Development of a Low-Cost Teleoperated Explorer Robot (TXRob)

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***Abstract*—Natural disasters such as earthquakes or mudslides destroy everything in their path, causing buildings to collapse, which can cause people to lose their lives or suffer permanent injuries. Rescuers and firefighters are responsible for entering these ruined buildings, this work being very dangerous for them because they can get trapped in the rubble or suffocate due to the harmful gases found inside these buildings. Taking into consideration the risk in this type of operations, technological innovations can be used to help in the exploration of ruined buildings and the rescue of people. Therefore, this article describes the development of TXRob, a low-cost teleoperated robot used in the exploration of post-disaster scenarios. TXRob has artificial vision, environmental gas recognition sensors, a real-time data display panel, is sized to enter buildings, and is capable of moving over uneven surfaces, such as debris or cracks, thanks to its track system. A human operator can remotely monitor and control the robot. The TXRob's versatility as well as sensors performance has been tested on uneven and harsh surfaces in a simulated disaster environment. These tests suggest that the designed robot is suitable for use in rescue situations.**

***Keywords*—Rescue robot; teleoperation; low cost robot; artificial vision**

I. Introduction

The Peruvian territory has suffered serious seismic episodes due to its location in the fire ring [1], [2]. Some of these earthquakes have occurred on June 23, 2001 with a magnitude of 8.4Mw (Moment scale), this event happened in Arequipa, leaving more than 240 dead, 70 people missing and 2400 injured [3]; in the province of Pisco on August 15, 2007, a 7.9Mw earthquake occurred, leaving 95 dead, 2,291 injured, 76,000 houses destroyed and uninhabitable and 431,000 people affected [4]; on May 26, 2019, an earthquake of 8.0Mw occurred in Alto Amazonas, which caused the death of 2 people and several injured people [5]. Due to these disasters, contingency procedures were developed to minimize the damage caused. In addition, systems capable of predicting these telluric movements have been created in order to minimize the post-disaster impact [6], but one must indeed have sufficient capacity to respond to a natural disaster, not only an earthquake, but also landslides or fires where the structure of the building of the place is affected.

After a disaster, access to the building is partially or totally inaccessible, so a teleoperated robot would assist with contingency programs in these hazardous situations, but the robot must be able to overcome obstacles and accurately locate potential survivors. For example, in the article [7] a rescue robot for miners trapped in a cave-in, equipped with cameras and sensors that detect toxic gas levels. Several robotics projects robotic projects have been designed with this approach, most of them remotely controlled to support human operators in SAR (search and rescue operations) tasks [8], [9].These robots work more efficiently and faster than a human human agent, which is reflected in the higher number of rescued people, this is the main objective of the robot. Rescue tasks are critical and are performed in dangerous environments for people, further reinforcing the need to employ this type of robots [10].

There are several approaches when designing a rescue robot. To understand and analyze the post-disaster environment, unmanned aerial vehicles (UAV) or unmanned ground vehicles (UGV) are used, an example of these vehicles is the Tactical Hazardous Operations Robot (THOR) [11]. In order to map a post-disaster scenario, SLAM (Visual Simultaneous Localization and Mapping) technology is used [12]. When rescuing survivors, the impact of the rescue robot on the survivor must be taken into account. Parameters such as the force induced by the robot and the speed of translation are important to analyze [13]. But these methods prove to be costly [14], this is why the development of a low-cost robot would be more accessible to the rescue teams.

In 2019, air pollution was considered the greatest environmental health risk. environmental health risk. The main sources of air pollution are large-scale burning of wood, biomass or crop residues, fuel adulteration, uncontrolled emissions from vehicles and factories, traffic congestion and accelerated construction. These sources cause smog and thus increase airborne particulate matter (PM_10, $PM_{2,5}$), NO_x, NH_3, SO_x , CO and other VOC (volatile organic compounds) in the air [15]. It is very likely that the concentration of gases after a disaster is not optimal for humans; this is due to gas leaks, fires caused by short circuits or ruptures of pipes inside buildings; there are several sensors that can detect these measurements but it is necessary to take these measurements remotely. Normally a gas sensor is incorporated to determine these parameters and thus secure the area for human intervention. These sensors are: CO_2 sensor, VOC sensor (Volatile Organic Compounds Sensor), NO_X sensor, PIR sensor, among others [16], [17].

