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LoRa-enabled remote-controlled surveillance robot for monitoring and navigation in disaster response missions

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ABSTRACT

Rescue missions must be conducted within a strict timeframe, and the safety of all rescuers and civilians is prioritized. The proposed system aims to design a remote-operated aerial surveillance robot for disaster-affected areas for search and rescue missions. Real-time video transmission and RS-232 long-range communication enable operators to navigate rough environments and monitor data collected in real-time. This powerful tool ensures the protection of human life while collecting accurate and meaningful data. Cloud storage for data and surveillance strengthens the system, preventing part failure and fostering collaboration among users. This is a significant step towards using Internet of Things systems alongside remote-controlled robots in disaster response. The robot's key contribution to disaster management is identifying the environment, addressing issues of no visibility, complicated terrains, and speed. Its modification and expansion capabilities make it useful in armed surveillance, industrial monitoring, and environmental studies, making it an important innovation for many other fields.

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1. INTRODUCTION

Search and Rescue robots are increasingly used in natural disasters to ensure safety, but compromised infrastructure hinders real-time communication between robots and rescue teams, affecting their effectiveness [1]. The disaster management system (DMS) is a novel approach to disaster management, based on low-power wide-area networks (LPWANs) LoRa technology. It consists of three solutions: coordination, communication, and navigation. The system aims to improve communication and safety in disaster-affected areas [2]. LoRa is a popular choice for transmitting small data over long distances, particularly in rural farming and smart metering. However, in disaster contexts, it's rarely used for long-range communication [3]. LoRa-based Internet of Things (IoT) architecture connects end devices to servers, enabling over 25 billion devices to communicate by 2020, driving societal demand and influencing various aspects of life [4]. The Cognitive Rover project aims to revolutionize portable robotics by integrating neuro-technologies with long-range communication devices, enabling autonomous movement and interaction with the environment [5]. Earthquakes primarily impact civilians, causing destruction and burying them in wreckage. The first three days are crucial, but the rescue becomes hazardous due to increased wreckage. Active UAV systems offer remote site rescue, but lack customization [6]. The LoRa mesh networking-based emergency environmental monitoring system expands wireless communication capabilities, enabling more responsive low-rate data transmission during emergencies [7]. LoRa-based disaster response system enhances emergency services efficiency, coordination, and effectiveness by providing a flexible communication network, continuous environmental surveillance, and an alarm system for immediate response [8]. A new architecture integrates LoRaWAN communication as a secondary means of communication, enabling crawler robots to function in areas with severe damage, overcoming the issue of loss of coverage through primary communication sources [9]. In remote environments, traditional communications may be unavailable due to disasters. To improve reliability and avoid decoding errors, a UAV-enabled LoRa architecture is proposed. This architecture uses a distributed topology control algorithm and virtual spring forces to adapt to the LoRa node movement. Simulation results show feasibility [10]. A LoRa transceiver module is proposed for disaster management, enabling reliable communication, voice playback, GPS location tracking, and cloud-based data access for emergency management and victims [11]. The project aims to enhance surveillance efficiency in critical areas globally, transmitting real-time video and avoiding obstacles using an Arduino C-based microcontroller and Ethernet shield [12]. The project aims to create a cost-effective IoT surveillance robot with self-propelling features, environmental sensors, and streaming capabilities, capable of real-time video feeds for effective surveillance [13]. A low-powered LoRa-based wireless communication system was successfully used to track water pollution, enhancing power efficiency and accuracy while utilizing fewer sensors [14]. The contribution of this study is to develop a LoRa-enabled surveillance robot for reliable communication and surveillance in disaster-affected areas. The study examines the effectiveness of LoRa technology in communication and remote control for disaster response robots, especially focusing on data integrity, range, and reliability. Also, the study develops a dashboard for information display and control.

