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Human Controlled Search and Rescue Robot with BLE-based Victim Localization

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Abstract:- This study presents the development of a human- controlled ground search and rescue robot with victim localization using modified BLE beacons and an ESP32 camera. The system is designed to aid rescuers during search and rescue operations, reducing their risk by providing ambient conditions and live video footage of the vicinity. The system uses Arduino as its microcontroller and HC-12 transceiver modules to wirelessly control the robot. The system is also equipped with a GPS Module and a BLE Beacon to track the location of the robot. Through numerous tests, the robot can accommodate the rescuers in the localization of victims, and the researchers recommend further improving some functions of the robot.

Keywords:- *Ground Search and Rescue Robot, BLE Beacon, ESP32 Camera, Global Positioning System (GPS), HC-12 Transceiver Module.*

I. INTRODUCTION

AS a country under the Pacific Ring of Fire, Philippines is vulnerable to volcanic eruptions and earthquakes [1] and is oneof the most susceptible to natural disasters. In the disaster response phase, where there is a limited window with a decreasing likelihood of rescuing trapped individuals, effective planning of search and rescue operations has a significantimpact [2]. The ability to search for and locate trapped survivors after an earthquake or the collapse of a built structureis vital. Urban search and rescue teams must intervene manually with caution to prevent subsequent collapses that could endanger the rescuers. Cluttered debris could make it impossible for anybody to get near the victims, and structures must be propped up before human assistance due to the possibility of more landslides [3].

Reference [4] – [5] developed a Bluetooth Low Energy (BLE) based close detection system that is supported by terrestrial and aerial robots to determine whether such a system is feasible in the localization and detection of victims inunfamiliar and complex disaster areas. [6] designed an IoT-based multi-function remote-controlled rescue robot system, which uses several technologies like a sensor Global Positioning System (GPS), single-chip microcomputer, Wi-Fi, and Android. The system uses multiple technologies to provide an auxiliary rescue platform with a multi-agent network that incorporates sensing, motion, communication, and operating capabilities. [7] developed a semi-autonomous mobile search and rescue robot for alive human detection. Their system uses a PIR sensor for human detection, a joystick, RF technology for control, an ultrasonic sensor for obstacle detection, a gas sensor to detect leaks, and an IP camera to analyze and observe environmental conditions. A PIR sensor at the first level detects people using their radiated heat. Afterwards, an IP camera at the second level and an infrared wave confirm the human presence in disaster-affected areas.

This paper will supplement the previous studies of [5] relating to the use of temperature, humidity, gas sensors, and a camera. The previous study did not implement these features, which would have helped rescuers better understand the disaster environment around possible victims. Aside from that, the paper will also fill the gap left by [6] in their paper, wherein the wheel structure of their rescue robot has a simple design, lightweight and quick but struggles when faced with obstacles or complex and rough terrains. To address this, the researchers will use track wheels to provide more maneuverability when it comes to rough terrains such as stairs, slopes, and unstructured ground, which is especially needed in the aftermath of an earthquake. Furthermore, this paper will also fill the gap by

[7]related to the usage of BLE and GPS technology to help rescuers mark and navigate to the exact location of nearby possible victims. The previous study did not have any positioning system installed and therefore relied heavily on thefamiliarity of the rescuers with the area.

This study seeks to develop a robot for search and rescue equipped with a camera, temperature, humidity, and gassensors, as well as BLE and GPS technology. This study aims to

- Develop a ground vehicle prototype that allows rescuers to locate victims in real-time using a camera
- Monitor the temperature, humidity, and presence of gasses in the target area
- Build a prototype that can navigate through rough and complex terrains such as stairs, slopes, and unstructured ground
- Develop a communication system that will transmit data from the robot to the user using a wireless transceiver module
- Control the search and rescue robot using a wireless controller
- Provide outdoor positioning via GPS and indoor relative positioning using BLE beacons for the localization of possible victims.