Good body temperature control is vitally important in a survivor, because monitoring body temperature can predict stroke; sensors such as the UHF RFID temperature sensor are used to obtain a more accurate measurement [18], [19]. Estimating the maximum response time that can be expected is vital to prevent the survivor from suffering severe respiratory distress due to hypothermia, considered below 35C°, which could result in death [20]. There are several ways to detect life signs in survivors in a post-disaster scenario, considering that there is a 24-hour life time frame, these signs become a priority for the rescue robot operator. Sound acquisition serves as a possible support to other sensors in order to locate survivors quickly and efficiently [21], [22]. In today's technology, the use of infrared cameras is necessary for the detection of heat signatures within an environment to be explored. Due to the relevance of this tool in the exploration of environments for the detection of people, the processing of images from the camera is performed [23], [24].

The stereo vision has the advantage of being wireless, so it is the main component of the artificial vision modules of the detection systems in robots [25]. An application is the tracking of objects, where it is necessary to estimate the distance of the object, thus achieving a high accuracy in real time [26]. Being complementary to other systems such as "leap motion" for interfaces "man-robot" for applications in robots EOD (bomb disposal) [27].

An anti-shock system is used to assist the operator in manipulating the robot by avoiding obstacles that may pass unnoticed by the operator. The main components of this system are usually infrared sensors, ultrasonic sensors, among others [28].

In the communication with the robot and the control center there are several options, for example the Zigbee model which has a central coordinator, routers and end devices using as XBee-PRO ZB S2B module [29], but taking into account the low cost objective of the project, it is considered to create a local WiFi network configured with the Raspberry Pi 4 controller. Due to studies conducted on different platforms of the different versions of Raspberry, it is concluded that the latest versions support better the WiFi network [30].

This document is divided as follows: The Methodology is presented in Section II. Section III describes the development of TXRob. Section IV presents the development of the control center. Section V presents the results obtained. Finally, Section VI presents the conclusions of the research.

II. Methodology

This paper presents the development of an exploration robot for post-disaster areas, TXRob. The reason for the development of the TXRob robot is the great need of agents dedicated to the rescue of people trapped in ruins caused by a natural or human disaster. The main features of TXRob are:

- Ability to overcome rugged surfaces and debris, dust and moisture resistance, and teleoperated control.
- Perfect for simple fabrication due to its low cost.
- Weight less than 10Kg and dimensions of 20cm x 30cm x 15cm, according to the category of exploration robots.
- It has gas, audio and webcam sensors to collect data from the environment where it is located and transmit them to the operator through its graphic interface located in the control station.

Fig. 1 is the representation of the complete system in a block diagram. First, the control station generates a wifi server, the TXRob robot connects to this network as a client. Through this network, the robot sends the data from the sensors and the video captured in real time. The values obtained by the gas sensors will serve to determine the environmental conditions, while the video, the microphone and the ultrasound will allow the detection of people trapped in the rubble. Later, again at the control station, the operator visualizes this information on the user interface and through a command can generate instructions that control the movement of TXRob through the motor drivers. A bidirectional communication is generated between the robot and the control station.

