Modular Robot LUWA-E

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***Abstract*—Natural disasters, such as earthquakes, happen frequently in many parts of the world. Unfortunately, people are sometimes trapped within fallen buildings. This article presents the design and development of a snake-type-robot capable of moving between the debris to help find stranded people. The modular robot is remotely controlled and carries a communication system which allows the rescue team to find trapped people. The last module of the robot can be separated and left behind to serve as a repeater which extends the communication range. This paper includes the design, implementation details, and tests of the modular robot called LUWA – E.**

Keywords—modular robot, rescue robot, ESP32

I. Introduction

Earthquakes are natural disasters that can destroy buildings which consequently can leave people trapped below the rubble. The rescuing process for these situations has to be as quick as possible, and rescue teams have always struggled to find these people because they have to deal with going under the unstable rest of the buildings. This is why small vehicles that can enter this environment and send information about the insides is a good tool for saving lives. A robot that has the structure of a snake can imitate its movement and take advantage of its small body to reach places where humans cannot.

Through the years several authors have proposed vehicles that provide solutions for disasters like this. One example is the mobile unit that using hydraulic actuators can carry heavy weight loads and create bigger gaps for the rescuers to work. It can spread a gap from 3 cm to 20 cm. lifting 1200 kg [1]. However, moving the unstable rest of the demolition could damage the trapped people below them.

Another proposal is to use monocular simultaneous localization and mapping (SLAM) systems with the assistance of 2D LIDAR to create a real scale map of the environment, and facilitate the understanding of the place [2]. This system could be helpful to create a level of autonomy for rescue robots. However, as far as the authors know, this technology has not been mounted on a moving rescue vehicle.

Some rescue robots take advantage of image processing to take pictures using unmanned aerial vehicles and analyze the image to potentially provide information about where people might be trapped. The Robo-Res version 1.0 is an experimental prototype of a humanoid rescue robot that uses multiple algorithms in aerial pictures taken to interpret it without missing details [3]. Although helpful for the inspection of the surface, it cannot observe what happens below the superficial layer.

The radar technique is another of the most effective ways to detect human vital signs in certain circumstances. An antenna transmits electromagnetic waves which when reflected can be analyzed to detect the victim [4]. This technique is good to find people, but it has not been implemented to rescue robots due to the noise and clutter problems found when analyzing the signals.

Similar projects to those described in this paper, imitate the body structure of a snake to maneuver under the debris and find useful information of stranded people. The snake robot designed by Carnegie Mellon University is a robot that tries to imitate the movement of a snake to move along its path. It is highly articulated which allows it to perform complex movements. The control of the robot comes from a cable attached to its tail. This feature is a strong constrain since it limits the distance between the controller and the robot [5]. J. Gao, et al. made a robot that uses any surface contact to drive force for its movement [6]. However, the signal controlling the robot will limit its movement to be close to the user.

In this paper, we propose a snake-like remote-controlled vehicle capable of moving between debris and transmitting video to the control center. This robot could be used after a natural disaster (such as earthquakes) to find people trapped inside dangerous or difficult access zones. The implementation of the robot is detailed in four subsections. First, System Block Diagram describes of the modular behavior and shows the elements contained within each module. Then, the Communication System subsection explains how the information from the sensors and controllers travel to the different systems. In the Control System subsection, the tasks of the microcontroller are introduced. The Physical Model presents the design and the selected materials. Finally, the Results section describes the tests and evaluation performed to LUWA-E.

II. Implementation

A. System Block Diagram

The robot works like a chain, all the modules send and receive information to the next module (i.e. module Alpha to module Bravo, module Bravo to module Charlie); but only the module Charlie, sends and receives information from the Control Center. Fig. 1 shows a general block diagram of the modules and their connections.

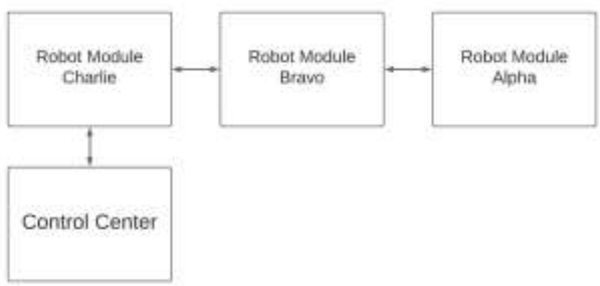

Fig. 1. Block diagram of the interconnected modules

The robot can be formed by many modules. However, for this first implementation, only 3 modules were used.

A single module is based on a configuration like the one presented in Fig. 2. Modules Alpha and Bravo include sensors and module Charlie includes a repeater. All the information is sent to the Control Center through the communication system. The user can analyze this information to make decisions in terms of the movement. The Control Center sends variables to all the modules with the instructions for the robot's movements.