This study will aid search and rescue teams in locating casualties following an earthquake. Furthermore, this study will help reduce the risk for rescuers by providing them with ambient data such as the vicinity's temperature, humidity, and gas. This study will also help rescuers navigate through areas that are hard to reach, like tight spaces and cluttered debris. Aside from that, since the proposed search and rescue robot can scout the target area first, the risk of injury to rescuers would be significantly reduced. The results of this research will provide further knowledge for future research on disaster response.

The scope of the study will only focus on developing a search and rescue robot that can measure ambient conditions and provide localization of possible victims after an earthquake. The researchers aim to contribute to search and rescue operations in the aftermath of calamities like earthquakes, including debris from a building or structure. The proposed system for the robot consists of a Camera, BLE Beacon, GPS, and multiple sensors, including temperature,humidity, and gas sensors. Aside from that, the proposed design also includes using track wheels for the ground robot for it to be able to navigate through rough terrains such as stairs, slopes, and unstructured ground. The detection of victims will be manually done by the rescuer, who is controlling the robot through a live feed via an LCD screen. Data from the robot, including information gathered from the camera and sensors, and data from the rescuers, including user inputs and controls, shall be exchanged using an HC-12 Wireless Transceiver Module with a legal frequency band of 433.4 MHz to 473.0 MHz. The researchers selected the module due to its relativelylow cost, networking capability, data security, and considerable communication distance. Based on its specifications, the module provides long-distance wireless communications of upto 1000 meters in open space. The study will also explore the practicality of these claims and the communication range of the module in an interior setting. For the robot to access difficult- to-reach regions in disaster zones, its size must also be minimal. The study will also exclude the identification of any potential collapses or falling debris within the disaster zone that might hinder the ground robot's function.

II. REVIEW OF RELATED LITERATURE

Reference [8] explained the importance of search and rescue robot in search and rescue operations by extend the ability of the rescuers to grasp and act in a search and rescue operation to quickly locate, evaluate, stabilize, and free victimswho cannot be reached easily.

Camera and sensors are crucial components of a search and rescue robot. [9] proposed a tracked robot prototype with ESP32-CAM face recognition and video streaming capabilities using a military robot as the basis of the simulated tracked robot. According to the results, streaming the video is excellent, which is possible due to the fast connection of the server. [10] developed a sensor network with gas sensor nodes for detecting hazardous substances in times of disaster. This is done by combining various inexpensive and power-efficient sensors for gas, temperature, and humidity with intelligent information fusion and signal processing, while [11] used a sensor system using three different sensors: a C02 sensor, a microphone, and a thermal camera for human rescue. The system's performance in living victim detection under debris istested in a simulated high-fidelity disaster area.

GPS is a useful technology for outdoor localization. [12] integrated a GPS in a search and rescue drone, [13] equipped a search and rescue Autonomous Surface Vessel with a GPS, and [14] developed a fully autonomous UAV with a GPS that pinpoints coordinates of human presence once the drone detects it.

For indoor relative positioning, BLE is an effective technology. [4], [5] both integrated a BLE-based detection system in search and rescue robots for the localization of victims in unknown complicated disaster areas. [14]said that search and rescue robots should be agile and quick. At the same time, the robots should be able to manage rough terrains and, if possible, climb stairs if it requires the rescuers to access higher levels of the area. [16] compared different ground search and rescue robots that used tracked wheels, while [17], [18] designed a search and rescue robot capable of navigating complex terrains because of its track wheels.

III. METHODOLOGY

A. *Research Design*

Researchers employed a developmental research approach. Developmental research is the scientific study of creating, producing, and assessing educational programs, procedures, and products that must fulfill internal consistency andeffectiveness requirements [19]. In this case, the researchers developed a search and rescue robot that can navigate through complex terrain, locate victims, and record the temperature, humidity, and presence of gas within the disaster area. This research seeks to develop a device that will contribute to the search and rescue teams.

B. Design of the System

The system comprises essential components such as sensors, a camera, wireless communication modules, user controls, and a display.

