data center. The robot periodically moves in the corridors between the equipment cabinets of the data center to capture photographic images during the route. The captured images are sent to Google Drive. The robot's access to the Internet is done through a WiFi access point installed in the data center. The distance from the access point to the furthest location of the robot on the followed path is 28 meters. When it detects an obstacle or person in front, at a distance of 30 to 750 centimeters, it stops moving forward and transmits an alert message to the data center manager's mobile phone. The achieved Wi-Fi communication range of the robot was 37 meters using an external 2.4 GHz antenna.

Keywords*—Data center, Google Drive; mobile robot; photographic images; presence monitoring; WiFi.*

I. INTRODUCTION

The data centers house computing and telecommunications equipment for clients and users in which the applications that support the productivity of companies and institutions are executed. It is essential that these facilities have the measures, mechanisms and procedures to maintain the physical and operational integrity of these equipment. This includes access systems to facilities and stored information, which include biometric security devices, CCTV, presence sensors, monitoring of equipment and perimeter rooms, among other mechanisms. The last physical access point is the rooms, bunkers or cages, where the equipment is located. These areas of the data centers are only allowed access to a small number of people, such as maintenance personnel, consultants, and individuals who need to perform specific and special tasks on the equipment.

It is important to have a mechanism for permanent monitoring of the presence of people in these rooms. Although it is true that this type of monitoring can be done through CCTV, there are some blind spots that cannot be covered by CCTV cameras and where it is not possible to see what people are doing. In some data centers, surveillance personnel are the ones who carry out periodic routes of the equipment rooms without having evidence, such as photographs, for example, of who is in these rooms. In other data centers, the CCTV is configured to capture images, or video, only when there is movement or when the presence sensors are activated.

The objective of this work was to develop a mobile robot that periodically moves in the corridors between the equipment cabinets of a data center to capture photographic images during the route. The robot path is fixed and marked with a line. The captured images are sent to Google Drive. The robot's access to the Internet is done through a Wi-Fi access point installed in the data center. The distance from the access point to the furthest location of the robot on the followed path is 28 meters. It was requested that when the robot detects an obstacle it stops and waits. In case the obstacle remains for more than three minutes, the robot must send an alert SMS to the phone of the data center administrator so that it can carry out the necessary actions and release the robotadvance. The perimeter of the data center is 25 x 50 meters.

Line follower robots have been built for several years for both static and dynamic routes. They have been used in various applications ranging from entertainment and teaching, handling and collecting materials, searching for objects and people, to supervision of facilities, among others [1]. Different electronic devices and increasingly sophisticated technologies have been used. However, since there are a large number of electronic components and mechanisms available and suppliers, there are many types of robot followers with different characteristics [2]. A common feature is that, by using different components in the robot structure, it is necessary to make several connections between them. Functional modules are not commonly used in the implementation of the robot, which causes its size and weight to increase, as well as the complexity of operation, maintenance and modification to add functionalities [3].

In recent years, the development of technology has allowed the emergence of different providers of embedded modules for both digital controllers and infrared or radar sensors and motor drives to manipulate wheels and tracks. These devices reduce the weight of the robot and facilitate the design and implementation, resulting in a more robust device with the possibility of accessing the Internet and capturing images and video [4]. These technological advances have been used in the implementation of this work to obtain a robot that eliminates the traditional complexities of most line trackers, also pointing out that the robot was designed to be used inside a data center which is not a common application and that until now has not been carried out [5].

To achieve the stated objective, a three-wheeled mobile robot was designed, two wheels located on the robot's axis and an idle wheel at the front to facilitate movement and stability. The natural option was to implement a line follower robot that integrates a high-resolution camera and a Wi-Fi wireless communication interface. In order to facilitate the movement of the robot, as well as its functionality, operation and maintenance, compact and efficient electronic devices were used. For this reason, the design is based on an ESP32 CAM embedded system which has a controller, a video camera and a Wi-Fi interface.