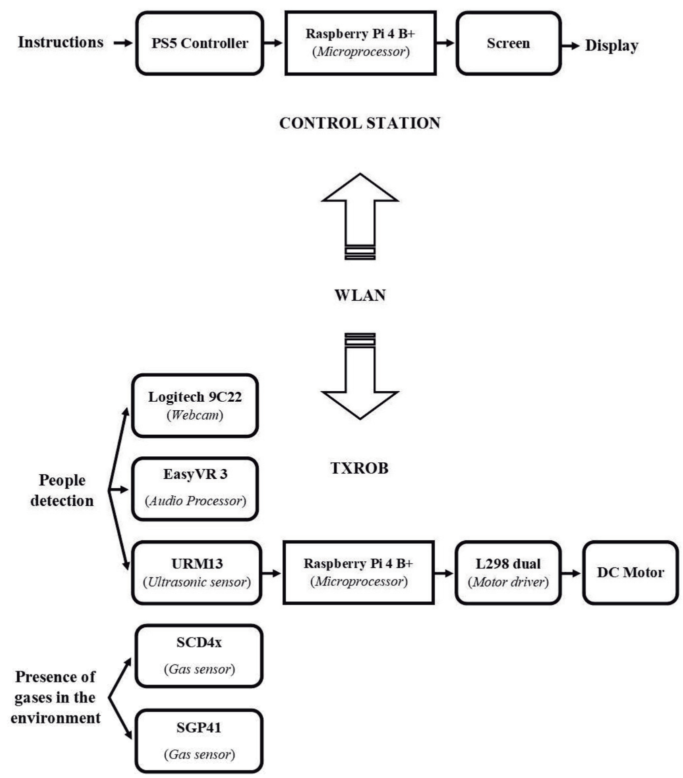

Fig. 1. System Block Diagram

The performance of the robot was measured in two evaluations, the first was an evaluation of the sensors in two different situations: an environment under normal conditions and an environment simulated under disaster conditions using a gradual and sustained increase in temperature, humidity and CO2. The second evaluation was focused on the versatility in displacement of TXRob on a flat surface and a rough surface, where the time needed to reach a given distance in meters was obtained.

III. TXRob Development

A. Mechanical Structure Design

SolidWorks software was used to produce the 3D design and generate the 2D drawings. The chassis of the robot is designed to be made of stainless steel, for its high durability and strength, so that the electronic components are fully protected. The motion system has a hybrid configuration between the rocket-buggie system, used in Martian rover explorers, and a crawler system, see Fig. 2 and 3. This rear-tracked configuration takes advantage of both systems; on the one hand, the left and right rocker suspensions are connected to the body through a differential balancing mechanism, which decreases chassis instability and pitching, while the tracked system is ideal for exploring rough terrain. The two front wheels allow for better handling and more efficient turns. Ultrasonic sensors are mounted front and rear to avoid collisions with the environment, and the top-mounted camera allows a greater field of vision.

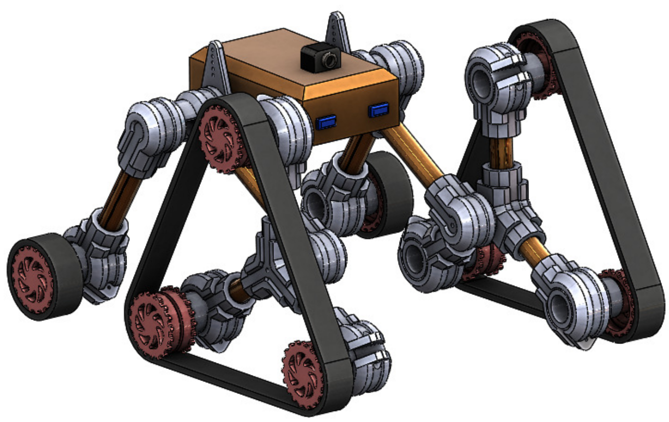

Fig. 2. Isometric View of the Mechanical Structure Design.

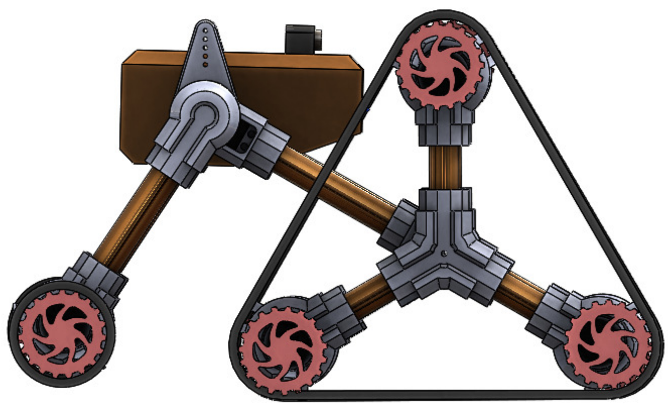

Fig. 3. Side View of the Mechanical Structure Design.

B. Electronic Circuit Assembly

For the development of the electronic and schematic design, the EasyEDA software with free license is used, available at the URL https://easyeda.com/es. This software has proven to have good performance and a fast learning curve at the basic and intermediate levels. Fig. 4 shows all the connections made for TXRob in addition to proper pin labeling. The component connections of the TXRob robot is centered on the Raspberry Pi 4 model B+ board, this Raspberry Pi model is the most recent on the market and has 8GB (gigabytes) of RAM, necessary to perform the video processing, data transmission and motion control of TXRob. This Raspberry Pi board is powered by a 7805 voltage regulator, shown at the beginning of the electronic diagram in Fig. 4, through pin 2, in addition this 5v power pin is also power supply for the sensors and webcam, and also provides a control level for the motor drivers (L298 dual). The L298 driver in addition to using 5v also requires a 12v source to power the motors, this voltage is supplied by the batteries through the VIN pin. The VIN pin is also the input to the 7805 regulator circuit.

