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BMO 2.0 Rescue Robotic platform for Victim Localization in Hostile Terrain

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***Abstract*—Natural disasters continue to pose significant threats to human life, often leaving victims trapped under collapsed structures where time-sensitive response is critical. Search and Rescue (SAR) robots have emerged as essential tools to support emergency teams by accessing hazardous or unreachable areas. This paper presents the design, construction, and functional validation of BMO 2.0, a ground-based mobile rescue robot designed to assist in victim localization and environmental monitoring in disaster scenarios. The robot features a modular 3D-printed chassis, optimized for low center of gravity and structural robustness. It integrates a hybrid sensory system, including a thermal camera (MLX90640), a vision module (ESP32-CAM), gas and environmental sensors (MQ-2, AHT21), a PIR motion sensor, and an inertial measurement unit (MPU-6050). The core of the system is managed by an Arduino Mega microcontroller and an ESP8266 module for Wi-Fi-based communication with a custom mobile application. The robot was tested in simulated post-disaster environments, demonstrating stable locomotion, real-time wireless data transmission, and accurate thermal and presence detection. The results confirm the viability of BMO 2.0 as a low-cost, adaptable solution for preliminary SAR operations, particularly in regions with limited access to commercial robotic systems.**

Keywords*—*3D printing, Arduino Mega, disaster monitoring, embedded systems, environmental sensors, ESP32-CAM, mobile robotics, remote vision, search and rescue, thermal imaging.

I. Introduction

The increasing incidence of natural disasters —ranging from earthquakes to hurricanes— has had a significant impact on human safety: in the past decade alone, between 14,389 and 314,503 people have died annually due to extreme events, while over 100 million individuals are affected each year [1]. In this context, search and rescue (SAR) robots have emerged as essential tools for operations in inaccessible or highly hazardous areas, minimizing the risks faced by human emergency teams [2].

The global rescue robot market shows rapid expansion: by 2025, its value is estimated between USD 30 and 35 billion, with a projected compound annual growth rate (CAGR) ranging from 14.8% to 19% through 2030 [3]–[6]. This trend is driven by increased government investment, advancements in sensing and connectivity technologies, as well as progress in the autonomy of SAR systems [2], [5].

Nevertheless, several key technical challenges remain maneuverability in collapsed terrain, efficient sensor integration, low energy consumption, and structural adaptability [2], [7]. In response to this scenario, the present work introduces the design, construction, and validation of the BMO 2.0 rescue robot—a low-profile ground prototype that integrates hybrid sensing (conventional vision, thermal imaging, and environmental monitoring) and is remotely controlled via Wi-Fi through a mobile application. Its modular architecture and real-time data transmission capabilities position it as a functional, adaptable, and low-cost solution for emergency response scenarios.

II. State of the Art

Over the past decade, research in rescue robotics has experienced significant growth, driven by the urgent need to develop effective technological solutions for natural disaster scenarios. Various approaches have been proposed in terms of sensing, control systems, locomotion, and data processing. This section provides a comparative review of the most relevant developments that support the design of the BMO 2.0 robot.

Athira et al. [8] developed a gesture-controlled robot using an Arduino Uno, equipped with PIR sensors for motion detection, an MQ-9 sensor for toxic gases, an ESP32-CAM module for video transmission, and wireless communication via nRF24L01. This modular architecture stands out for its versatility and low cost; however, its range and processing power remain limited.

Bhondve et al. [9] proposed a system based on the PIC16F877A microcontroller, incorporating LDR, PIR, MQ-7, and LM35 sensors, along with a camera for visual recognition. This approach enables the generation of real-time environmental graphs, which enhances decision-making during rescue operations. The use of the PIC microcontroller represents an interesting alternative to Arduino due to its industrial-grade robustness.