During the last years, a variety of robots used in different applications have been made, from commercial and industrial uses to the military field [6]. Most of the robots are autonomous and line following, which use sophisticated algorithms to detect and follow a route, avoid obstacles and to implement guidance navigation and control (GNC) architectures [7]. To this end, recent research, which represents the state of the art in this area, has used different methods and technologies such as those indicated below. It can be clearly seen that a significant number of underwater snake robots have been developed. Some of them have been carried out to investigate the presence of constant irrotational ocean currents [8]. Still others use techniques based on predictive control (MPC) models [9], 3-D direction control [10], undulatory ribbon-fins and fuzzy logic models [11], robotic dolphins with learning-based path planner and adaptive following controllers [12], extended state observer and projection neural networks [13] deep Interactive reinforcement learning [14] and velocity and input constraints via neurodynamic optimization models [15]. Other technologies used are: 2D or 3D laser range finder to identify, track and follow the target person in dynamic environments [16]-[17], barrier-based adaptive line-of-sight (ALOS) three-dimensional (3-D) systems [18], matrix of a petri net (PN) and radio-frequency identification (RFID) technology to recognize the position of a robot [19], mmWave-based positioning for a target localization problem [20], curved path following for unmanned surface vehicles [21] and knowledge learned during the off-line states and neurons [22]. Other relevant applications developed are, without a doubt, the machine-learning-based humanoid robots, the physical human-robot (pHR) in the health and medicine sector to ensure the safety in robot surgery

[23] and the remotely operated vehicles. (ROV) [24].However, an application like the one presented here oriented to a data center has not been carried out until now.

II. Materials and Methods

The operation of the supervisor robot is based on following a dark line marked on the floor of the data center's equipment room. The line allows the robot to follow a path that passes through the front and back of the cabinets, so that the opening of the cabinet doors does not interfere with the robot's movement. The line is drawn in the center of the aisles between the cabinets as indicated in Fig. 1. The path ends at the starting point of the line.

The mechanical part of the robot uses three wheels. Two wheels, installed on the rear axle, provide the movement of the robot and are controlled by DC motors. An idler wheel was installed at the front to provide traction and stability on the move. The electronic part is responsible for monitoring the line, detecting obstacles, controlling the motors, capturing the images that are transmitted to Google Drive and sending the alert SMS. This part uses an architecture made up of four elements: the embedded system, the line detection module, the motor drive module, the ultrasonic sensor and integration with Google Drive and programming, as shown in Fig. 2.

A. Embedded system

The embedded system used was the ESP32 CAM. This device is of compact size and low cost that works using the ESP32 SoC or the ESP-32S SoM, depending on the selected provider. Integrates the following resources: dual core TensilicaXtensa LX6 32-bit CPU, 520 KB SRAM, external 4 MB PSRAM, Wi-Fi 802.11b/g/n wireless interface with built-in antenna, IPEX connector for external antenna, UART, SPI, I2C, Bluetooth, and 4.2 BLE interfaces, ADC and DAC, socket for a MicroSD card, OmniVision Serial Camera Control Bus (SCCB) interface to connect an OV2640 or OV7670 video camera and GPIO (General Purpose Input/Output) terminals.