2. REVIEW OF LITERATURE

Natural disasters like earthquakes and mudslides often involve broken structures, endangering victims and rescue staff. Rescue operations can be hazardous, with hazards like poisonous gas, suffocation, or rubble trapping [15]. Disaster management is a complex process requiring coordination and collaboration among actors, with technology offering opportunities but also creating new challenges that can overwhelm decision-makers [16]. The aim is to develop a cost-effective, real-time IoT-based gas leak detection robot that can be used indoors as well as outdoors. The product is cost-effective, using cheap but reliable components and sensors [17]. During a disaster, maintaining communication infrastructure is crucial for disseminating critical information, but existing systems have a significant communication range drawback [18]. The integration of IoT and LoRa technology can help ensure resilient communication networks during natural disasters, addressing communication disruptions and situational awareness issues [19]. Tests show that LoRa can send data at a distance of 2.0 km in an environment full of obstacles, which enhances its ability and efficiency for disaster communication systems [20]. The increasing use of AI, IoT sensors, and advanced robotics in disaster management, such as in the Wenchuan earthquake and Fukushima nuclear disaster, is crucial for data collection, search, rescue, and hazard monitoring [21]. A compact, economical rescue robot, designed for real-time information retrieval in difficult-to-access locations in the course of rescue missions. The system incorporates FPV cameras mounted on a tilt assembly, which stream live video over the Internet [22]. Unmanned ground vehicles (UGVs) are remote-operated robots designed for dangerous environments, enabling fearless visual data acquisition through agile maneuvers like climbing and navigating tight spaces [23]. An IoT-based surveillance robot is defined as an intelligent, dependable, and effective autonomous security system. The construction includes several features and capacities that allow for improved monitoring and protection [24]. A low-cost remote sensing system has been proposed that is wireless, involving the use of Arduino Uno microcontrollers and Dragino transceivers to carry out the LoRa protocol [25].

3. METHODOLOGY

The surveillance node is designed to serve as the primary environmental data collector for a robotic surveillance system capable of functioning in disaster zones. It acts as a singular complex system that performs all the directives given within a certain area, and its outer peripherals are connected to it, greatly aiding it with its tasks. The block diagram for the surveillance node is shown in Figure 1. In the block, the main control is the Surveillance Node. It is the Arduino Uno microcontroller that is the central processing unit of the system. The robotic unit is fully operational, and it gets instructions via remote control; hence, sensors determine its location and give the data to a computer where an algorithm analyzes it, allowing commands to be given to the actuators. The Arduino Uno is responsible for communication between the different peripherals and for controlling the robot according to the instructions received from the remote control. The system employs a LoRa RF Module for communication with the Remote Node, as this kind of system allows long-range communication. This technology is used where the energy transmission has to be reliable and low energy in comparison to regular systems that would drain power. Such technologies further increase the usefulness and aid where regular wireless data systems would fail. The environmental data collected and movement commands given to the Surveillance Node by the remote operator are communicated through the LoRa module. The ESP32 Camera module is supplemented to allow video streaming features. It collects the live video of the robot's environment and sends it to a laptop or control center over the internet through an assigned IP address. This is important to allow the operator to control the robot in remote areas, like disaster zones, and keep an eye on the area from afar.

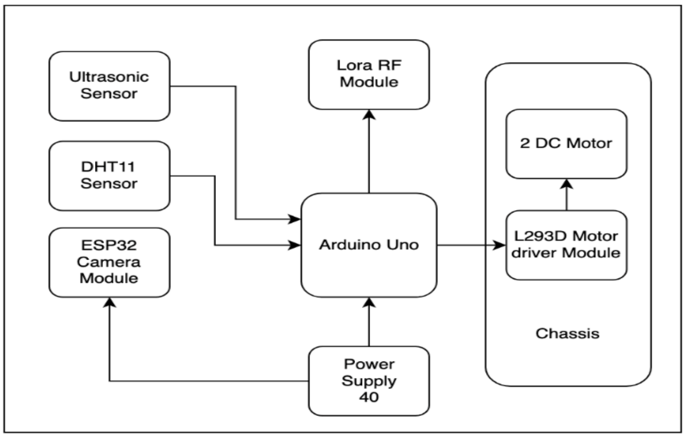

Figure 1. Block diagram of the surveillance node

The recording of environmental monitoring is achieved using a combination of several sensors. Measuring the distance between itself and obstacles on its trajectory, the Ultrasonic Sensor will avoid collisions, while the DHT11 Sensor measures temperature and humidity in order to prepare for the conditions in the disaster zone. This is paramount to identify risk and ensure the protection of survivors and rescue workers. The mobility of the system is ensured by two DC Motors connected to an L293D Motor Driver Module. As a bridge between the Arduino Uno and the motors, the motor driver allows the microcontroller to transform electronic signals into the desired movement of the robot. With such capabilities, the Surveillance Node is able to traverse through rubble and rough terrain without any trouble. The Remote Node serves as a system control unit, allowing operators to operate and watch the Surveillance Node using its navigation features and monitoring tools. It has several elements that enable communication, control, and feedback processing systems to support operation in a disaster environment.

