CONESCAPANHONDURAS2025paper62.pdf

Institute of Electrical and Electronics Engineers (IEEE)

Document Details

Submission ID

trn:oid:::14348:477774941

Submission Date

Jul 31, 2025, 11:26 PM CST

Download Date

Aug 12, 2025, 2:41 PM CST

File Name

CONESCAPANHONDURAS2025paper62.pdf

File Size

2.1 MB

6 Pages

3,714 Words

21,360 Characters

9% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Match Groups

- **14** Not Cited or Quoted 6%
  Matches with neither in-text citation nor quotation marks
- **3** Missing Quotations 1%
  Matches that are still very similar to source material
- **4** Missing Citation 2%
  Matches that have quotation marks, but no in-text citation
- **0** Cited and Quoted 0%
  Matches with in-text citation present, but no quotation marks

Top Sources

8% Internet sources
7% Publications
0% Submitted works (Student Papers)

Integrity Flags

0 Integrity Flags for Review

No suspicious text manipulations found.

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.

Match Groups

14 Not Cited or Quoted 6%
Matches with neither in-text citation nor quotation marks

3 Missing Quotations 1%
Matches that are still very similar to source material

4 Missing Citation 2%
Matches that have quotation marks, but no in-text citation

0 Cited and Quoted 0%
Matches with in-text citation present, but no quotation marks

Top Sources

8% Internet sources
7% Publications
0% Submitted works (Student Papers)

Top Sources

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

1	Internet	ijai.iaescore.com	1%
2	Publication	Sachini Wickramasinghe, Allan Manalo, Omar Alajarmeh, Charles Dean Sorbello, ...	<1%
3	Publication	Frabosilio, Jakob. "Design and Implementation of An Inverted Short Baseline Aco...	<1%
4	Internet	portfolio-pplus.com	<1%
5	Internet	open.uct.ac.za	<1%
6	Internet	rua.ua.es	<1%
7	Internet	www.repositorio.ufop.br	<1%
8	Internet	ojs.observatoriolatinoamericano.com	<1%
9	Internet	pure.tue.nl	<1%
10	Publication	Yarong Gu, Tianhao Li, Li Zhao, Jiankun Ji, Yangzhong Zhao, Liantai Duan, Yanpei ...	<1%

11 Internet

repositorioacademico.upc.edu.pe <1%

12 Internet

epdf.pub <1%

13 Internet

www.mdpi.com <1%

14 Publication

Steven Cumming, Philip Branch. "A LoRa-Based Monitoring System for Agricultur... <1%

15 Internet

www.authorstream.com <1%

16 Publication

Hanqi Qian, Bo Jiang. "Silicone Resin Applications for Heat-Resistant Coatings: A ... <1%

17 Internet

www.carlisletechnology.com <1%

18 Publication

Franco, Tiago Sanches. "Clinical Decision Support System to Electrostimulation Tr... <1%

19 Publication

Van Thanh Pham, Quang Bon Le, Duc Anh Nguyen, Nhu Dinh Dang, Huu Tue Huy... <1%

Prototype of an Intelligent Firefighter Helmet with Improved Localization System and Toxic Gas Detection for Wildfire Scenarios

***Abstract*—This paper presents the redesign of an intelligent firefighter helmet prototype to improve safety during wildfire combat in Honduras. The original system monitors vital signs (heart rate and blood oxygen), environmental temperature, firefighter posture, and location, transmitting data through LoRa technology to an operation interface. The improved design integrates an upgraded GPS location system for fast calibration, toxic gas detection (specifically carbon monoxide), thermal / water-proof protection for electronic components, and a new operation interface to show the information collected in both quantitative and qualitative form to facilitate the understanding of the context in which the helmet user and his environment find themselves. The prototype demonstrated reliable performance in tracking the location of firefighters (with a GPS accuracy of ±2.5 m), detecting hazardous CO concentrations, and withstand temperatures up to 85°C. Thanks to this intelligent helmet, the occupational safety of Honduran firefighters who fight forest fires and the management of these kinds of emergencies will be improved, as the information gathered will provide an overview of the situation and will allow them to make informed strategic decisions.**

***Index Terms*—Smart Firefighter Helmet, Location System, Gas Detection, Wildfire, LoRa, Heat Resistance, Waterproof**

I. Introduction

Forest fires in Honduras pose a critical threat to ecosystems and human safety, with 3,060 fires recorded in 2023 (223,501 ha affected) and 2,541 in 2024 [1]. Firefighters face high risks due to extreme conditions (high temperatures, rugged terrain, toxic gases) and the absence of real-time health and location monitoring systems.