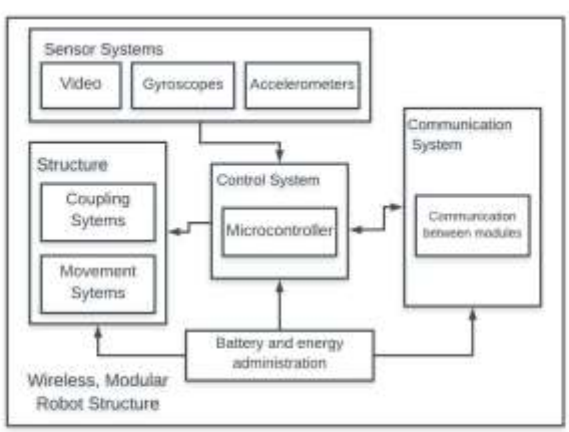

Fig. 2. General diagram of a module

B. Communication System

Three aspects are considered when choosing the communication protocol. It must be wireless, fast, and reliable for data transmission. Wi-Fi connection is one of the most common ways to connect devices. There already exist a variety of options for microcontrollers and microcomputers with integrated chips that include Wi-Fi connections. The integrated chip helps in terms of space and design and makes coding simpler. Therefore, the robot communicates wirelessly between modules using Wi-Fi connection. The ESP32 microcontroller is chosen for the communication between modules, since it can send information, work as the main computer in the Control Center, and be configured as a Wi-Fi repeater for Charlie.

C. Control System

The ESP32 is a microcontroller that can communicate wirelessly, transmit video, and it is economic and small. It offers a user-friendly interface that can be programmed using the Arduino IDE, that includes fully developed libraries for its different characteristics. One of these libraries allows sending simple packages of instructions between microcontrollers. There is one of these microcontrollers in every module of the robot. The microcontroller of Charlie receives instructions of the Control Center (made also with an ESP32), and then sends it to the rest of the microcontrollers for robot's movement control. After that, every microcontroller executes its respective instructions. In parallel, there is another ESP32 connected in each module executing specific commands. The Alpha module contains a CCD camera connected to the microcontroller. In Bravo, the controller is reading movement values from the accelerometer/gyroscope MPU6050, since the configuration of the ESP32 does not allow to read sensors and share data between them at the same time. And the parallel microcontroller of Charlie is configured as a Wi-Fi repeater that is connected to the MPU6050 and the video to send the information to the Control Center.

In summary, a module includes one microcontroller that receives and sends information for the rest of the modules in terms of movement instructions, and another microcontroller that sends data information to the Control Center and is repeated through a Wi-Fi repeater inside Charlie.

Another important feature is that Charlie can detach itself and keep acting as Wi-Fi repeater. This allows the robot to connect with the Control Center from a longer distance. Also, Alpha has a special type of ESP32, which includes a CCD camera. This makes easier the transmission of video to the Control Center.

D. Physical Structure

The robot intends to have a movement like a snake. This structure allows it to move properly among the debris due to its small size and allows it to ascend when needed. Fig. 3. shows the 3D isometric view of the three built modules.

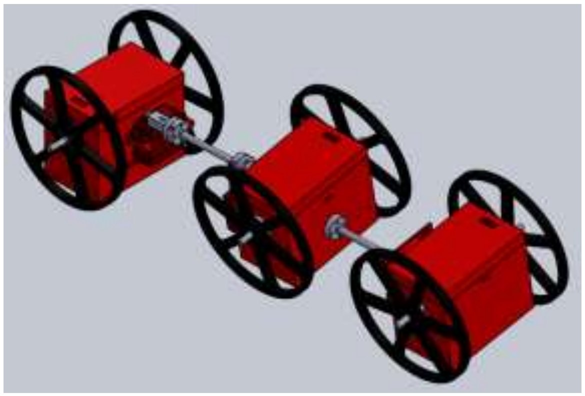

Fig. 3. Isometric view of three modules of the robot

The selection of the materials was influenced by its density, since the robot's movement will be dependent on its weight, and by the external and internal forces that the robot has to withstand, therefore the strength of the used materials was also prioritized.

The PLA for 3D printing and aluminum were considered as materials to build the structure. Table I contains the characteristics of these elements. Only shear strength is used as a comparison of its resistance since the other strength properties are proportional to this one for these materials.

TABLE I. ROBOT'S STRUCTURE MATERIALS

Material	***Shear strength***	***Density***	***Conductivity***
PLA for 3D printing	40 MPa	1.3 g/cm^3	No
Aluminium	207 MPa	2.7 g/cm^3	Yes

The parts that must bear the biggest stresses are made from aluminum to prevent fractures. Since the links between modules of the robot will experience great forces, aluminum is used. On the other hand, PLA is adequate for the parts that were designed since it can be easily 3D printed. This allows us to have freedom when creating components.