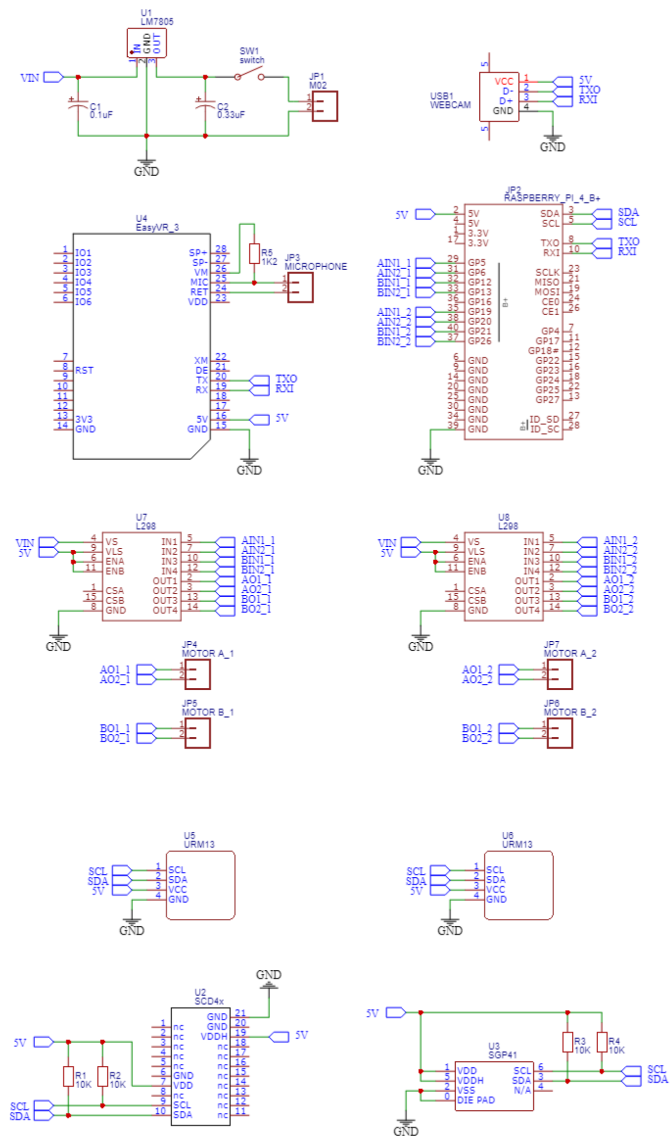

Fig. 4. Schematic Diagram.

1) Gas Sensors: In the exploration stage after a disaster, the environments are more closed, which increases the concentration of gases harmful to humans, so the measurement of these gases is a relevant point for rescuers.

- CO_2 Sensor: The CO_2 is not really a toxic gas but it produces the displacement of oxygen and in high concentrations of more than 30,000 ppm, it can produce asphyxiation. The use of this sensor will allow us to measure the ppm of the explored areas and to be able to analyze the different levels (See Table I). To determine the ppm values we have used the SCD41 sensor that allows us to measure a wider range, between 400 and 5000 ppm, has a typical minimum consumption of only 0.45mA at 3.3V and 0.36mA at 5V, which allows us to create CO2 meters with great autonomy.

TABLE I. CO_2 LEVELS

CO_2 **levels.**	**Air Quality**
250 -450 ppm	Typical atmospheric concentration
450-600 ppm	Acceptable concentration in the interior.
600-1000 ppm	Concentracion aceptable en el interior
1000-2500 ppm	Tolerable concentration. Drowsiness
2500-5000 ppm	Tolerable concentration. Headache. Stagnant air. Loss of concentration and attention.
6000-30000 ppm	Dangerous concentration, only light exposures.
30000-50000 ppm	Extreme concentration. Intoxicant
$>$ 50000 ppm	Extreme concentration. Permanent brain damage and death.