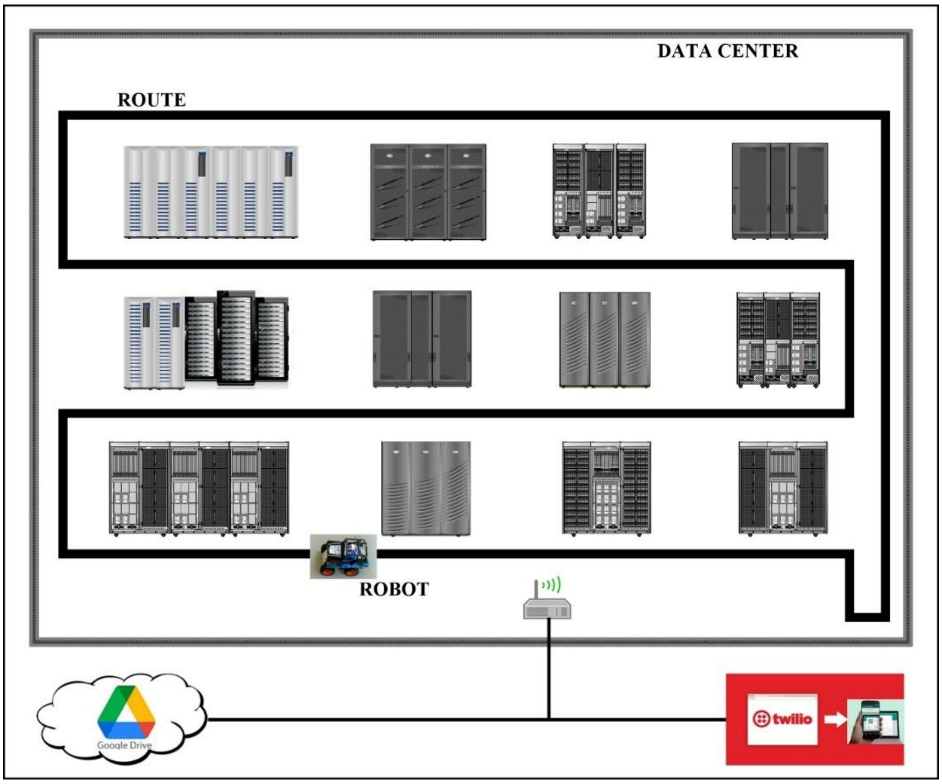

Fig. 1. Supervisor robot operation

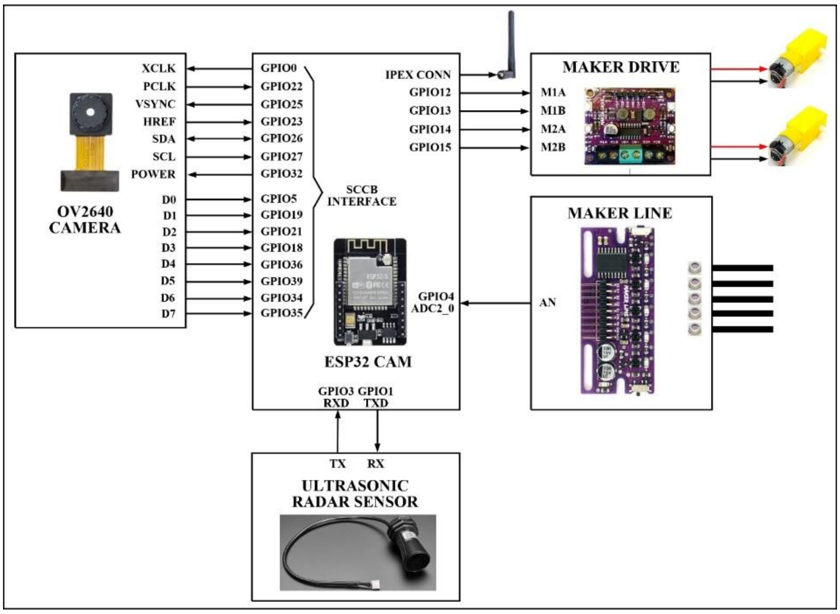

Fig. 2. Supervisor robot architecture

The video camera installed on the robot was the OV2640. This camera has a 2 Megapixel CMOS sensor, which provides a UXGA photo resolution of 1622×1200 pixels and a video resolution of 1080p30, 720p60 and 640x480p90. Images are full-frame, sub-sampled, scaled or windowed 8-bit/10-bit in different formats such as JPEG, BMP and grayscale. The use of this embedded module facilitated the process of capturing images on the robot, since the OV2640 camera connects directly to the SCCB interface of the module, the only task that the ESP32 controller must perform is to configure it before it can be used. more connections or additional hardware. The camera was installed on the front of the robot.