Figure 2 depicts the remote node block diagram. The core of the Remote Node is an Arduino Uno microcontroller, which is responsible for coordinating the Remote Node and the Surveillance Node communication. The Arduino Uno also works with the LoRa RF module; it receives data and issues control signals, takes command instructions from the operator through the keypad, and issues appropriate movements, including turning on the buzzer. The LoRa RF Module allows long-distance communication with the Surveillance Node and is one of its main components. It receives movement control commands from the Remote Node and sends the commands to the Surveillance Node. It also transmits environmental sensing data and node status to the users of the Remote Node. The ability of the LoRa module to operate at low power and at long distances makes it suitable for places with conventional communication networks inoperable, like in disaster zones. The LoRa-enabled surveillance robot provides a range of 15 km in open areas and 5 km in urban environments if there are some hurdles in between for communication, with 8 hours of battery life and 1.5-second video latency, which ensures efficient real-time monitoring in disaster zones. The NodeMCU has been incorporated into the Remote Node on top of the system in order to improve its capabilities. The NodeMCU serves as a transmitter of data to the Blynk cloud server. Its function includes uploading information and status updates received through LoRa to the cloud. Thus, users can access the environmental factors of the disaster zone. Structures of the cloud help to guarantee that the data will be available contemporaneously to a multitude of users, which increases the ability to make decisions during the search-and-rescue activities. The Keypad serves as a controller enabling the operator to guide the movement of the robot. The operator can give directional commands such as forward, backward, left, or right. These are read by the Arduino Uno and transmitted to the Surveillance Node through the LoRa module. Planning and controlling the movement of the robot using the keypad is easier for the operator, especially those who have to deal with high-stress situations. The Buzzer is designed as an alert feedback mechanism to the operator when there is an appending incident. The buzzer can send information such as transmission of the command is successful, communication broken, or critical information from the Surveillance Node. This kind of feedback ensures that every user is prepared and can utilize the equipment in real-time situations.

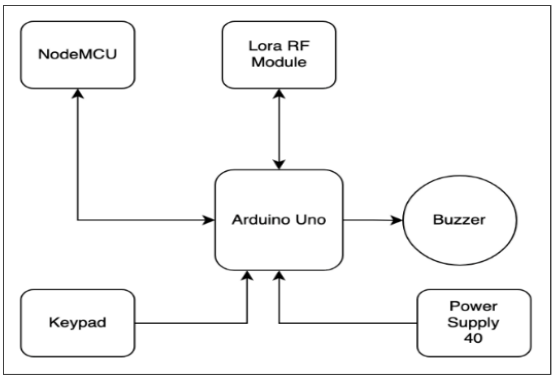

Figure 2. Block diagram of remote node

3.1. Hardware development

The hardware connections of the Surveillance Node have elements as shown in Figure 3. The GND pin of the DHT11 temperature and humidity sensor is connected to the GND pin of the Arduino Uno. The Vcc pin of the DHT11 sensor is connected to the 5V pin of the Arduino Uno to provide power. The Data pin of the DHT11 is connected to digital pin A0 on the Arduino Uno. This setup allows the Arduino to retrieve and monitor temperature and humidity data from the environment for climate analysis and control applications. The ESP32-CAM module's ground pin is hooked to the GND pin of the Arduino Uno, while the Vcc pin of the ESP32-CAM is connected to the 3.3V pin of the Arduino Uno. This ensures that the module works on the desired voltage. The RX of Arduino Uno is connected to the D3 of the ESP32-CAM, while the TX of Arduino Uno is connected to the D2 of the ESP32-CAM. This allows for the Wi-Fi enabled ESP32-CAM module to capture still images or videos for surveillance and send them over the internet, making it possible to monitor in real-time.

