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Semi-Autonomous bore well Rescue Robot with ML-Based Human Detection and Audio Alert

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Abstract: Bore Well accidents are difficult to manage because of restricted access, poor visibility, and delays in locating trapped victims. This paper presents a semi-autonomous Bore Well rescue robot integrating live video monitoring, machine-learning-based human detection, audio alerts, environmental sensing, and wire-less control. An Arduino Uno manages control operations, while an ESP32-CAM transmits video to a laptop for MobileNetV2-based detection. ABMP180sensor and an LDR monitor pressure, temperature, and light conditions. Bluetooth control and a servo-operated arm support remote operation and small-item delivery. The prototype has not yet been experimentally tested.
Index Terms: Bore Well rescue, rescue robotics, human detection, MobileNetV2, ESP32-CAM, Arduino Uno, environmental monitoring, audio alert.

I.INTRODUCTION

Bore well accidents present a serious rescue challenge be-cause narrow and deep openings restrict direct access to a trapped person. Poor illumination, limited visibility, communication difficulties, and uncertainty about the victim's condition can complicate rescue planning. Conventional rescue methods may require excavation around the Bore Well, which can involve considerable time, equipment, labour, and site preparation. Robotic inspection provides a way to obtain information from locations that are difficult or dangerous for people to access. Previous research has investigated bore well rescue robots, camera-based inspection, robotic mechanisms, and methods of monitoring the condition of a trapped person [1]–[4]. These approaches motivate the development of compact systems that combine visual observation and remote operation. A camera can transmit images from inside a bore well, but identifying a person from continuous video requires the operator to examine the feed carefully. Machine-learning-based object detection can assist this process by identifying image regions that may contain a person. MobileNetV2 provides light weight convolutional neural network architecture intended to reduce computational requirements while retaining useful visual features [9]. This paper presents a semi-autonomous rescue-assistance robot combining embedded control, video transmission, human detection, audio notification, environmental sensing, and wireless operator commands. The Arduino Uno coordinates the control hardware, while the ESP32-CAM captures and transmits images to a laptop. The laptop performs human detection using a Mobile NetV2-based model and generates an audio alert when the configured detection condition is satisfied. The robot also includes a BMP180 pressure and temperature sensor, an LDR for light-level measurement, an HC-05 Bluetooth module, movement motors, and a servo-operated arm intended to deliver small supplies. Similar integrations of cameras, sensors, and wireless control have been explored in mobile robotic systems [5],[6]. The proposed system is intended to assist trained rescue personnel. It is not a certified life-support system, and the supply-delivery arm is not designed or validated to lift a person.

II. PROBLEM STATEMENT AND OBJECTIVES

A. Problem Statement

Conventional bore well rescue operations may be affected by restricted physical access, insufficient lighting, difficulties in locating the victim, and delays in obtaining information from inside the bore well. Manual video inspection can also place a continuous monitoring burden on rescue personnel. A compact robot that provides live video, automatic human-presence alerts, selected environmental measurements, and remote control could help operators observe conditions with-out immediately entering the hazardous area.

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However, the reliability of such a system depends on image quality, communication stability, sensor suitability, mechanical design, and testing.

B. Objectives

The main objectives of the proposed system are:

- To design a compact robotic platform suitable for controlled Bore Well inspection.
- To transmit live images from an ESP32-CAM to a remote laptop.
- To use a Mobile NetV2-based model to assist human-presence detection.
- To generate an audio notification when a configured detection condition is met.
- To monitor pressure, temperature, and relative light level using the selected sensors.
- To support operator commands through an Android application and Bluetooth.
- To investigate a servo-operated mechanism for delivering small essential supplies.