- Volatile Organic Compounds Sensor (VOC): Volatile Organic Compounds are air pollutants that, when mixed with nitrogen oxides, react to form ozone. The presence of high concentrations of ozone in the air we breath is very dangerous. The measurement of $VOCs$ is also relevant to the air quality in a space.
- NO_X Sensor: NO_2 is a toxic and irritating gas. Continued exposure to NO_2 is associated with various respiratory tract diseases.

For the measurement of VOC and NO_X, the SGP41 sensor was used, which has a measurement range from 0 to 1000ppm of ethanol equivalents and 0 to 100ppm of NO_2 equivalents, with a response time of less than 10s for VOC and less than 250s for NO_X necessary for real time sampling to determine the air quality of the area to be examined.

2) Ambiental Sensors:

- Temperature Sensor: The temperature in an environment is an essential indicator that can give us data, the presence of heat can give us to understand the presence of a person who is stuck in the debris.
- Humidity Sensor: Humidity is a factor that we must take into account, the excess of it in an environment can generate diseases or respiratory conditions.

3) Proximity Sensors: To support the teleoperation of the robot, it was decided to use these sensors, which allow us to measure distances and object detection. For the design, they were used for object detection and for an anti-shock system of the robotic structure.

- Infrared sensor: The infrared sensor is used in the market to measure distances in environments with absence of light which will allow us to detect obstacles within the area to be explored.
- Ultrasonic Sensor: The use of ultrasonic sensor as a support in the measurement of distances will help us to obtain more reliable values for the manipulation of the robot. The URM13 ultrasonic sensor has an excellent sensitivity with an effective measurement range of 15 cm to 900 cm with 1% accuracy and I2C communication.

4) DC Motor with Caterpillar: Greartisan DC motors are ideal for the movement of the robot. The proposed crawler system allows the robot to be transported over rough terrain and the powerful motors allow this system to be put into operation. The working voltage of the motors is 12v DC. The gearbox ratio is 1:22, with the specifications being: rated torque of 2.2Kg.cm, rotational speed of 200RPM and rated current of 100mA.

5) Camera: Vision is relevant in scanning robots in order to provide visual information of the operation environment. In addition, a camera was implemented to provide real-time video of the scanned scenario. Due to the costs, a USB camera was chosen. To achieve a teleoperation, through programming in Python language and the Flask framework, the real-time video display was converted to the WiFi network generated by the RaspBerry of the control station, i.e., the USB camera was configured to work as an IP camera, thus saving costs and obtaining the same benefits.

C. Motion Detection Algorithm

The developed detection algorithm performs a subtraction between a first frame captured by the camera ($t = n$) and the next frame ($t = n + 1$), when the value of each pixel obtained by this difference exceeds a threshold , considered threshold of 100 for presenting better results, the algorithm sends an alert to the operator, indicating that the robot has detected a person. Fig. 5 shows a person lying on the ground, which does not move, for that reason, the algorithm does not place red rectangles in the right window, and the left window is completely black. On the other hand, in Fig. 6, white areas are shown on the left, this is because the person has stood up, in addition, on the right there are six red rectangles around the person.

a) b)

Fig. 5. Camera Frame without Motion Detection. a) Differential Window. b) Original Video Window Plus Motion Limiting Zones.

a) b)

Fig. 6. Camera Frame with Detected Motion. a) Differential Window. b) Original Video Window Plus Motion Limiting Zones.

IV. Control Station Development

A. Robot Control

The robot is controlled by a PS5 Dualshock5 controller connected to a Raspberry Pi (Control Station), which through wireless communication sends the instructions received by the controller to another Raspberry Pi located in the robot. The signal acquisition from the controller was made possible thanks to the implementation of Pydualsense, a package that uses the HID library to capture the controller signals, as well as offering the possibility to control various features of the controller such as LED activation, vibration level, etc.

B. Graphic Interface

The graphical interface refers to the video experience perceived by the user operating the robot. The interface shows the measurements collected by the different sensors, as well as relevant data and information about the system overlaying the video captured by the video camera. The interface was developed using Pygame and OpenCV for its versatility and ease of use.

C. Communication

For the reception and transmission of data between the control station and the robot, a local WiFi network was created in the control station, which handles server and client protocols in the data bus, in addition to this, the use of sockets is proposed for sending and receiving the values obtained from the different sensors.