The testing robot has three modules: Alpha, Bravo and Charlie. Alpha is at the frontal one that has the camera. It has a servo at the back which connects it to the Bravo and allows the head to rotate right or left; this movement ends up translating to the other modules moving to this direction. Bravo is the middle module; at the front it has a servo that will make Alpha (and the rest of the robot) move up and down. The last module is Charlie. This module has a detachment system which allows it to separate from the rest of the robot when the user sends a signal to do so.

A servo inside Charlie allows a rotating piece to lock the link attached to that box. The servo can rotate to change the position of this part and allow the link to be freed by just keep moving forward. The left image in Fig. 4 shows the attachment mechanism in lock position and the right image illustrates the unlock position.

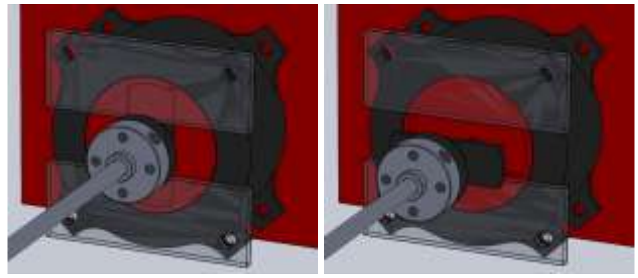

Fig. 4. Attachment mechanism between modules: lock position in left image and unlock positoin in the right image

III. RESULTS

This section presents the results from the tests performed to the robot. Fig. 5 shows a photo of the final implementation.

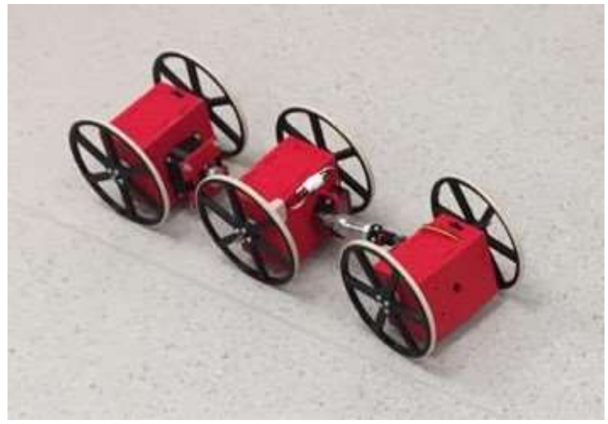

Fig. 5. LUWA-E, modular wireless search robot

To evaluate the robot's expected functionalities, the specific objectives are listed in Table II. These objectives were grouped within the robot's ability to move, to sense, to connect, and to be economically feasible. Table II depicts these objectives along with their achievement level.

TABLE II. LEVEL OF ACHIEVMENT OF THE SPECIFIC OBJECTIVES

	Specific objectives	***Level of Achievement***
1	Build with strong lightweight materials	Meets expectation
2	Move skillfully	Meets expectation
3	Smallest size posible	Partially meets expectation
4	Ability to detach module	Meets expectation
5	Ability to visualize its surroundings	Meets expectation
6	Sense rotation and movement	Meets expectation
7	Autonomous source of power	Exceeds expectation
8	Remote controlled	Exceeds expectation
9	Transmit video to the Control Center	Meets expectation
10	Economic solution	Meets expectation

To evaluate the objectives, the robot was subjected to several tests. These include:

- the remote-control movement to avoid obstacles,
- the detachment of Charlie to extend communication abilities,
- the control of the robot using only the video provided to the Control Center,
- the repetition of the transmitted signal after a certain distance and
- the ability to read the position data from the accelerometer/gyroscope sensor.

All the tests were passed successfully since the robot could move smoothly and avoided the obstacles with ease; it was controlled using only the information coming from the camera and the gyroscope. The user was able to control the movement of the robot and the Charlie module could be detached as shown in Fig. 6; the Control Center constantly received data regarding its position and rotation; and there was connection between the modules and repeaters even after reaching 18 meters of distance apart.

Fig. 6. Detachment of the last module of the robot

Additionally, each module is energized by a 2500 mA-h power bank, which feeds all its internal components. The robot final dimensions are 105 x 76 x 65 mm, small enough to fit between some of the rubble of a fallen building. The robot was capable of successfully performing all the tests and gave validation to the specific objectives presented in Table II. Finally, the total cost of the system is less than $4,000 MXN, thus being an economical feasible prototype.

IV. Conclusions

A snake-type remote-controlled robot was design and develop using Wi-Fi communication and ESP32 microcontrollers. The system formed by three autonomous modules and a control center demonstrated the robot's abilities to move skillfully around obstacles. A person can control the robot using only the image coming from the onboard camera and data from the accelerometer and gyroscope. The distance between the control center and the robot was double by leaving a repeater module in the middle. The attachment mechanism was successfully controlled to achieve a longer distance communication. The final solution is relatively low cost and lightweight, which makes it ideal to use in dangerous fallen buildings when searching for trapped people. Further improvements can be done by reducing the size of the robot, increment the number of modules and add two ways voice communication.

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