Fig 1 General Block Diagram

Figure 1 shows the system block diagram and its components: control, sensors and location, the system microcontroller, and user access and display. The first block refers to the inputs received and gathered by the robot, including the temperature, humidity, and gas sensor and the controls fed to the robot by the user, visual data from the camera, and location information from indoor and outdoor positioning using BLE and GPS. These data will subsequently be stored in the Arduino microcontroller and sent to the user side using an HC-12 Wireless Transceiver Module to communicate. The robot and user side will have a microcontroller and wireless transceiver modules. On the robot side, the data gathered from all the inputs will be sent to the user, and in turn, the robot will receive instructions and control from the user.

C. Conceptual Framework

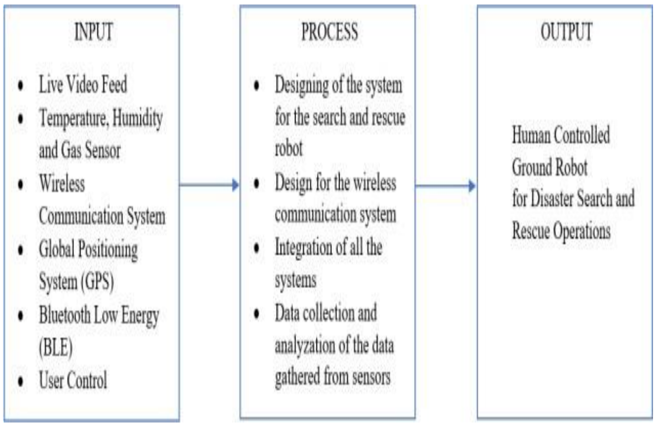

Fig 2 Conceptual Framework

Figure 2 shows the conceptual framework of the search and rescue robot, in the first diagram includes the inputs that the robot receives and gathers, such as the temperature, humidity, and gas sensors, the user-supplied commands, the visual information from the camera, and the location data from both indoor and outdoor positioning utilizing BLE and GPS. Following storage in the Arduino microcontroller, this information will be transmitted to the user side using an HC-12 Wireless Transceiver Module. Microcontrollers and wireless transceiver modules will be present on both the robot and user sides. The user will instruct and control the robot by giving it commands after it has received the data it has acquired from all the inputs.

The following block design demonstrates how the researchers will apply BLE for indoor positioning. The rescuercontrolling the robot will have visual feedback of the robot's immediate surroundings, enabling them to assess the situation and make judgments regarding the presence of a victim. The user can direct the robot to drop a BLE beacon in its current location after a victim has been found. The robot will also offer a wireless communication system to form a two-way communication between the victim and the rescuer controllingthe search and rescue robot.

D. System Architecture

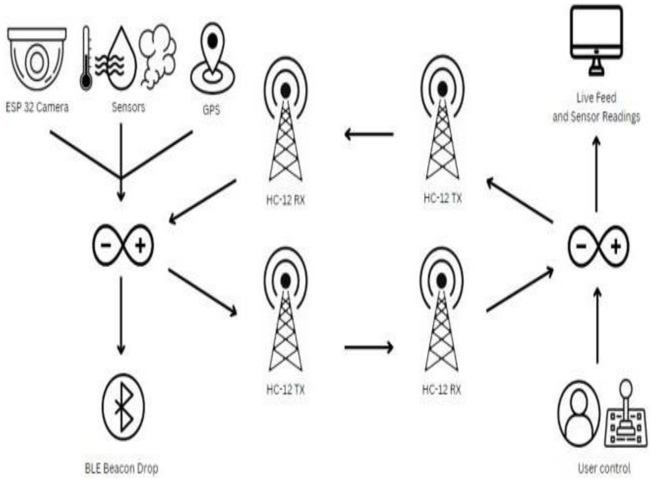

Fig 3 System Architecture

As shown in Figure 3, the architecture of the system consists of two-way communication between two Arduino Mega microcontrollers, one connected to the search and rescuerobot and the other to the controller and display. The system uses a total of four HC-12 transceiver modules to function properly. This is because each HC-12 module only supports half-duplex communication, meaning it can only transmit or receive data at any given time. The first pair of HC12 will transmit controller data from the user to the robot, and the other pair will transmit sensor data from the robot to the user. On the robot side, the first HC-12 will receive the controls from the user, and the second HC-12 will transmit data from the sensors connected to the robot toward the LCD found on the user side.