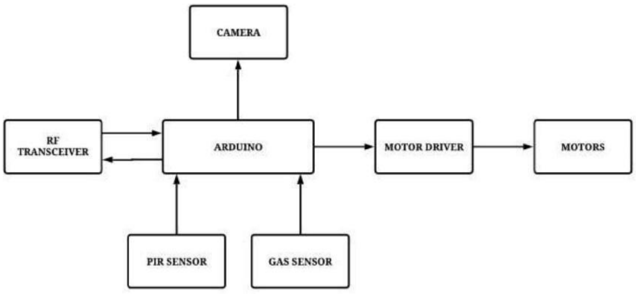

Fig. 1. Gesture-controlled robot using Arduino Uno. (*Habibian et al.*)

Cedillo et al. [10] introduced a robot controlled by a Pentium processor, featuring GPS, a compass, temperature sensors, and tracked loc11omotion capable of climbing slopes up to 60°. While the structure is advanced, its rigidity and weight may hinder performance in uneven terrain and rubble-filled environments.

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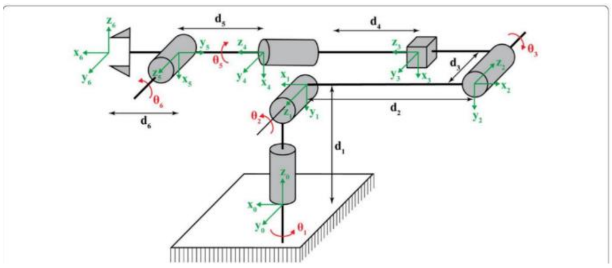

Fig. 2. KARO robot with 7 degrees of freedom. (*Habibian et al.*)

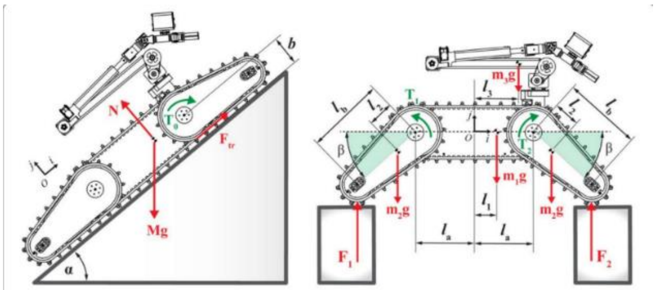

Fig. 3. Free body diagram of the KARO robot. (*Habibian et al.*)

García [12] proposed a hexapod robot using a Raspberry Pi and 18 servomotors, capable of overcoming obstacles through ROS and RGB cameras. Its insect-like design enhances mobility in collapsed terrains, although it involves greater mechanical complexity and higher energy consumption.

Rakesh et al. [13] implemented a robot featuring a Raspberry Pi, DHT11 and MQ-6 sensors, a microwave radar, a webcam, and six wheels. This approach stands out for its continuous life-detection capabilities and environment digitization, incorporating efficient mapping and navigation technologies.

Bing et al. [14] proposed a platform equipped with Beidou, a thermal camera, a 3D scanner, and gas sensors for compounds such as methanol and carbon monoxide. Its modular structure allows for precise navigation and can overcome obstacles up to 320 mm in height. However, it relies on a central station for data processing.

Fung et al. [15] developed a multimodal detection architecture based on TimCLR and MYOLOv4, capable of detecting individuals in densely populated environments through unsupervised deep learning and RGB-D data. While this technology is highly accurate, it demands significant computational power, exceeding the capabilities of a low-cost prototype.

In Mexico, the Universidad Tecnológica de la Mixteca [16] developed a robot with omnidirectional wheels and a suspension system on the front wheels, enhancing stability over uneven terrain. This model served as a structural reference for the BMO 2.0 design, although a rigid frame was ultimately chosen for ease of manufacturing.