The ESP32 CAM integrates a Wi-Fi antenna and an IPEX connector to connect an external antenna. The first one is used in environments where the module is close to a router or access point. The external antenna is used in applications where connectivity is poor, slow, or in video streaming applications with constant lags. In this work, despite the fact that the distance from the robot to the Wi-Fi access point, from any point of the route, is less than 28meters, an external antenna was connected to the ESP32 CAM to avoid communication problems since the robot moves close to the floor of the data center.The antenna used is 2.4 GHz SMA to IPX Omnidirectional and has a length of 8.8 cm.

B. Line detection module

In order to detect the line that marks the route to be followed by the robot, the Maker Line module was used. This device integrates five infrared sensors, S1 to S5, which allow to detect a dark or light line. It can detect lines located at a distance of 4 to 40 mm, it has a switch to select the color of the line, a button to calibrate the sensors, five digital output terminals and one analog output.

Through the digital terminals, D1-D5, the module indicates which sensor(s) were activated when the line was detected. Similarly, the above result is indicated by the Maker Line module via the voltage level of the analog output terminal ANas indicated in Table I.

TABLE I. ANALOG OUTPUTTERMINAL VOLTAGE

Line Not Found	S1 Left Sensor	S2 Sensor	S3 Center Sensor	S4	S5 Right Sensor	Cross Detected. S1-S5 ON
0 - 0.32 V	0.33 V	0.34 V –1.64 V	1.65 V	1.66 V - 2.95 V	2.96 V	2.97 V - 3.3 V

The ESP32 CAM controller integrates 2 SAR (Successive Approximation Register) ADCs, ADC1 and ADC2, supporting a total of 18 measurement channels (analog enabled pins). ADC1 has 8 channels and ADC2 has 10 channels of 12-bit resolution. The voltage measured is then assigned to a value between 0 and 4,095, in which 0 V corresponds to 0, and 3.3 V corresponds to 4,095. Any voltage between 0 V and 3.3 V will be given the corresponding value in between. Because the video camera's SCCB interface uses GPIO pins shared by the ADC channels, there are few analog pins and channels available. For this reason, in this work the analog output line of the Maker Line connected to the input of channel 0 of the ADC2 was used and the digital outputs of the ADC2 were not used.

In addition to the Maker Line being compact in size, another reason why it was used in this work was that the infrared sensors are positioned at a distance of 10 mm from each other, allowing lines from 13 to 30 mm wide to be detected. This avoids the possibility of the line being between two sensors and not being detected. Considering the above, a line from 13 to 30 mm wide will be detected by at least one sensor. Based on the above, once the robot has detected the line, dark in this case, it faces one of five scenarios to determine the next action: move forward, move left, move right, or stop, as shown in Fig. 3.