This work improves an existing smart helmet prototype [2] that initially included heart rate, oxygen saturation, tilt, and environmental temperature sensors, long-range (LoRa) communication, and GPS technology, addressing initial design flaws (slow GPS calibration, lack of heat / water resistance). In addition, a toxic gas sensor will be added, and the data interface will be improved to streamline decision-making in the control center. The goal is to improve occupational safety for firefighters and optimize emergency response through accurate data. The report outlines the design, the fabrication process, system limitations, and future research directions to tailor the technology to local needs.

15

II. Objectives

A. General Objective

Redesign an intelligent firefighter helmet with improved localization, toxic gas detection, and thermal/waterproof properties.

B. Specific Objectives

- Identify optimal long-range, low-cost localization technology integrable to the helmet
- Select appropriate toxic gas detection sensor for helmet integration
- Improve the operational interface for contextualized data presentation
- Develop a helmet adapted to wildfire combat conditions

III. State of the Art

An extensive literature review was conducted to examine previous developments in helmet-based technologies designed to aid firefighters. The study specifically focused on advances in location tracking systems, toxic gas detection and measurement, heat resistant and waterproof materials, and user interface design for real-time monitoring, all of which aimed to improve operational safety and effectiveness. The insights gathered from this analysis guided the design of an advanced smart helmet, which incorporates cutting-edge features to monitor vital signs and ensure real-time location tracking during wildfire response missions.

A. Prototype of an intelligent firefighter helmet for health monitoring and location in forest fire situations

"Fig. 1" shows the design of the smart firefighter helmet prototype developed to monitor vital signs and track the user in real time during wildfires [2]. Biometric and environmental sensors were integrated into a heat and moisture resistant structure. The main components used include an XIAO nRF52840 microcontroller, a MAX30100 heart rate and oxygen saturation sensor, a NEO-7M GPS module and an Ebyte E32-433T30D LoRa communication module. Custom 3D printed parts were designed, such as a clip for the ear pulse oximeter and an electronic housing box, using PLA filament. The system acquires the data, transmits them via LoRa, and displays them through the interface built in Visual Studio shown in "Fig. 2". The helmet delivers real-time information on heart rate, blood oxygen saturation, ambient temperature, posture, and location, enabling timely and safe responses in extreme conditions.

B. Proposal of an accident detection and location system for firefighters using LoRa technology

The prototype proposed in the paper uses LoRa technology for wireless data transmission, integrating sensors such as the DS18B20 for temperature measurement, the MPU6050

Fig. 1. Intelligent firefighter helmet assembled

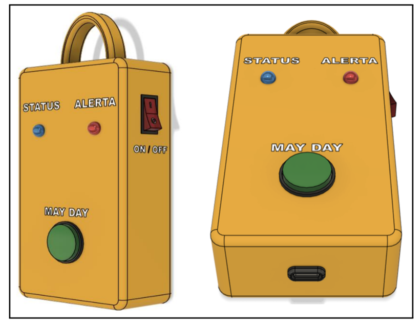

Fig. 3. 3D view of the proposed device

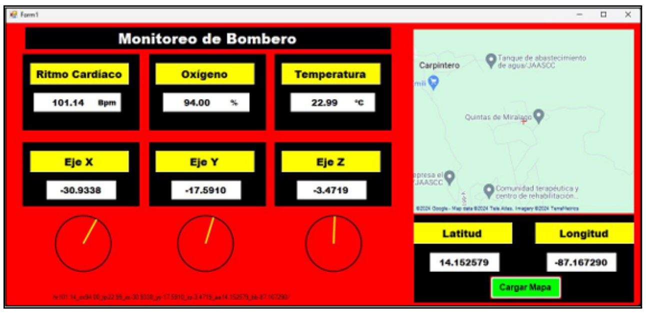

Fig. 2. Interface designed for monitoring vital signs and tracking the user in real time.