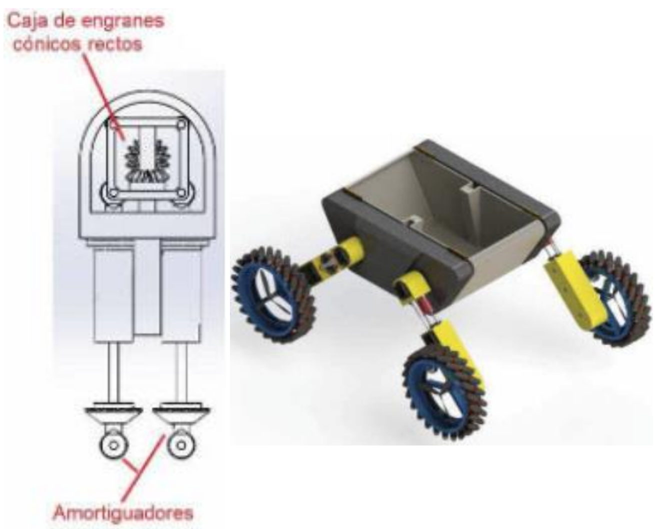

Fig. 4. Suspension System and Chassis (Universidad Tecnológica de la Mixteca)

Sánchez [17] proposed a mobile rescue platform equipped with tracked wheels, a robotic arm, a fire extinguisher, and a fire mitigation system. Its steel frame, along with temperature, gas, and video sensors, and its dual control via radio frequency and Wi-Fi, make it a functional and rapid-response solution for real-world scenarios

The technical review of robotic rescue platforms reveals a broad spectrum of solutions, ranging from basic designs using low-cost microcontrollers to advanced systems with autonomous capabilities, computer vision, and deep learning. Each proposal addresses specific environmental, budgetary, and operational requirements. In particular, highly sophisticated systems—such as KARO or those based on multimodal neural networks—demonstrate high levels of precision and adaptability; however, their complexity and cost limit their feasibility in contexts such as El Salvador.

Conversely, more accessible designs, though functionally limited, provide a solid foundation for the implementation of practical and scalable solutions.

BMO 2.0 positions itself as an intermediate proposal: functional, cost-effective, and specifically designed for local environments. It incorporates key elements from the reviewed studies—such as sensor integration, multi-terrain mobility, and real-time data transmission—while prioritizing operational simplicity, energy efficiency, and structural adaptability. This strategic synthesis enables the prototype to effectively meet immediate search and victim localization needs, without losing sight of future expansions such as advanced thermal vision, artificial intelligence, or robotic manipulators.

III. Methodology

The development of the BMO 2.0 robot was approached through an iterative methodology centered on user-oriented design. This process was structured into six stages: needs analysis, requirements specification, concept generation, final design, prototype construction, and functional validation.
Initially, the challenges associated with search operations in disaster scenarios were identified through interviews with key stakeholders, which enabled the definition of specific environmental needs. Based on this information, the system's technical requirements were established and prioritized using tools such as Quality Function Deployment (QFD) [18], [19]. During the conceptual phase, various mechanical and electronic configurations were explored. After a multi-criteria evaluation, a compact, modular, and low-profile design was selected—capable of integrating multiple sensors and operating in irregular terrain.

The prototype was constructed using a 3D-printed chassis made of PLA, reinforced with acrylic supports. It incorporated a range of sensors, including gas, temperature, humidity, presence, conventional vision, and thermal imaging. The traction system consisted of four wheels powered by DC motors [20]. The control system was based on an Arduino Mega microcontroller, complemented by an ESP8266 module for Wi-Fi communication with a mobile application developed using App Inventor.

Finally, the robot underwent functional testing in a simulated rescue environment, where its performance was evaluated in terms of locomotion, human detection, environmental data acquisition, and stability of data transmission [2].

IV. Construction of the BMO 2.0 UDB

A. Mecanical Design

The mechanical design of the prototype focused on structural stability, functional distribution of modules, and optimization of internal space. A chassis with a compact geometry and a low-profile design was developed, aiming to maintain a low center of gravity to enhance maneuverability in uneven environments typical of rescue scenarios.