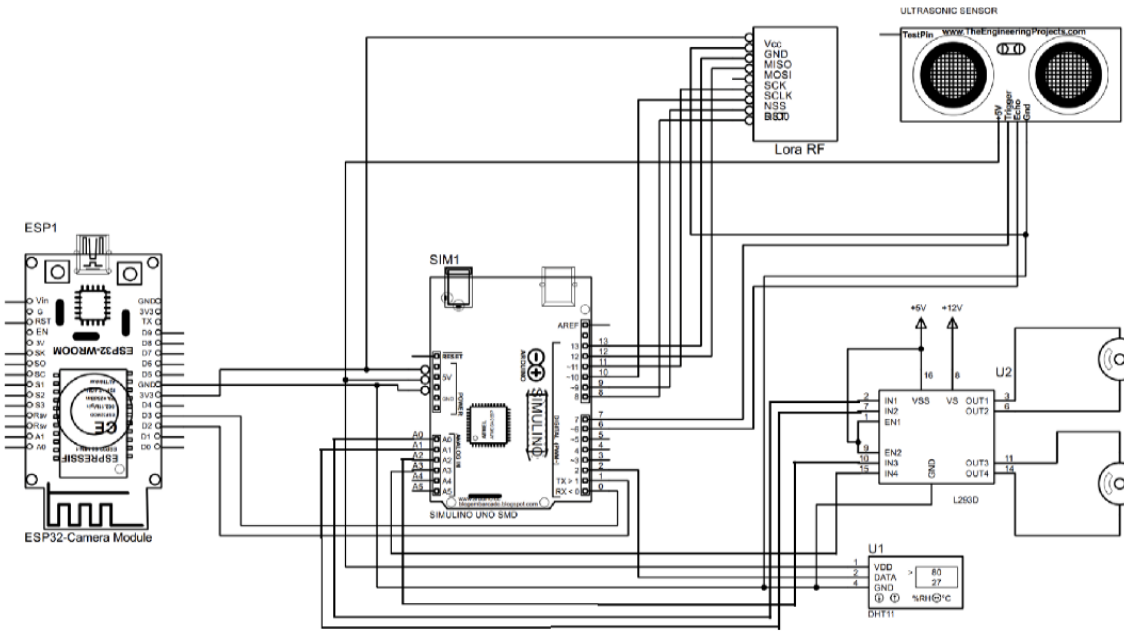

Figure 3. Connection diagram of surveillance node

The GND pin of the Arduino Uno is connected to the LoRa RF module's Ground pin. To power the LoRa module, its Vcc pin is connected to the 5V pin on the Arduino Uno. For SPI communication, the MISO, MOSI, and SCL pins of the LoRa module are connected to pins 12, 11, and 13 of the Arduino Uno, respectively. The NSS pin goes to pin 10, while the DIO0 and RST are connected to the digital pins 9 and 8. This configuration enables the LoRa module to wirelessly send and receive data over large distances, which is why it is perfect for remote communication and IoT usage. The GND pin of the HC-SR04 ultrasonic sensor is connected to the GND pin of the Arduino Uno. For powering the ultrasonic sensor, the Vcc pin is connected to the 5V pin of the Arduino Uno. The Trigger pin of the ultrasonic sensor is connected to digital pin 7, and the Echo pin to digital pin 6. This allows the Arduino Uno to transmit ultrasonic pulses and record the timing of the echo, which makes it possible to measure the distance as well as detect obstacles. The GND pins from the L293D motor driver IC were connected to the GND pin of the Arduino Uno. Pin Vss (pin16) of L293D is connected to +12V, which powers the motors, while pin Vs (pin 8) is connected to +5V for the IC logic. FOR pins IN1 (2) and IN2 (7) of L293D, they are connected to A0 and A1 on Arduino Uno for controlling the first DC motor, while pins IN3 (10), IN4 (15) are connected to A2 and A3 on Arduino Uno for controlling the second DC motor. The first and second DC motors are connected to OUT1, OUT2 and OUT3, and OUT4 pins, respectively. This configuration permits bidirectional control of the motor, allowing it to be powered forward or backward on command from the Arduino. The hardware connections of the Remote Node have the following elements, as shown in Figure 4. In the specific arrangement of the project, the ground pin of the NodeMCU (ESP8266) is attached to the GND pin of Arduino Uno, resulting in a common ground connection for both microcontrollers. NodeMCU's Vcc pin is connected to the 3.3V pin of Arduino Uno, which powers the ESP module. The D3 pin of the NodeMCU is connected to the RX pin 0 of the Arduino Uno, while the D2 pin of the NodeMCU is connected to the TX pin 1 of the Arduino Uno. In turn, these allow the Arduino UNO and NodeMCU to communicate over UART, allowing NodeMCU to transmit and receive data using Wi-Fi. The ground pin of the LoRa RF module is connected to the GND pin of the Arduino Uno, while the Vcc pin of the LoRa module is connected to the 5V pin of the Arduino Uno for powering the module. The MISO, MOSI, and SCLK pins of the LoRa module are connected to digital pins 12, 11, and 13 of the Arduino Uno, respectively, for SPI communication. The 10th digital pin is connected to NSS, while DIO0 and RST pins are connected to 9 and 8 digital pins, respectively. This enables the Arduino Uno and the LoRa module to exchange information and allows wireless data transmission over long distances. The Keypad's ground pin is attached to the GND pin of the Arduino Uno. The Button's pins are routed to 6, 5, 4, 3 no pins of the Arduino Uno. With such a configuration, the Arduino Uno is able to determine the key pressed and also capture the user inputs; therefore, the keypad can be utilized for any sensitive security purposes, for password input, or menu selection. The negative pin of the buzzer is linked to the GND pin of the Arduino Uno. The positive side of the buzzer is connected to digital pin 2 of the Arduino Uno. The connection is done so in order for the Arduino to control the buzzer, in cases when specific conditions are true, like in a situation where the password is incorrect, unauthorized access is attempted, or an alarm condition received through LoRa or Wi-Fi connection is activated.