V. Results

A. Sensor Evaluation

For the evaluation of the integrated sensors, it was proposed to make two measurements in two different conditions, the first one a simulation of disaster environment, where the robot will remain for 25 minutes to take the necessary measurements and a second measurement but in a clear environment under normal conditions for a human being. The results obtained are reflected in Fig. 7 for the measurements in disaster environment and in Fig. 8 for the measurements in normal environment.

The results obtained in a simulated disaster environment show a sustained increase of CO_2 and temperature values over time, which could be reflected in a hypothetical case of disaster, where a potential victim's health would be compromised in a very considerable time interval. The analysis of these data allows the generation of a standard regression curve in which an estimation of the maximum time in which the person would reach critical values is obtained, taking into account the permitted levels of CO_2 in a closed environment, see Table I.

The distance sensors were also evaluated to measure their reliability in providing information to the operator about the perceived distances in the environment. Measurements were made with the sensors as shown in the Table II below.

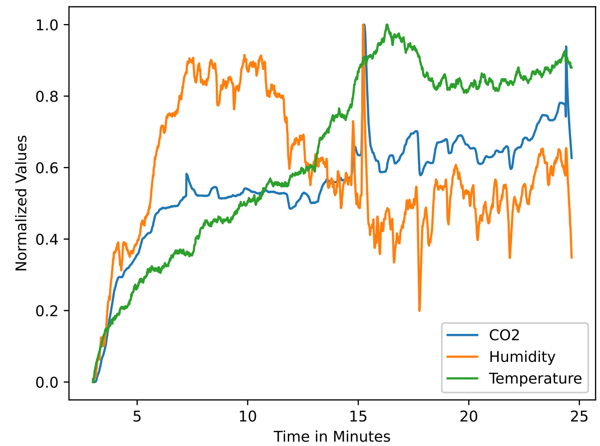

Fig. 7. Measurements taken by TXRob in a Simulated Disaster Environment.

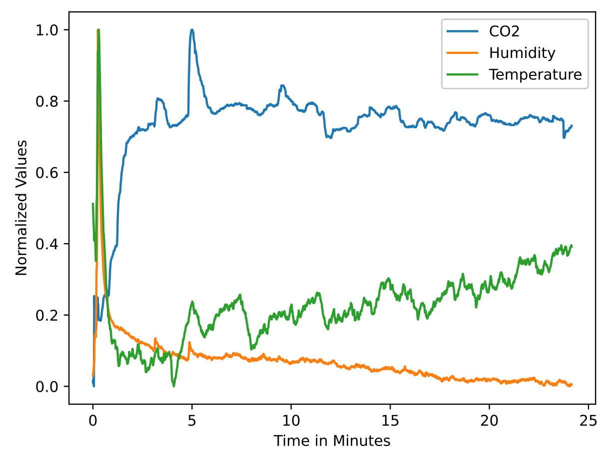

Fig. 8. Measurements taken by TXRob in a Normal Environment.

TABLE II. Measured Distances

Real	100cm	105cm	110cm	115cm	120cm	125cm	130cm
1	101cm	107cm	109cm	114cm	121cm	124cm	130cm
2	101cm	105cm	109cm	113cm	122cm	125cm	131cm
3	100cm	107cm	110cm	112cm	120cm	125cm	130cm
4	101cm	105cm	109cm	113cm	119cm	126cm	128cm
5	99cm	105cm	109cm	114cm	119cm	125cm	130cm
6	100cm	105cm	110cm	112cm	120cm	125cm	131cm
7	99cm	106cm	111cm	113cm	120cm	125cm	129cm
8	100cm	105cm	110cm	114cm	121cm	124cm	129cm
9	98cm	106cm	109cm	115cm	120cm	126cm	132cm
10	100cm	107cm	109cm	115cm	121cm	124cm	131cm

B. Robot Performance

Fig. 9 shows the graph of the time required for the robot to reach the place where the injured person is. From the results, the time required for TXRob to be able to reach the location is directly proportional to the distance it is for flat terrain with no slope. In Fig. 10 the time required for TXRob to reach the site is shown in the same way, but in this test an uneven terrain was considered, with rubble and a slightly steep slope (15 degree slope). It can be seen that for the second test the time increased, but this increase is not so great, so it is not a problem for the robot.