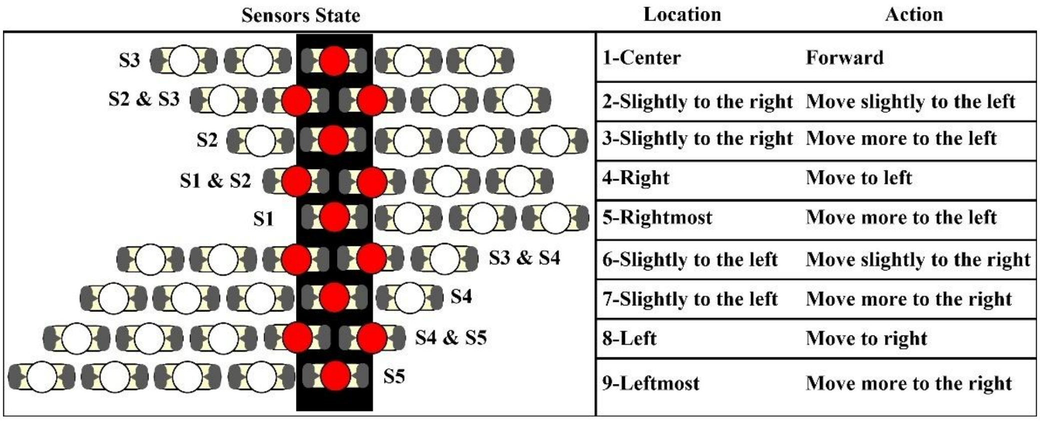

Fig. 3. Activation of sensors on the tracked line

C. Motor drive module

Two brushed DC electric motors, motor 1-M1 and motor 2-M2, were installed on the main axis of the robot, located at the rear. To control the direction of rotation and speed of the motors so that the robot moves in the necessary direction, the Motor Drive module was used. This module has four input and four output terminals. Two input terminals, M1A and M1B, were connected to the controller's GPIO12 and GPIO13 output terminals for the embedded module to supply the PWM signal that drives M1. The other two pins, M2A and M2B, were connected to output pins GPIO14 and GPIO15 to supply the PWM signal that drives M2. The logic state present in these terminals indicates the direction of rotation of the motors, as indicated in Table II, while the frequency of the PWM signal determines the speed.

TABLE II. MOVEMENT OF MOTORS DEPENDING ON THE VALUE OF THE INPUT TERMINALS

Input A (M1A/M2A)	Input B (M1B/M2B)	Motor Movement
Low	Low	Brake, stop
Low	High	Forward
High	Low	Backward
High	High	Coast, dead point

Taking this as a reference, to achieve the actions indicated in Table 2, through the direction of rotation and speed of the motors, the function *motorX.setSpeed(Y)* of the *CytronMotorDriver.h* library was used. The *X* indicates the motor, 1 or 2, and the *Y* argument the speed. So, if *Y*=0 motor stops, if *Y*=128 motor runs forward at 50% speed, if *Y*=255 motor 1 runs forward at full speed, if *Y*=-128 motor runs backward at 50% speed and if *Y*= -255 motor runs backward at full speed.Regarding the output terminals of the Motor Drive, two of them were connected to M1 and the remaining two to M2. Motors direction depends on the polarity of these outputs.

D. Ultrasonic sensor

To detect obstacles in the robot's path, an ultrasonic radar sensor module model DYP-A01-V2.0 was used. This module uses high-frequency signals, 40KHz ±1.0KHz, to determine distance to the surface of an object, or person, and a horn that guides the signal so it can reach farther without spreading too wide. The range of the sonar is from 28 cm to 750 cm with a read resolution of 1 mm and an accuracy of ±1cm + 0.5%. This module features a 100 ms response time and provides distance measurement through a UART output at a rate of 9,600 bps using a 16-bit word. On the robot, the TX and RX terminals of the ultrasonic sensor module were connected to the RXD and TXD terminals, respectively, of the UART0 of the ESP32 CAM.

E. Integration with Google Drive and programming

Google Drive is a cloud file storage service created by Google. It offers a REST API, the Google Drive API, which allows you to create applications to upload, view and share files in the Google Cloud. Through this API, applications running on computers and digital or mobile devices can access files stored in the Google Drive Cloud.To integrate the application presented in this work with Google Drive and invoke the Google Drive API services, the following tasks were performed from the Google Cloud Platform console:

1-Create the project. A project is the basic part by which the developer creates, enables, and uses Google Cloud services and tools, including APIs. In this phase, the name of the project to which the application or program belongs, which is executed when the ESP32 CAM module sends the captured images to Google Drive, was indicated. The platform assigns an ID and a number to the project.

2-Select and enable the Google Cloud APIs that will be used in the project. In this case, the Google Drive API was used to send and access Google Drive files.