III. RELATED WORK

Research on Bore Well rescue robotics has explored mechanisms for entering narrow openings, monitoring trapped victims, and assisting rescue personnel. The work titled “Bore Well Child Fall Safeguarding Robot” describes a robotic approach involving camera monitoring and a mechanism intended to assist the rescue process [1]. Research on in-pipe robots has also examined the collection of information about a victim’s condition, environmental conditions, and harmful gases during Bore Well rescue operations [2]. The study “Child Rescue System from Open Bore Well using Robot” discusses a robotic system intended to address the limitations of conventional rescue procedures [3]. More re-cent research has investigated multifunctional Bore Well rescue robots that combine video monitoring, sensors, and robotic mechanisms [4]. These studies establish Bore Well rescue as an application in which compact hardware and remote observation can be useful. Wireless monitoring and computer vision are also relevant to the proposed design. An IoT-enabled rover integrating an ESP32-CAM, environmental sensing, and remote control demonstrates the relevance of combining image acquisition and sensor monitoring with in a mobile platform[5].An-other study investigates an IoT-enabled mobile robot for AI-powered object detection and remote monitoring[6].Research on smart-camera surveillance robots has similarly explored embedded controllers, wireless video, and remote observation [7]. AI-assisted Bore Well monitoring has also been investigated through systems combining camera modules and machine-learning techniques [8].These developments motivate the use of automated visual analysis alongside direct operator observation. For image classification and detection, MobileNetV2 pro-vides an efficient convolution architecture using inverted residual blocks and linear bottlenecks [9]. The COCO dataset provides labeled object categories, including the person category, for object-detection research [10]. The suitability of a particular model and dataset for dark, narrow Bore Well scenes must nevertheless be verified experimentally. The proposed work combines these research directions in a single design. Its distinguishing objective is the integration of laptop-side human detection and audio notification with embedded movement control, selected environmental sensing, and a small-item delivery mechanism. No comparative performance advantage is claimed because the prototype has not yet been tested.

Table I – Main Hardware Components

Component	Function
Arduino Uno	Coordinates sensors and actuators.
ESP32-CAM	Captures and transmits video.
BMP180	Measures pressure and temperature.
LDR	Provides a relative light-level measurement.
HC-05	Supports Bluetooth communication.
Motor driver	Interfaces with the movement motors.
DC motors	Provide robot movement. Servo motor and arm Supports small-item delivery.
Battery and regulators	Supply and regulate electrical power.
Laptop	Runs visual detection and audio-alert software.

IV. PROPOSED SYSTEM

The proposed system is organized into six functional units: image acquisition, wireless video transmission, machine-learning inference, audio notification, environmental sensing, and robot control. The ESP32-CAM captures images from the Bore Well and transmits video over Wi-Fi to a laptop. The laptop receives the video stream and processes frames using a MobileNetV2-basedmodel.Whenapersondetectionsatisfiestheconfigured confidence threshold, the software displays the detection and generates an audio alert. The Arduino Uno manages movement commands and interfaces with the selected sensors and actuators. An HC-05 Bluetooth module provides a communication path from an Android application to the controller. The motor driver operates the movement motors, while a servo motor controls the small-item delivery arm. The laptop and Arduino perform separate tasks. Laptop-side processing is used for visual inference, while the Arduino handles embedded control. This separation reduces the need to execute the full vision model on the microcontroller.

A. System Architecture

Fig. 1 illustrates the functional architecture of the proposed system. The camera-to-laptop path supports video monitoring and detection, while the sensor and actuator path supports robot operation.

B. Hardware Components

The principal hardware components and their intended functions are presented in Table I.

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The components must be selected according to the required Bore Well diameter, expected operating depth, available power, and mechanical load. The robot chassis must be sufficiently compact to pass through the intended opening. Cable routing, sensor mounting, motor protection, and retrieval arrangements should be considered during construction.

C. Sensor Arrangement

The BMP180 is used to measure atmospheric pressure and temperature, while the LDR provides a relative indication of incident light. These measurements can help describe selected conditions around the robot, but they do not provide a complete assessment of Bore Well safety. The BMP180 is not a toxic-gas sensor, and the LDR is not a substitute for a calibrated illumination instrument. Monitoring oxygen deficiency or hazardous gases requires suitable gas sensors and a validated measurement procedure. The sensor readings should be interpreted with these limitations in mind.