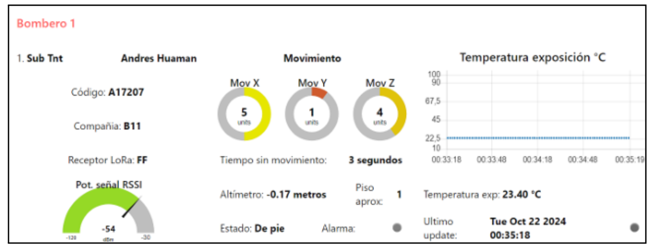

Fig. 4. Interface proposed for the accident detection system

(accelerometer and gyroscope) for the detection of falls and postures, and the BMP180 (barometer) for altitude measurement. These components are connected to a Raspberry Pi Pico microcontroller, which processes the data and transmits it through a LoRa SX1278 module. The system includes a lithium 18650 battery with a TP4056 charging module for energy autonomy, as well as a buzzer and LEDs for local alerts.“Fig. 3” presents the design of the proposed device. The monitoring interface is implemented on a Raspberry Pi 4B with Node-RED, allowing real-time visualization of firefighters’ personal information, movement, and environmental conditions (see “Fig. 4”). Additionally, the interface offers sections for alarms (in case of falls, high temperature exposure, no movement, or panic button activation), editing firefighters’ personal information, and a register of emergencies in progress). The ergonomic design of the device, manufactured via 3D printing, ensures seamless integration into the Personal Protective Equipment (PPE) of firefighters [3].

C. *Multi-sensor data fusion in a real-time support system for on-duty firefighters*

This work presents a system designed to support firefighters on duty by detecting falls, loss of physical performance, and elevated levels of CO [4]. The prototype integrates a microcontroller with five key sensors: a 3-axis accelerometer, gyroscope, and magnetometer (all contained in ADXL345), a barometer BMP180, and an MQ-7 gas sensor. Its architecture leverages data fusion techniques to analyze critical events in real time. Sensors capture acceleration, orientation, atmospheric pressure, and CO concentration. Information is processed using detection algorithms capable of identifying falls, prolonged inactivity, and exposure to toxic gases. A simple Kalman filter enhances accuracy by stabilizing barometric and gas sensor data. In critical situations, such as confirmed falls or hazardous CO levels, alerts are transmitted to the incident commander through an nRF24L01 wireless module, allowing for rapid intervention. The system was validated with real firefighters and achieved high detection accuracy (up to 97.96 percent) for key operational events.

IV. Methodology

A. *Approach*

The project will employ a mixed experimental methodology that combines quantitative and qualitative approaches to develop an enhanced firefighter helmet. This strategy will enable the collection of both numeric metrics (heart rate, body temperature, toxic gas levels) and descriptive metrics regarding the user’s physiological status and environmental conditions. This hybrid approach will facilitate multidimensional data acquisition, optimizing the accuracy of the real-time monitoring system and geolocation of personnel during emergency responses.

B. *Research Variables*

1) *Independent Variables:*

- Geo-location system: Compasses positioning technologies implemented, such as GPS, GNSS, ultra-wideband (UWB), etc.
- Gas detection technology: Includes electrochemical sensors, nondispersive infrared sensors, photoionization detectors, and metal-oxide-semiconductor sensors.

- User interface design: This refers to the way in which the information from the helmet modules will be presented to the user to provide a quantitative and qualitative description of the firefighter's vital signs, the situation of his environment, and his location in real time.
- Structural materials: Includes the materials used to house the electronic components of the helmet to protect and integrate them into its structure to form a unit.

2) Dependent Variables:

- Helmet thermal resistance: The term refers to the material's capacity to reduce or limit heat flux transfer through its structure.
- Helmet water resistance: Indicates the protective capability to prevent liquid penetration, moisture absorption, or material degradation when exposed to water/humidity.
- Power supply system: Provides stable energy to the circuitry, requiring precise voltage regulation and current delivery matching all components' operational specifications.
- Helmet design: Incorporates the geometric configuration of the transmission circuit housing, ensuring ergonomic integration with the base helmet structure while maintaining optimal antenna performance.
- Module/sensor dimensions: It is determined by the selected components, which should balance size and functionality.

C. Applied Techniques and Instruments

- SolidWorks: Used for the design of the 3D printed parts and thermal study.
- PrusaSlicer: Used to define the printing parameters of the parts, in order to print parts with the highest possible quality.
- Arduino IDE: Sensors and module programming.
- Visual Studio: Design and programming of the user interface to display the data obtained from sensors and modules.