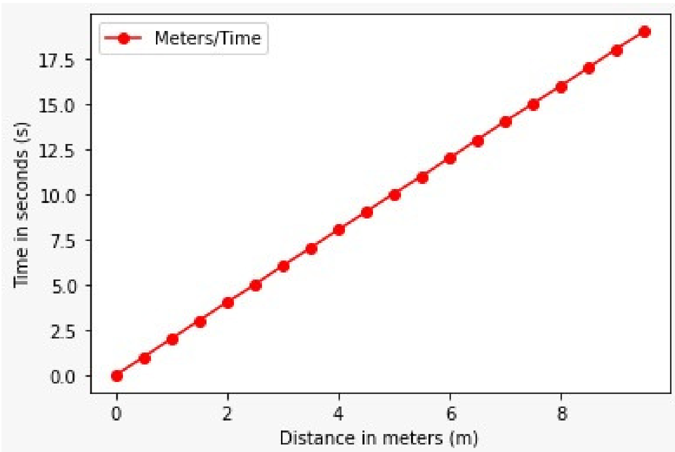

Fig. 9. Plot of the Time required for TXRob to reach the Location on Flat Ground.

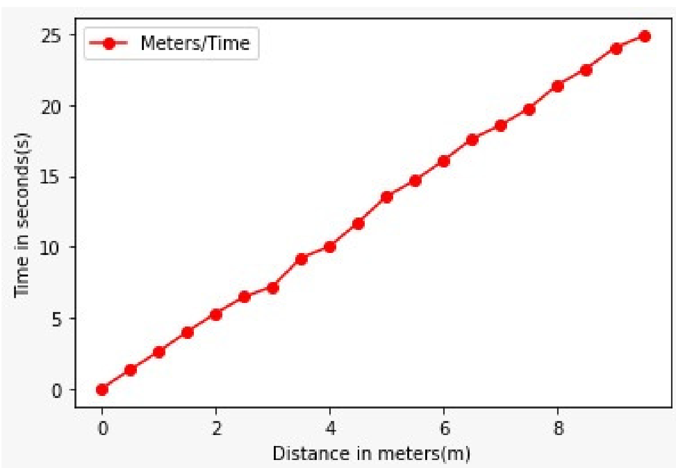

Fig. 10. Plot of the Time required for TXRob to reach the Site on Rough Terrain, with Rubble and a Slight Slope.

C. Display to User

The user display is composed of the video transmitted live by the camera in 720p resolution, together with the measurements obtained in real time by all the built-in sensors. The user display is shown in Fig. 11.

VI. Discussion

Based on the results obtained, the sensors measured and recorded satisfactorily the changes in temperature, humidity and CO_2 when they were subjected to a disaster environment, in the section of Robot Performance, TXRob reached the average speed of 0.47 m/s on a flat surface and 0.36 m/s on a rough surface, making possible the task of exploration in a hypothetical case of disaster where access to possible victims is very reduced due to obstacles, so it is possible to affirm

Fig. 11. Display Shown to the User.

that the measured characteristics of TXRob can fit perfectly in a low-cost robot for exploration and possible rescue work in areas of incidence of natural disasters such as landslides and earthquakes.

VII. Conclusion

This paper presents the successful development of a rescue robot for post-disaster scenarios (TXRob), capable of being remotely controlled, i.e. teleoperated. Demonstrating the reliability of the built-in WiFi network based on the Raspberry Pi4 platform. This robot has advantageous features, such as the ability to automatically detect the movement of potentially trapped or endangered people, analyze the environment and determine if it is suitable for rescue agents to enter, and has a suitable design that allows it to move over rough terrain and debris. TXRob also has the ability to avoid strikes by having proximity sensors that alarm the operator, with the results demonstrating the accuracy of the proximity sensors. In addition, its compact structure allows it to access areas inaccessible to humans, which means better exploration of landslides. From the experimental results we can conclude that TXRob can detect different concentrations of gases such as CO_2, NO_2, among others.At the same time that the data obtained by means of the sensors are satisfactorily shown on the display, being the object of future research to be shown in a virtual environment. Finally, it is demonstrated that the robot is able to move through rough terrain in a short time, in summary TXRob is a versatile robot for the rescue of people.

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