The search and rescue robot side provides four functions the user will receive: ESP32 Camera, Sensors, GPS, and BLE. The ESP 32 Camera will serve as the user's eye as the user maneuvers the robot within the area to detect potential victims. The robot is connected to Temperature, Humidity, and Gas sensors. The sensors will provide users with data and information regarding the ambient conditions of the area, allowing them to detect any possible fire hazards and giving extra precautions to the user. The GPS module connected to the robot will provide the coordinates of the current location of the robot. Additionally, upon victim detection, the user can drop BLE beacons which will allow users to mark the exact position where the user found the victim. All data collected from the robot will then be sent to the HC-12 Module and interpreted with an LCD.

E. Visual Footage System

Fig 4 Block Diagram of Visual Footage System

Figure 4 shows how the researchers used the ESP32 camera for live video feedback. The ESP32 camera hosts a video-streaming web server that users can access with any device connected to the same network. The ESP32 Camera is interfaced and programmed using an Arduino Mega. After programming, a link was provided in the serial monitor of the Arduino IDE, where the user accessed the video from the camera. The ESP32 Camera only needs to be programmed once, and afterwards, it can be used if its 5V and GND pinsare connected to the board.

F. Remote Monitoring System

Fig 5 Block Diagram of Remote Monitoring System

Figure 5 shows the process of monitoring the temperature, humidity, and gas of the area. The research mounted the DHT22 Temperature and Humidity Sensor and MQ-5 Gas Sensor outside the robot. These sensors are connected to the Arduino Mega microcontroller connected to the robot. Data gathered from the sensors are then programmed to be sent by the HC12 module connected to the robot toward another HC12 module connected to the controller. The gas, temperature, and humidity data received by the HC12 module in the controller are then programmed to be displayed by an LCD connected to the controller.

G. Robot Mobility

Fig 6 Block Diagram of Robot Mobility

Figure 6 shows how the user controlled the wheels, arms, and BLE dispenser of the robot. For this study, the researchers used two motor drivers, a VNH2SP30 motor driver, and an L298N motor driver, to ensure that the power towards each DC motor connected to the robot is maximized. The VNH2SP30 was responsible for the movement of wheels in the main body of the robot, while the L298N was dedicated to the forward and backward movement of the arms. Furthermore, the robot is also connected to two servo motors, an MG90S micro servo for dispensing BLE beacons and an MG996R for moving the arms up and down.

H. Wireless Communication System

Fig 7 Block Diagram of Wireless Communication System

Figure 7 shows how the researchers used HC12 Wireless Transceiver Modules to develop a wireless communication system that transmits data between the robot and the user. There were two Arduino Mega Microcontrollers, one for the user and the other for the robot. Since the HC12 Wireless Transceiver Modules are half-duplex, the researchers used four HC12 Wireless, two HC12 Transceiver Modules are for transmitting data, while the other two are for receiving data.

I. Wireless Controller

Fig 8 Block Diagram of Wireless Controller

Based on Figure 8, the researchers used a wireless controller to control the function of the search and rescue robot. The wireless controller consists of push buttons for the search and rescue robot's navigation and arm movement, dispensing BLE beacons, and refreshing the sensors and GPS reading.

J. Outdoor Positioning

Fig 9 Block Diagram of Outdoor Positioning

Figure 3.14 shows how the outdoor positioning using NEO6MV2 GPS Module works. The GPS module sends the coordinates to the Arduino Mega Microcontroller, which is then displayed on the LCD in the controller. The coordinates are displayed on the LCD, which is then put in Google Maps to see the actual location of the search and rescue robot.