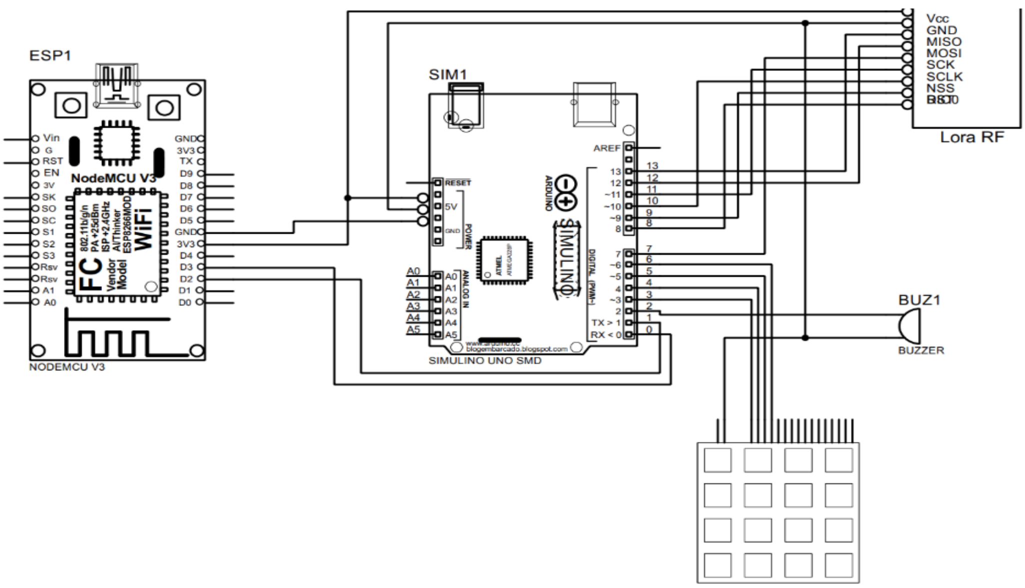

Figure 4. Connection diagram of central data capturing

4. RESULTS AND DISCUSSION

The technology behind the surveillance node focuses on combining the elements of sensing, navigation, and communication for effective and efficient use during disaster situations. All the factions of the Surveillance Node actively assist it in monitoring and navigating through hazardous terrains, making it capable of transmitting vital information in real time and aiding effective searches and rescue missions. A more comprehensive description of the methodology of working is provided below. As the main controller, the Arduino Uno coordinates the functioning of various components connected to it. Its key task is to receive input from the sensors and communication modules, and in turn, control the robots' movements and data transmission. The system is dependent on Arduino Uno to coordinate the hardware and software of the whole system. On the other hand, the LoRa RF Module is used to send and receive the signals to and from the Surveillance Node and the Remote Node for range communication. Directional commands are sent from the Remote Node to the LoRa Module, which in turn commands for navigation. The sensors are attached, then relay back the environmental data collected to the Remote Node. Since normal communication ways cannot work in disaster situations, this two-way communication is very useful and increases operational efficiency. The real-time footage of the robot's environment is the purpose behind the use of the ESP32 Camera Module. This stream of video gets transferred via Wi-Fi to be available to the rescue operators using the desktop computer at the control center through a specific IP address. Figure 5 depicts the prototype designed for the Surveillance Node. The operators, through the live video, are able to get acquainted with the environment, control the robot's movements remotely, and take actions concerning the situation based on the available information. For monitoring the environment, a combination of approaches using various sensors is employed. The DHT11 sensor, which gauges temperature alongside humidity, is useful in getting precise conditions within the disaster area. While the robot is in motion, the ultrasonic sensor aids in collateral damage by identifying any obstacles within the robot's trajectory. This allows the robot to maneuver through debris and tight spaces. It is at this node where the information gathered by the sensors is sent to the Remote Node for further evaluation and prompt decisions.