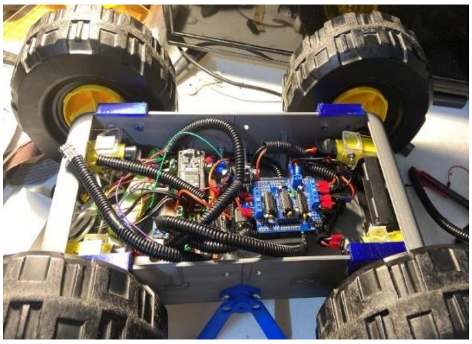

Fig. 5. Dise Mechanical Design of the BMO 2.0 Rescue Robotic Platform

The initial version (v1.0) featured a tracked traction system; however, functional testing revealed deficiencies related to structural resistance and traction capability. As a result, the locomotion system was redesigned, adopting an architecture based on four independent wheels. These were coupled to DC motors via custom bearings and couplings, ensuring efficient torque transmission.
The chassis was segmented into three functional modules:

Front module: Integration of vision and proximity sensors (ESP32-CAM and PIR HC-SR501).

Central module: Housing of processing units (Arduino Mega + ESP8266), inertial sensors, and auxiliary boards.

Rear module: Accommodation of the power system (Li-ion battery) and motors.

The structure was modeled using CAD software and 3D printed with PLA filament, divided into two sections to optimize printing and reinforce mechanical strength. Electronic components were mounted on acrylic shelves, manually cut and secured with screws, allowing proper ventilation and maintenance access. The top section features a removable cover that facilitates internal system handling.
Each sensor was individually evaluated through test routines designed to validate its operability, data transmission fidelity, and compatibility with the overall system architecture. Specific code modules were developed for the following devices:

- Gas sensor (MQ-2)
- Temperature and humidity sensor (AHT21)
- Inertial sensor (gyroscope/MPU6040)
- PIR presence sensor
- Thermal camera (MLX90640)
- ESP32-CAM camera
- Lighting system (front LEDs)

Each device underwent unit testing and serial communication verification with the microcontroller. Once validated, progressive integration was performed into a main program developed within the Arduino IDE environment, applying modular programming principles. Firmware stability and data synchronization among devices were prioritized.

The user interface was developed using App Inventor, enabling wireless control of key functions such as locomotion, lighting, real-time visualization, and data collection via a Wi-Fi network managed by the ESP8266 module.

Specific code modules were developed for the following devices:

- Gas sensor (MQ-2)
- Temperature and humidity sensor (AHT21)
- Inertial sensor (gyroscope/MPU6040)
- PIR presence sensor
- Thermographic camera (MLX90640)
- ESP32-CAM camera
- Lighting system (front LEDs)

B. Prototype Assembly

The assembly process was structured into sequential phases to ensure precise and functional integration:

a) Installation of mounts and motors::

- SAcrylic mounts for the motors were manually secured using screws.
- The motors were aligned and coupled to the wheels using 3D-printed couplings.
-

b) Assembly of the power supply system and thermal camera:

- The battery holder was installed at the rear of the chassis.
- The thermal camera was positioned at the lower central part, aligned with an opening that allows the lens to protrude

c) Integration of the control system and inertial sensing

- The microcontroller and auxiliary boards were mounted in the central area of the chassis.
- The gyroscopic sensor was fixed on a rigid base to ensure its stability and accuracy

d) Assembly of front sensors

- The ESP32-CAM camera and the PIR sensor were positioned in the front section, ensuring proper alignment to maximize the field of view and motion detection

e) Electrical and communication connections

- Wiring was carried out between the motors, sensors, and controllers, following an optimized bus architecture.
- The communication network was established between the Arduino Mega and ESP8266 modules, enabling interaction with the mobile application.

d) Installation of environmental sensors

- The gas and temperature/humidity sensors were placed at the top of the robot, oriented to capture representative environmental data.