3-Create, from Google's authorization servers, the credentials that authenticate and verify the identity of the users and accounts of the project, allowing access to the resources and functions of the API. Google Drive API uses the OAuth 2.0 authorization protocol which is based on the use of application access tokens. In this process, the API key, the OAuth client ID and the service account credential used when the robot programming requests the Google Cloud service were created.

4-Create in the project, using the Google Apps Script Console, the program, or application, that is executed when the robot sends the captured image to Google Drive. This program is written in the Google Apps Script programming language, has the extension *.gs* and is based on JavaScript. The goal of this program is to implement automated actions in the Google Cloud. This program, or script, was published as a web app used by the robot and a url used in the programming of the robot was assigned to invoke the services of the project and Google Drive.

Once the previous tasks were carried out, the programming that is executed in the embedded ESP32 CAM module was carried out using the open-source Arduino Software IDE (Integrated Development Environment). This is because there is a significant number of function libraries that make it easy to write code for a variety of applications, mainly IoT ones.

To configure the Wi-Fi interface, the *WiFi.h* library was used, similarly, to configure and capture images with the OV2640 camera, the *esp_camera.h* library was used. To interact with the Maker Drive module, the *CytronMotorDriver.h* library was usedand the *esp32cam-gdrive* library was used for integration with Google Drive.

To send the alert message to the mobile phone of the data center manager when the robot encounters an obstacle, stops moving forward and the obstacle remains for more than 5 minutes, the Twilio Internet platform was used. Twilio is a CPaaS (Communications Platform as a Service) cloud communications and services platform that enables the development of applications for making phone calls, sending text messages, and communication and registration functions using an API. The Internet primarily uses the HTTP (Hypertext Transfer Protocol) protocol at the application layer. Telephone networks use a variety of complex protocols, which are sometimes proprietary, and appropriate to the service they offer. It is not an easy task to implement and work with these protocols, which increases the cost and time of application development. Twilio provides an interface, through an API, that makes it easy for software developers to perform tasks between the Internet and telephone operators. Twilio's public REST API receives HTTP requests and performs the required task. Using Twilio, you can make phone calls and send text messages, among other services. In this work, the open-source function library *twilio-esp32-client.h* was used in the programming of the robot to transmit the alert message.

III. Results and Discussion

In Fig. 4 the constructed robot is shown. The robot starts and stops its operation manually and moves at a speed of 1 meter/second. It was proved that the robot follows the route traced correctly without losing communication with the Wi-Fi access point, which is installed at a distance of 28 meters from the furthest point of the route.