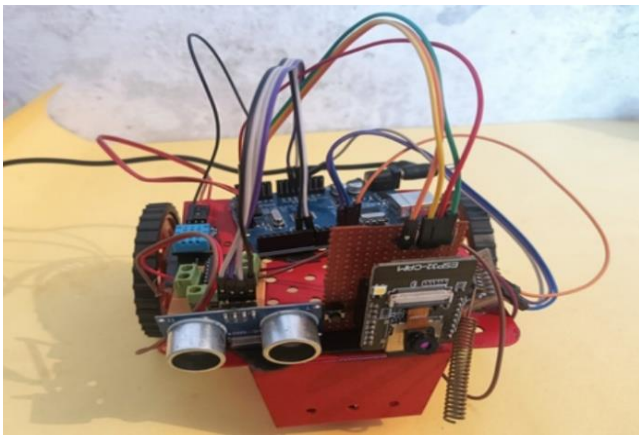

Figure 5. Hardware setup used in surveillance node

DC motors are also the ones that move the robot. The motors are rotated with the aid of an L293D Motor Driver Module, which is connected to the Arduino Uno. The motor driver takes control signals from the L293D and makes it possible for the robot to move. This makes it possible for the robot to receive signals from the Remote Node and move in the desired direction, such as forward, backward, turn, or stop. The combination of the motor driver and the DC motors provides reliable and responsive movement across different surfaces, and the robot is controlled using the remote control. All the parts are mounted on a sturdy chassis built strong enough to withstand the rough conditions that is encountered in disaster areas. To put it simply, the Surveillance Node serves as an all-purpose robotic unit that is able to traverse unfavorable conditions, while actively monitoring important parameters and providing first-person live footage. The design and method allow the Nightmare Nanny to be useful in the Japan disaster response missions as it reduces the risks to human responders and increases the speed and accuracy of search and rescue missions. In any disaster response mission, the Remote Node acts as a monitoring and control station for the Surveillance node's activities. It employs a sophisticated combination of multifunctional approaches that include user input, cloud monitoring, and wireless communications. This enables the operator to provide monitoring and receive feedback in real time. Each individual part in the remote node works to enhance the performance and accuracy of the system. The heart of the Remote Node is an Arduino Uno, which is an essential core controller. It receives information from the user sent by the armed troops and, through a thumb switch, enables the transmission of information to the surveillance node using the keypad and LoRa RF Module. This allows the operator to send control signals to the robot, and the Arduino Uno receives user input commands and converts them into control signals that instruct the robot what actions to perform. To control remotely the surveillance node, the RF module is crucial, as it facilitates the control signals like directions (forward, backward, left, or right) so the surveillance node can send back the environment readings and update status. As a part of the fire protection system, node communication serves to send control signals and receive feedback and is thus relevant for a timely response. In order to add additional features, the NodeMCU is incorporated into the Remote Node. The NodeMCU functions as a mediator between the Remote Node and the cloud. It collects data like environment parameters and the status from the LoRa RF Module and then sends them to the Blynk cloud server. Consequently, with cloud access, systems offer rescuers and policymakers the ability to receive essential data no matter where they are, which improves teamwork and response. Through the keypad, the operator can control the robot's movements in an easy and intuitive manner. As the buttons on the keypad are depressed, commands are sent to the Arduino Uno, which translates them into encrypted signals that are sent to the Surveillance Node through a LoRa RF Module. With this particular control, an operator can maneuver the robot in the disaster zones effectively, even under adverse conditions. The Buzzer allows the 2 operators to be alerted in an immediate manner. Figure 6 shows the Prototype built for the Remote Node. It could help an operator to be informed about whether the command was successfully relayed, if there were communication problems, or if there were important changes coming from the Surveillance Node. Thanks to this system, the operator does not need to check the system interfaces constantly and can forget about some measures and arrangements, thus increasing the reliability and ease of operations. Therefore, this Remote node encompasses all the elements of communication, control, and feedback systems for the proper administration of the Surveillance Node. Because of its long-range communication with LoRa, integration into cloud services using the NodeMCU, and ease-of-use with user operations, the operators are able to accurately and confidently control the robot and observe the disaster areas. Such an effective design ensures complete disaster supply and response management as well as the safety and efficacy of the rescue operations.