Se incorporaron LEDs de alta intensidad en el frente del robot, configurados para ser activados remotamente desde la interfaz móvil, permitiendo operaciones en entornos con baja visibilidad.

To provide a clear and structured overview of the components that make up the rescue robot, Table 1 presents a detailed summary of the prototype's technical specifications, classified by subsystem. This table allows for the identification of critical functional modules, including the processing system, environmental sensing, computer vision, locomotion, wireless communication, and power supply.

TABLE 1. TECHNICAL SPECIFICATIONS OF THE PROTOTYPE

Subsystem	Component	Model / Type	Main Specifications
Chasis	Structure	Custom design, 3D printed	PLA, divided into 2 sections, low profile, compact design
	Internal supports	Manually cut acrylic	Supports for boards, motors, and sensors
Locomotion	Wheels	4 wheels	Coupled with bearings and 3D-printed joints
	DC Motors	6V geared motors	Torque suitable for movement over uneven terrain
Processing	Main microcontroller + WiFi communication module	Arduino Mega 2560	54 digital pins, 16 analog inputs
		ESP8266	Control remoto vía App Inventor
Vision and Detection	Main camera	ESP32-CAM	VGA/SVGA resolution, integrated WiFi
	Thermal camera	MLX90640	Matrix 32x24, range -40°C a 300°C
	Presence sensor	PIR HC-SR501	Passive infrared detection, range up to 7 m
Environmental Sensing	Gas sensor	MQ-2	Detects ammonia, alcohol, smoke, CO_2
	Temperature/humidity sensor	AHT21	Rane 0–50°C / 20–90% HR
Navigation	Sensor inercial (IMU)	MPU-6050	3-axis accelerometer + gyroscope

Illumination	Front LEDs	High-intensity white LED	Remote activation via app
Power Supply	Energy source	7.4V Li-ion battery	Rechargeable, mounted in rear battery holder
	Power distribution system	Direct connection + switch	Separate power supply for control and motors with voltage regulator
User Interface	Mobile application	App Inventor	Control of movement, sensors, and remote visualization

C. *Functional Block Diagrams*

a) System-level design.

Additionally, functional block diagrams were developed to represent the system's logical architecture. The primary diagram illustrates the relationships between the main modules and their data flow, while the subsystem schematics provide visualization of the integration and functional dependencies among specific components. This modular representation facilitates design analysis, signal traceability, and fault diagnosis during the prototype testing and validation phases.

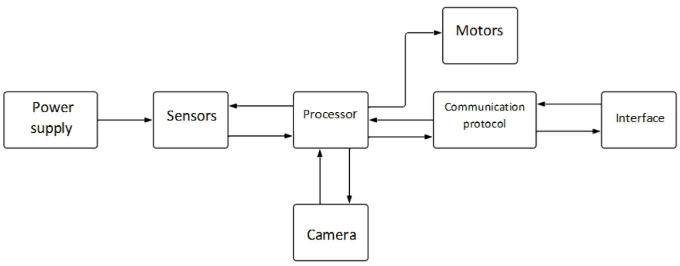

Fig. 6. Functional Block diagram for BMO 2.0.

b) Mechanical-Electrical Design

Development and integration of each subsystem were carried out with dimensional, functional, and structural precision. This approach aimed to ensure compatibility among the mechanical, electronic, and sensor components of the system, prioritizing a low profile and a modular internal space layout. The chosen material was selected for its favorable balance between mechanical strength and manufacturability.
The electronics were organized in a distributed architecture centered on the Arduino Mega 2560 as the main controller. Dedicated communication channels were established for each sensor module and actuator. The ESP8266 module handled wireless connectivity with the mobile application, operating in Access Point mode to facilitate field deployment without relying on existing network infrastructure.