K. *Indoor Positioning*

Fig 10 Block Diagram of Indoor Positioning

Figure 10 shows how the researchers utilized BLE for indoor positioning. The user, who controls the robot, sees the current environment of the robot through the live video feedback from the ESP32 Camera. Thus, the user will be the one who will detect if there is the presence of any victim in thearea. Upon detection of the presence of a victim, the user can instruct the robot to drop a BLE beacon in its current location, which allows the user to mark the relative position of the victim. The researcher used NRF Connect Mobile Application to scan and detect the dropped BLE beacons.

IV. RESULTS AND DISCUSSION

Several testing procedures under different conditions were conducted to evaluate the accuracy and reliability of the search and rescue robot. All experiments were conducted using the integrated parameters and components of the complete rescue robot.

- *Live Feed Accuracy Test*

Table 1 Pass Rate for Live Feed Accuracy Test

Condition	Pass Rate (%)
Well-Ventilated Room	100
Hallway	100
Outdoor (Rough Terrain)	100
Outdoor (Sloped Terrain)	100

The 100% pass rates indicate that every user successfully detected victims in each condition. This implies an important level of proficiency and effectiveness in detecting victims using the ESP32 camera. The consistency in the pass rates across different conditions suggests that the user using the ESP32 camera for live feedback was able to determine the victims in each condition. However, users must carefully navigate the environment to ensure thorough coverage and accurate detection of victims.

- *Temperature Accuracy Test*

Table 2 T-test Table for Temperature Paired two Sample for Means

Parameter	Temperaturewith DHT22 sensor	Temperaturewith Galaxy Sensor Application
Sample Mean(°C)	29.27	30.12
Variance	1.25	3.00
Degrees of Freedom	38	
t-Value	-1.83	
p-Value	0.07	

Using a two-tailed t-test and a significance level of 0.05, theDHT22 temperature sensor used in each of the four conditions was found to be accurate enough to determine the temperature of the environment.

- *Humidity Accuracy Assessment*

Table 3 T-test Table for Humidity Paired two Sample for Means

Parameter	DHT22 Humidity	Galaxy SensorApplication Humidity
Sample Mean (%)	75.02	50.39
Variance	8.67	6.16
Observation	20	20
Degrees of Freedom	38	
t-Value	28.06	
p-Value	<0.001	

Using a two-tailed t-test and a significance level of 0.05, theDHT22 humidity sensor used in each of the four conditions was found to be inaccurate enough to determine the humidity of the environment.

➢ *Gas Sensor Concentration Assessment*

Table 4 Pairwise Comparison Table: Turkey HSD Test

Condition Pair	Difference in Means	TukeyHSD p-value	Significant?
Well-ventilated room	3.20	0.763	No
vs. Hallway			
Well-ventilated room vs. Outdoor: Rough	-32.40	0.001	Yes
Well-ventilated room vs. Outdoor: Sloped	-25.40	0.001	Yes
Hallway vs. Outdoor: Rough	-35.60	0.001	Yes
Hallway vs. Outdoor: Sloped	-28.60	0.001	Yes
Outdoor: Rough vs. Outdoor: Sloped	7.00	0.558	No

The post hoc test results with the Tukey HSD test indicate that the conditions presented significantly affect gas concentration reading in PPM.

➢ *Mobility Test*

Table 5 One-sample Proportion Test Table

Conditions	Pass rate	Z-statistic
Stairs	25	-2.23
Slope	100	4.47
Unstructured Ground	100	4.47

Using a one-sample proportion test, the 100% pass rate for slope and unstructured ground indicates that the searchand rescue robot is capable of navigating slopes and unstructured ground, while the 25% pass rate for stairs suggests that the robot struggles in navigating stairs or other elevated areas.

➢ *Response Time vs. Distance*

Table 6 Linear Regression Results

Distance (m)	Response Time (seconds)			
	Trial 1	Trial 2	Trial 3	Mean
5	0.11	0.15	0.23	0.16
10	0.43	0.55	0.55	0.51
…	…	…	…	…
50	3.56	3.00	3.98	3.51

Table 6 shows that in an obstructed condition, there is a delay between the control and the robot that increases as the distance between them increases. It was also examined using linear regression analysis as shown in Figure 11. This is also the same for the BLE dispenser response time in an obstructed condition.