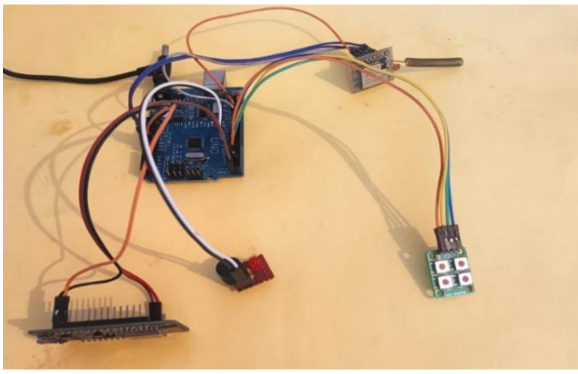

Figure 6. Hardware setup used in central data capturing node

In a comprehensive sense, the Blynk monitoring control dashboard and the live video streaming depict a vibrant monitoring contour. The sensor's details shown on the dashboard provide estimable details of the environment, the video footage allows operators to perceive the qualitative features of the environment. This type of layering functionality increases both productivity and safety because operators have access to real-time information and visual monitoring. This feature is very important for the project because it gives the opportunity to respond to disasters in a safer and effective manner. The Blynk Cloud Web Dashboard is the focal point where all essential environmental information that the robot collects is displayed. Using Label widgets, the readings of temperature and humidity from the DHT11 sensor are visualized in real time. Therefore, these widgets allow operators to visualize the environment in a more structured way so that they can mitigate risks in the disaster area, like fires, overheating temperatures, and areas with excessive humidity that may have water. Furthermore, the dashboard contains a Gauge widget to indicate the distance from the Ultrasonic Sensor. This widget enables users to witness a visual representation of the robot's skeleton, allowing users to actively avoid obstacles even when navigating through cluttered and small spaces.

Information on the dashboard is updated dynamically, which ensures that all information is up to date and actionable during critical moments. At the same time, the operators can monitor the environment surrounding the robot in real time using the live video feed from the ESP32 Camera Module. Available on a laptop via the camera's IP address, this video feed helps the operator understand the environment better. The users of the robot can examine the area for obstacles, survivors, or any hazards while having a visual aid along with the sensor data on the Blynk dashboard. The ability to provide real-time visual feedback improves situational understanding and aids users in navigating complex terrains.

The LoRa-enabled RC Robot has come out as beneficial for pilot tests conducted on disaster and search missions. The system entails sophisticated features such as monitoring the robot remotely at the work site through LoRa communication and simultaneously collecting information about the surrounding area. Adding to the speed of the operator's decision-making, the remote surveillance node can operate from within those uncontrollable areas and offer video feed from the physical node for real-time parameter data from the remote region. The importance of the LoRa technology is demonstrated as high-energy communication, with low bandwidth, spewed data is sent from poorly structured areas. The integrated camera with the Blynk server has an additional advantage of sending information about the drone's surroundings to everyone for prompt reaction. The system has been built in a modular way such that the RC robot is able to traverse the complex terrain while maintaining operational effectiveness. The test results of the system's deployment have shown practicality and reliability. Combining the Blynk Cloud Web Dashboard with live video streaming creates a simple yet powerful interface for monitoring and controlling the robot. It gives the operator direct access to quantitative data, such as the sensor readings, and qualitative insights, such as the video feed, on their control interface. The web dashboard displays the video and sensor data live, as seen in Figure 7.