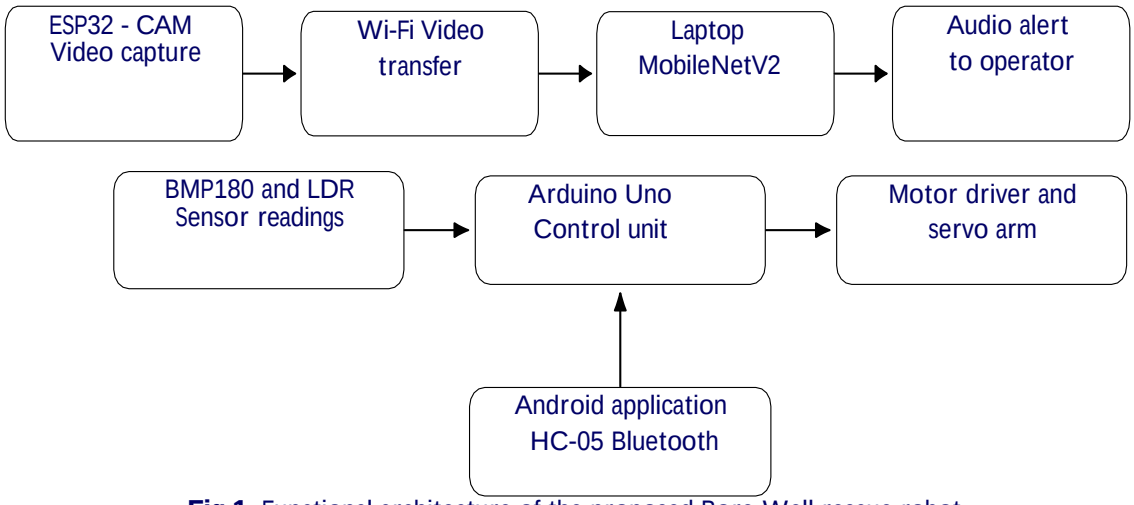


Fig.1. Functional architecture of the proposed Bore Well rescue robot.



Fig.2. Prototype photograph of the Bore Well rescue robot

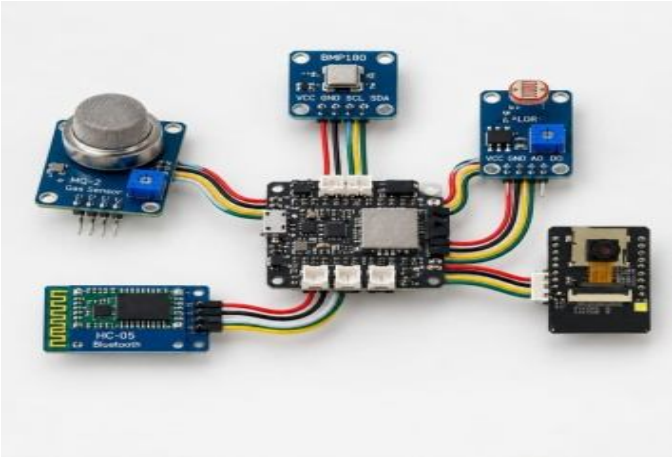


Fig.3. BMP180 pressure and temperature sensor and LDR module used in the proposed system

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D. Software Components

The Arduino IDE is used to develop the embedded controller program. Python is used for laptop-side video process-ing and model inference. OpenCV may be used to receive and process camera frames, while the MobileNetV2-based model performs person detection. A text-to-speech package, such as pyttsx3, can provide spoken alerts when configured in the application. The Android application serves as the operator interface for sending movement and arm-control commands. The Bluetooth communication program and Arduino firmware must use a consistent command format to avoid ambiguous or un supported operations.