➢ *GPS Reception Accuracy*

Table 7 Coordinates Between GPS Module and Mobile Phone GPS for Indoor Condition

MobilePhone Latitude	GPS Module Latitude	MobilePhone Longitude	GPS Module Longitude
14.636235	NA	121.027593	NA
…	…	…	…
14.636235	NA	121.027593	NA

Since the GPS module failed to receive signals indoors, it isconcluded that the NEO6M V2 GPS module has low reception strength in indoor usage.

Table 8 T-test table for Coordinates

	MobilePhone Latitude	GPS Module Latitude	MobilePhone Longitude	GPS Module Longitude
Sample Size (n)	5	5	5	5
Mean Longitude	14.63 5614	14.63 5606	121.02 5920	121.02 59054
t-value	1.00	-	0.81	-
Degreesof Freedom	8	-	8	-
p-value	0.35	-	0.44	-

Showed that the sensor accurately reads gas concentration in different conditions. The robot successfully navigated through Paired Two Sample for Means the different conditions. The prototype showed an excellent 100% pass rate on slopes and unstructured ground and an unsatisfactory 25% pass rate on elevated areas. The inclination of the slopes ranged from 7-9 degrees, 19 degrees, and 23 degrees. At the same time, the successful navigation of the robot in an elevated platform has a height of 2.5cm and 6cm, where the material of the platform also affects its success rate.

The communication between the robot and the control system was also reliable. The response time is proportional to the distance since the computed R squared is 93.1% and fits the line trend. Hence, the significant relationship between response time and distance can delay the command of the prototype. Furthermore, the response time on dispensing the At a 5% significance level, it was determined that no significant difference between the actual coordinates values and the coordinates values from the GPS module exists. tindicates that the GPS module accurately gathers datacompared to the Mobile Phone GPS in an outdoor setting.

➢ *RSS vs Distance of BLE Transmitter from Receiver to Analyze Path-loss (dBm)*

Table 9 Results of Measurement of RSS vs Distance of BLE Transmitter from Receiver

Distance (m)	RSS in dBm			Mean
	Sample1	Sample2	Sample3	
1	-59	-60	-61	-60.00
2	-65	-67	-62	-64.67
…	…	…	…	…
9	-87	-87	-85	-86.33
10	-88	-90	-91	-89.67

With a minimum -70dBm acceptable RSS level for BLE devices, the BLE beacons provided a reliable indoor relative positioning system.

V. CONCLUSION

After conducting several tests under different conditions,the result shows that the human-controlled search and rescue robot used for victim localization has been able to accommodate the possible needs of the rescuers in terms of localizing the victims after an earthquake. The human-controlled ground robot for disaster search and rescue operations utilized an ESP32 camera to detect victims with 100% accuracy. Using descriptive statistics, by collecting the pass rates for each condition, researchers determined the proficiency and effectiveness of the prototype. Subjectively, users must ensure careful analysis of the provided live feedback to consider the accurate detection of victims sincethe prototype will only guide the user in localizing the victims through the camera. The sensors utilized in the prototype provided valuable ambient data, which includes the temperature, humidity, and gas presence in the vicinity. Using a two-tailed two-sampled t-test, researchers concluded that theDHT22 Temperature and Humidity sensor accurately provided ambient data in different environmental conditions. While for the MQ5 Gas sensor, the one-way ANOVA test results BLE was similar to the delay in commanding the prototype. Increasing the distance also increased the response time of the prototype. Regarding positioning reliability using the GPS Module, the GPS Module was found to have low signal reception strength in an indoor setting but is reliable in an outdoor setting. Various factors affect the signal the GPS receives when trying to reach a receiver indoors. Structures like buildings, walls, and roofs can attenuate the signals, leading to decreased reception strength and degraded accuracy. While for indoor relative positioning, using BLE beacons and NRF Connect mobile application to obtain the RSS of the beacons, results showed that the BLE is an effective tool for indoor relative positioning.

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