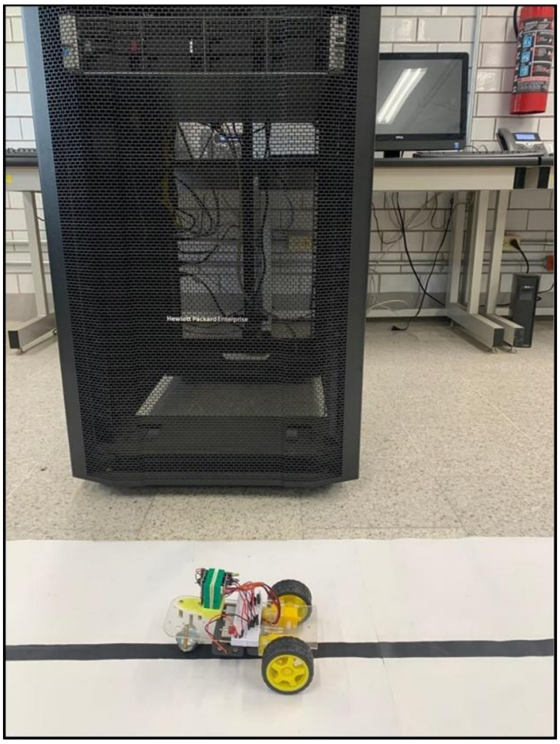

Fig. 4. Robot build

During the movement of the robot, a set of tests was carried out whose objective was to measure the level of RSSI (Received Signal Strength Indicator) of the Wi-Fi signal during the tracking of the route. To carry out these tests, a routine was included in the robot's programming that stores the RSSI value every 5 meters, as indicated in Fig. 5, so that at the end of the route, the program sends a file to Google Drive with the registered RSSSI values as shown in the graph of Fig. 6. Although there were no problems in the wireless communication between the robot and the access point, a second set of tests was carried out to determine the range of Wi-Fi communication. In order to carry out these tests, the robot was located in different locations distant from the access point, even outside the path without movement of the robot, to determine, in the same way as in the first group of tests, the level of RSSI. The results obtained in these tests showed that the communication range was 37 meters and the RSSI level was -71 dBm, at distances equal and equal to the previous one, communication with the robot is lost.