V. MACHINE - LEARNING-BASED HUMAN DETECTION

The human-detection subsystem processes frames received from the ESP32-CAM. A MobileNetV2-based model is used to identify image regions that may contain a person. The architecture is relevant to resource-conscious vision applications because it uses inverted residual blocks and linear bottlenecks [9]. The proposed processing sequence consists of frame acquisition, image preprocessing, model inference, detection filtering, visual annotation, and audio notification. The model produces class predictions and associated confidence values. The software checks whether detection corresponds to the person category and satisfies a configured confidence thresh-old. For illustration, a threshold of 0.70 may be used during development. This value is a design example, not a measured optimum. The final implementation must state the actual threshold used and explain how it was selected.

A. Dataset and Detection Conditions

The COCO dataset includes a person category and is commonly used for object-detection research [10]. If a pretrained model associated with this data set is used, its class labels and preprocessing requirements must be checked against the implementation. The availability of a person category does not guarantee reliable detection in a Bore Well. Low illumination, image blur, partial occlusion, unusual camera angles, and small subject size may reduce detection reliability. The camera should therefore be evaluated under controlled conditions that resemble the intended environment. Any additional training or fine-tuning must be documented separately.

B. Audio Alert

The audio-alert subsystem is intended to draw the operator's attention to a potential human detection. When the configured detection condition is met, the software can announce a message such as "Human detected." Repeated alerts should be controlled to prevent continuous announcements when the same person remains visible across consecutive frames. The alert is intended to support operator awareness rather than make an independent rescue decision. The operator must examine the image and assess whether the detection is genuine. False positives, missed detections, and communication interruptions must be included in the system evaluation.

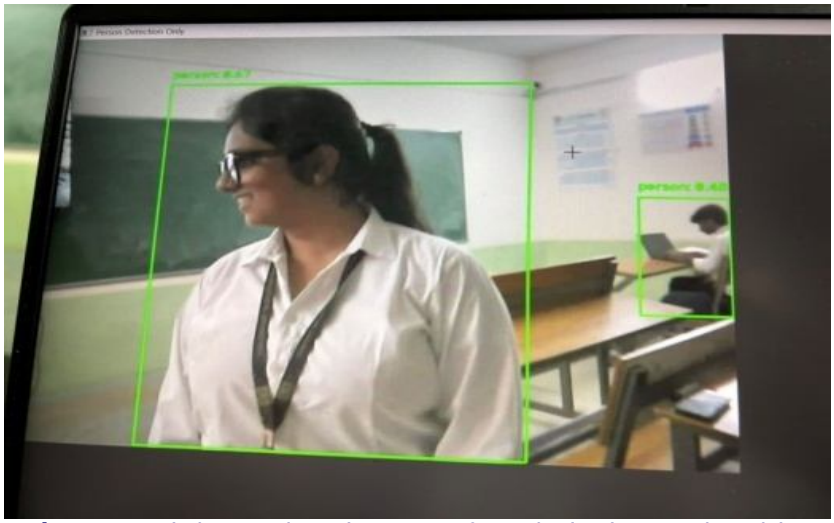


Fig.4. Example human-detection output from the implemented model



Fig.5. Android application interface for remote robot control

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VI. CONTROL, SENSING, AND SUPPLY DELIVERY

The Arduino Uno receives control commands through the HC-05Bluetoothmodule.TheAndroidapplicationsendssupported commands to move the robot or operate the servo arm. The Arduino interprets these commands and communicates with the motor driver and servo mechanism. A safe control implementation should define valid commands, reject unsupported input, and stop movement when a communication fault is detected, where the hardware permits. Movement should be checked at low speed in a controlled test environment before the robot is lowered into a Bore Well. The BMP180 readings and LDR values can be recorded during inspection to provide additional context. However, these measurements must not be treated as proof that the Bore Well atmosphere is safe. If hazardous gases or oxygen deficiency area concern, suitable dedicated sensors and established safety procedures are required. The servo-operated arm is intended to deliver small supplies such as lightweight items. Its payload, movement range, and positioning accuracy depend on the mechanical design and servo characteristics. It must not be represented as a human-lifting mechanism without separate engineering design, validation, and appropriate safety provisions.