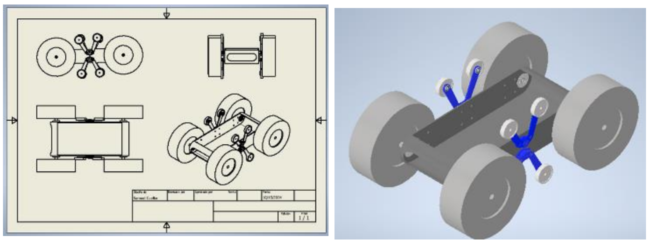

Fig. 7. BMO 2.0 3D Mechanical System Modeling

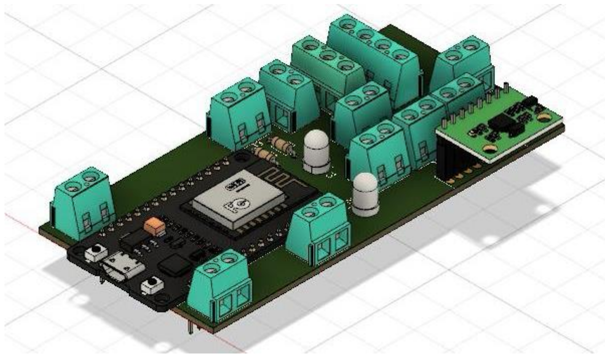

Fig. 8. 3D View of the BMO 2.0 PCB Board

V. RESULTS DISCUSSION

The BMO 2.0 prototype underwent functional testing in a simulated search and rescue environment designed to replicate structural collapse conditions. The results demonstrated that the system was capable of stable locomotion over uneven terrain, attributed to its low center of gravity and symmetrical mass distribution. The traction system, powered by DC motors, responded appropriately to forward, reverse, and turning commands; however, it was identified that the current motor inversion method for direction changes induces unnecessary mechanical stress, potentially compromising motor lifespan.

Regarding sensing, the environmental sensors (MQ-2, AHT21) provided stable readings of gases, temperature, and humidity. The PIR sensor HC-SR501 effectively detected movement within its field of view. The ESP32-CAM camera enabled real-time video transmission with acceptable latency, while the MLX90640 thermal camera successfully captured temperature gradients indicative of nearby human bodies.
Communication via the ESP8266 module remained stable within an operational radius of up to 20 meters in interference-free environments. The interface developed

with App Inventor allowed full system control, sensor data visualization, and image transmission.

Fig. 9. Testing with the BMO 2.0 Robot

VI. Conclusions

The development of BMO 2.0 has demonstrated the feasibility of building a functional, low-cost rescue robot tailored to the technical and economic conditions of Latin American environments. The prototype successfully integrated a set of critical sensors, vision system, wireless communication, and remote control, all assembled on a modular and lightweight structure.

The tests conducted validated its effectiveness as a support tool for search and rescue teams, particularly during the initial victim localization phase. However, key improvement opportunities were identified to enhance its operational performance, as outlined below:

Steering System: It is recommended to incorporate a mechanical servo for steering, replacing the current software-based direction inversion. This solution would reduce motor strain and improve maneuvering accuracy.

Motor Capability: The inclusion of higher-torque DC motors would resolve traction issues encountered during testing and enable scalability to more demanding mobility systems such as tracks or caterpillar treads. [22]

Field Maintenance: A modular and detachable motor configuration is proposed, allowing immediate replacement in critical situations without requiring specialized tools or interrupting operations.

Power Autonomy: To extend mission duration, the use of higher-capacity, energy-efficient batteries is suggested, ensuring compatibility with the updated motor power requirements.

Intelligent Sensing: Future developments aim to integrate computer vision and AI models to optimize autonomous victim detection through thermal, visual, and acoustic analysis. [23]

These enhancements will consolidate BMO as an adaptable, efficient platform capable of operating in real emergency scenarios, while also establishing a solid foundation for future locally developed research lines in rescue robotics.

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