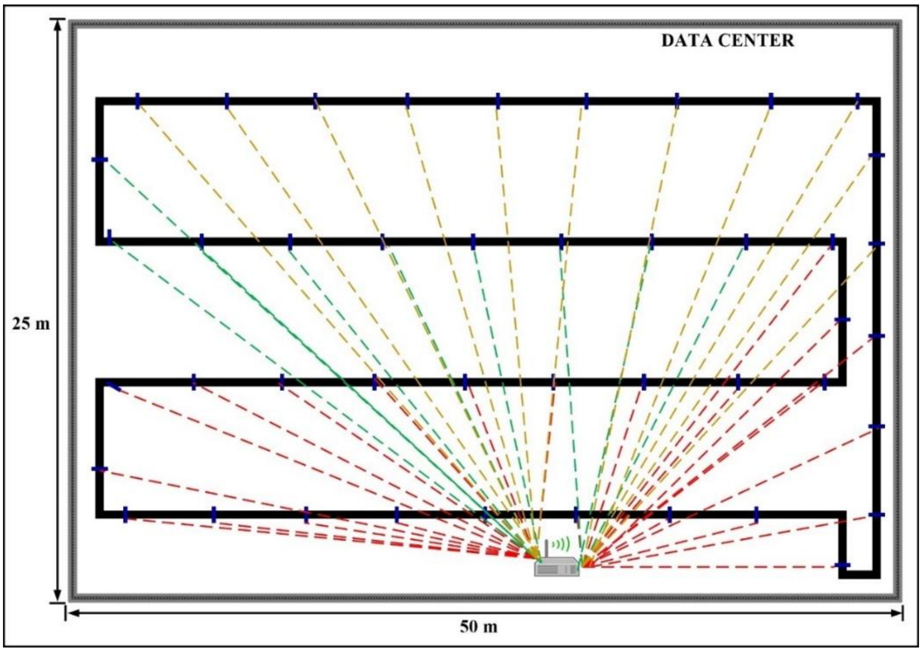

Fig. 5. RSSI level measurement points on the route followed by the robot

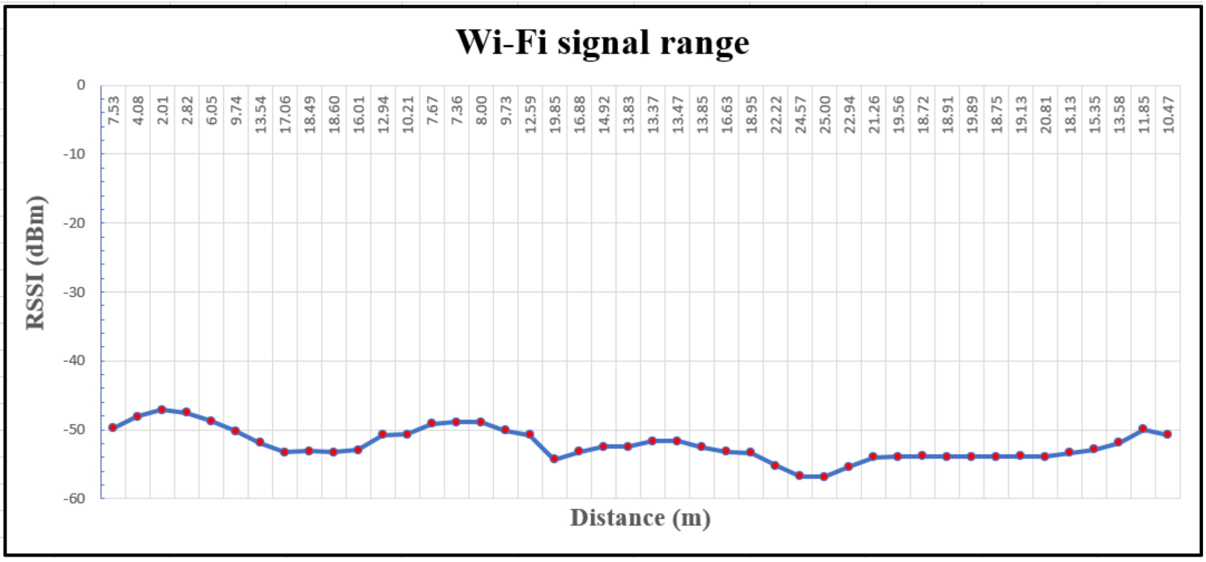

Fig. 6. RSSI level on the path followed by the robot

The third group of tests aimed to verify the robot's detection, by means of the ultrasonic sensor, of obstacles located 30 centimeters or more in front of the robot. To carry out these tests, objects and people were placed in front of the robot at 500 different distances, from 30 to 750 centimeters, and it was found that it stopped moving forward. In these tests, a routine that stores the distance value in a file and sends it to Google Drive was also programmed. The distance values were compared with those obtained with a tape measure, used as references, and the results obtained indicated that the measurement of the ultrasonic sensor has an accuracy of 0.354%, which is a little higher than the accuracy of 0.3% indicated by the manufacturer, which is finally an acceptable result. Additionally, during the development of these tests, the images captured by the robot sent to Google Drive were verified together with the alert message transmitted to the data center administrator's mobile phone. Fig. 9 shows one of the images and the corresponding alert message.

The fourth test that was carried out was to mark a dark line, perpendicular to the robot's path, to determine the behavior. The result was as expected, the robot stops. The Maker Line module detects the crossing of lines; however, the robot programming stops the advance until this condition is removed. This is because, at the moment, the route drawn in the data center will not have line crossings. If it is later necessary to incorporate this scenario, the routine that resolves this situation must be integrated into the programming.

IV. CONCLUSIONS

A robot was built that moves between equipment cabinets in a data center following a path drawn with a dark line. The robot was implanted based on an embedded ESP32 CAM module, an ultrasonic radar sonar and an OV2640 camera. Capture photographic images every 30 seconds and send them to Google Drive. When it detects an obstacle or person in front, at a distance of 30 to 750 centimeters, it stops moving forward and transmits an alert message to the data center manager's mobile phone. The achieved Wi-Fi communication range of the robot was 37 meters using an external 2.4 GHz antenna.

Work is being done to add the following features to the robot: 1-Despite the fact that there are no line crossings on the route, a joystick will be integrated to remotely control the start, stop and movements of the robot, which is useful in case of going out of the route, 2-Integrate a GPS module through which the robot sends through the alert message the location where it detected an obstacle or an event that causes it to leave the route, 3-Incorporate an SD memory module to record the coordinates of the route and the captured images and 4- Adding a Bluetooth LE (BLE) transceiver to achieve greater range in wireless communication. The last two functionalities may require the use of another embedded module, since the ESP32 CAM does not have additional terminals to implement these improvements.

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