VII. PROPOSED ALGORITHMS

Two main algorithms describe the operation of the visual detection subsystem and the embedded control subsystem. They represent the intended software logic and do not imply that the complete prototype has been experimentally validated.

Algorithm 1 Human Detection and Audio Alert
Require: Video stream, trained detection model, threshold τ
Ensure: Annotated video and operator notification
1: Initialize camera stream and detection model
2: **while** video stream is available **do**
3: Acquire current video frame
4: **if** frame is invalid **then**
5: Skip frame and continue
6: **end if**
7: Preprocess frame according to model requirements
8: Run model inference on the frame
9: Extract person detections and confidence scores
10: **if** any person score is greater than or equal to τ **then**
11: Annotate the detected person in the frame
12: Display detection to the operator
13: **if** alert is not already active for this detection **then**
14: Generate audio notification
15: **end if**
16: **else**
17: Display the frame without a person alert
18: **end if**
19: **end while**
20: Release video resources

A. Algorithm 1: Human Detection and Audio Alert
B. Algorithm 2: Sensor Reading and Operator Control

VIII. DESIGN METHODOLOGY AND WORKING PRINCIPLE

The development process is divided into hardware assembly, sensor integration, camera configuration, model deployment, control integration, and planned evaluation. First, the chassis and movement mechanism are assembled to fit the intended Bore Well opening. The camera, sensors, motor driver, and servo arm are mounted and connected to the relevant controller interfaces. Electrical power and grounding requirements must be checked before operation. Next, the ESP32-CAM is configured to transmit images to the laptop over Wi-Fi. The laptop application receives the frames and passes them to the human-detection model. The model output is filtered using the configured confidence threshold, and the audio-alert function is triggered when the required condition is met. The Arduino firmware reads the available sensor values and processes operator commands received through Bluetooth. The operator can inspect the video and control movement or the supply-delivery arm through the Android application. The robot is then intended to be lowered and retrieved using a suitable external arrangement under controlled conditions. The system is semi-autonomous because visual detection and notification are automated, while movement and operational decisions remain under human supervision. Automatic person detection alone does not constitute autonomous rescue.

Algorithm 2 Sensor Reading and Operator Control
Require: Bluetooth commands, BMP180, LDR, motor driver, servo
Ensure: Updated sensor values and control actions
1: Initialize sensors, motors, servo, and Bluetooth interface
2: **while** controller is powered **do**
3: Read pressure and temperature from BMP180
4: Read the LDR measurement
5: Update the available sensor readings

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6: **if** a Bluetooth command is received **then**
7: **if** command is a supported movement command then
8: Apply the corresponding motor control
9: **elseif** command requests a stop **then**
10: Stop movement motors
11: **elseif** command requests arm operation **then**
12: Move servo to the configured position
13: **else**
14: Ignore unsupported command
15: **endif**
16: **endif**
17: **if** communication fault is detected **then**
18: Stop movement where supported
19: Wait for safe recovery or operator intervention
20: **endif**
21: **end while**

IX.EXPERIMENTAL EVALUATION PLAN

The prototype status for this paper is *not tested*. The supplied project information does not establish completed experimental measurements. Therefore, no numerical detection accuracy, response latency, communication range, successful rescue rate, or field performance is claimed.

A. Human-Detection Performance

A labelled test set should be prepared using representative video frames. The test set should include different lighting conditions, viewing distances, and partial occlusion where these can be reproduced safely. The evaluation should report the number of frames, precision, recall, F1-score, and the procedure used to label the data. Precision and recall can be expressed as where *TP* represents true-positive detections, *FP* rep-resents false-positive detections, and *FN* represents false-negative detections. These measures should be calculated only after the model has been evaluated on labelled data.

$$\text{Precision} = \frac{TP}{TP+FP} \quad (1)$$

$$\text{Recall} = \frac{TP}{TP+FN} \quad (2)$$

B. Latency and Audio Response

The time required to receive a frame, perform inference, and generate an alert should be measured. Testing should record the number of trials and report representative and average processing delays. Any computer specifications, frame dimensions, and model settings affecting the measurements should also be documented.