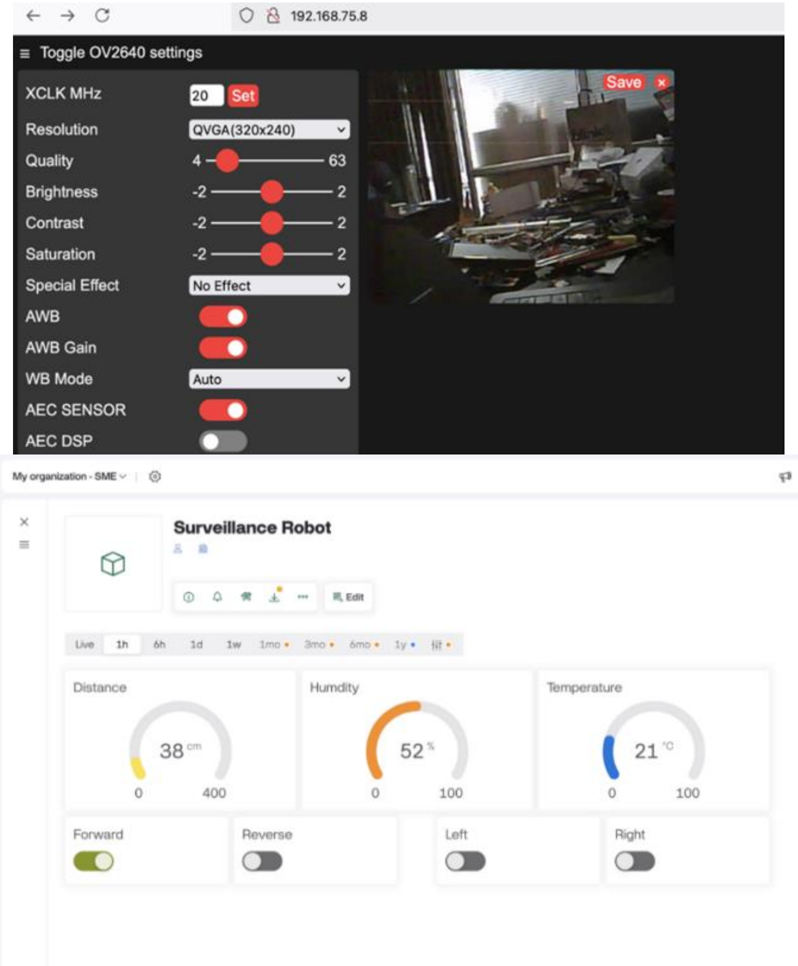

Figure 7. Live video visualization snap on web browser and live data visualization on Blynk IoT web dashboard

5. CONCLUSION

This pioneering change is an encouraging stride in the utilization of the IoT and robotics in bordering spheres like disaster recovery. The system has features of controlled movement, environmental sensing, and video streaming, which are the prerequisites for conducting search and rescue missions. These characteristics help reduce the risk faced by human responders and increase the speed and effectiveness of the operations undertaken so that the intervention can happen while there is still time. The system's modular and scalable architectural design enables it to be useful in a variety of cases, such as earthquakes, flooding, forest fires, industrial accidents, and even leaks of hazardous substances. The incorporation of LoRa technology and cloud management makes it possible to deploy the system in regions that have low or no coverage. The project presents a new frontier in robotics by combining it with IoT and long-range communication with the objective of improving disaster response mechanisms. This method can also be further enhanced and adapted for more effectiveness during a disaster. On a development note, it can be enormously helpful to fix thermal vision cameras to seek survivors in the hard-to-see or sight-barrier regions. The addition of these AI algorithms should truly assist in making the autonomous navigation functionalities and the rough terrain supervision free robots. Furthermore, its industrial defense and hazardous area application can be more multi-purpose with advanced sensors capable of identifying poisonous gases, radiation, or unstable structures. Solar panel-powered devices enhance the system's operational capability and increase its suitability for long-term stays in wilderness regions. This innovation, alongside the natural disaster's response aid, seems promising for others. It can serve a purpose in environment monitoring, security surveillance even in the military for scouting, making it a multipurpose gadget for many different uses. After research and development, this system can become a crucial safety tool for saving lives while boosting productivity.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest relevant to this study.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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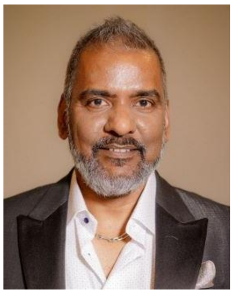

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