C. Communication and Mechanical Tests

Wi-Fi video continuity, frame rate, transmission delay, Blue-tooth command reliability, and operating distance should be examined under stated conditions. Sensor readings should be compared with suitable reference instruments. Motor movement, servo positioning, payload capacity, battery endurance, chassis stability, and retrieval safety should be evaluated separately. A human must never be used as a test payload. Testing should begin with safe dummy loads and controlled laboratory conditions. Field deployment should only be considered after the mechanical, electrical, communication, and operational risks have been assessed.

X. ADVANTAGES AND LIMITATIONS

A. Advantages

The proposed design integrates live video, machine-learning-assisted human detection, audio notification, selected environmental measurements, wireless operator control, and a small-item delivery mechanism. Its modular architecture separates laptop-side vision processing from embedded motor control. This structure also allows individual components to be examined and improved independently. The use of commonly available development hardware may support prototyping and educational evaluation. Remote monitoring may provide rescue personnel with additional visual information before they determine the appropriate action.

B. Limitations

The system depends on camera visibility, detection-model performance, laptop processing, and available Wi-Fi and Blue-tooth connectivity. Poor lighting, image blur, occlusion, and wireless interruptions can affect operation. The selected sensors do not detect oxygen deficiency or toxic gases. The arm's payload capacity and mechanical safety remain unverified. Most importantly, the prototype has not been tested. Its detection performance, response time, communication reliability, and mechanical behavior must be measured before any claims of operational effectiveness can be made.

XI. APPLICATIONS

Potential applications include Bore Well inspection, rescue-team reconnaissance, confined-space observation, underground monitoring, and educational demonstrations involving embedded systems and machine learning. The camera and remote-control architecture may also be adapted for other restricted-access inspection tasks.

These are potential applications rather than validated deployments. Actual emergency use requires engineering validation, suitable environmental monitoring, safe lowering and retrieval arrangements, and coordination with trained rescue personnel.

XII. FUTUREWORK

Future development should focus on improving low-light imaging, reducing communication interruptions, and evaluating the detection model on representative Bore Well scenes. Model fine-tuning may be considered if a suitable labelled dataset becomes available. Detection thresholds should be selected using measured precision and recall rather than assumed values. Additional development may include dedicated gas sensors, improved illumination, more reliable wireless communication, battery monitoring, a stronger protective enclosure, and better servo-arm positioning. The mechanical design should also be assessed for stability, snagging, retrieval, and safe operation within the intended Bore Well dimensions. Controlled experiments should be conducted to establish detection performance, response latency, sensor accuracy, communication reliability, and mechanical safety. The system's suitability for emergency use should only be assessed after the relevant tests and risk evaluations are completed.

XIII.CONCLUSION

This paper presents the design of a semi-autonomous Bore Well rescue robot integrating embedded control, live video monitoring, Mobile NetV2-based human detection, audio alerts, environmental sensing, wireless operator control, and a servo-operated supply-delivery arm. The Arduino Uno coordinates the control hardware, while the ESP32-CAM provides images for laptop-side visual processing. The BMP180 and LDR provide selected environmental measurements. The system is intended to assist victim localization and remote observation during Bore Well incidents. Its architecture combines automated visual notification with operator-controlled movement and supply delivery. However, the prototype has not yet been tested, and its detection performance, communication reliability, response time, and mechanical safety remain unverified. Controlled evaluation is necessary before considering operational rescue use.

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Investigation: Madhurekha M
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Writing review and Editing: Ananya S , Charan Kumar J
Supervision: Madhurekha M
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