D. Materials

- ESP32 DevKit V1
- Arduino UNO R3
- LoRa Ebyte E32-433T30D module
- NEO-M8N GPS module
- GPS antenna 1575 MHz 28 dB
- Heart rate and oxygen sensor MAX30100
- Gyroscope and accelerometer MPU6050
- Temperature sensor DS18B20
- Carbon monoxide sensor MQ-7
- 3D printed parts

E. Study Methodology

12 The prototype development began with a comprehensive review of the technical literature to identify innovative solutions in three critical areas: localization systems for harsh environments, accurate detection of toxic gas, and advanced materials for thermal and waterproof protection. Then, an iterative methodology was implemented to find the components that best met the requirements described in the specific objectives, among which were: long-range and low-cost localization technology, detection-capable toxic gas sensor, and module and sensors that are adapted to wildfire combat conditions (in other words, heat / water resistant) and helmet-integrable.

Initial unit testing in Arduino IDE validated the performance of each subsystem, ensuring reliable acquisition of physiological, environmental, and location data, and correct communication between LoRa transmitter and receiver modules. Next, the monitoring interface was programmed to get the data from the receiver module and present the information collected by the modules and sensors in the clearest, most concise, and orderly way possible to facilitate the user's understanding of it.

Subsequently, SolidWorks was used to design an ergonomic housing, with thermal resistance tested in thermal studies through simulations to guarantee that the circuit will be safe under extreme conditions (up to 85°C). Once the design was validated, the parts were manufactured using the 3D printing technique, as it offered one of the most versatile methods for manufacturing prototypes. Finally, the transmission and reception circuits were assembled in their cases. At this point, the final prototype tests were carried out to verify that the integration between the circuits and the operating interface had been successful.

V. Results and Analysis

A. Electronic Circuit

The changes made to the original design of the smart helmet (previously described in the State of the Art Subsection "A") started with the replacement of the XIAO nRF52840 with an ESP32 Devkit V1 for the transmitter circuit integrated into the helmet, as it had a limited number of I/O ports, so there was no way to add the gas sensor. ESP32 allowed the addition of more components and improved data processing. However, this decision produced the need to include an external inertial measurement unit and a temperature sensor because they were not found natively in the new microcontroller. During the component selection phase, key technologies were integrated: the MPU6050 module for position tracking (due to its adjustable sensitivity ranges [5]), the DS18B20 sensor for high temperature monitoring (for its waterproof probe and wide operating range up to 125 °C [6]), the NEO-M8N module for real-time location tracking (due to its multi-GNSS signal reception, precision, and energy efficiency [7]), and the MQ-7 CO sensor (for its detection range from 20 to 2000 ppm, low cost, high accuracy, and low power consumption [8]). From the original prototype, only the Ebyte E32-433T30D LoRa module [9] and the MAX30100 heart rate and oxygen saturation sensor [10] were retained due to their positive performance.

Various toxic gases are produced during combustion, including carbon monoxide (CO), carbon dioxide (CO2), sulfur dioxide (SO2), volatile organic compounds (VOC) and hydrogen cyanide (HCN) [11]. Among them, CO is particularly dangerous due to its colorless, odorless, and tasteless nature, earning it the label "silent killer". The health impact of CO exposure depends on its concentration, ventilation conditions, and duration of exposure. Symptoms range from headache, dizziness, and fatigue at 35 to 400 ppm, to nausea, respiratory failure, and death at concentrations between 3,200 and 12,800 ppm [4]. According to the US OSHA Code of Federal Regulations, the maximum safe level of CO on the job is 35 ppm [12]. However, the toxic gas detection system on the smart helmet is designed to alert firefighters to a lower threshold of 30 ppm before alerting the firefighter to use respiratory protection.

Moreover, pull-up resistors were added to the components that, according to their datasheets, required them to ensure a well-defined logic state on their signal lines when the ESP32 is not driving their buses and to prevent them from floating and picking up noise. "Fig. 5", "Fig. 6" and "Fig. 7" present the transmitter circuit diagram. The components of the original receiver circuit (the Arduino UNO R3 and the LoRa module) were maintained, and pull-up resistors were added to the communication lines and a voltage divider to adapt the communication logic level of the Arduino to that of the LoRa module. "Fig. 8" provides the receiver circuit diagram.

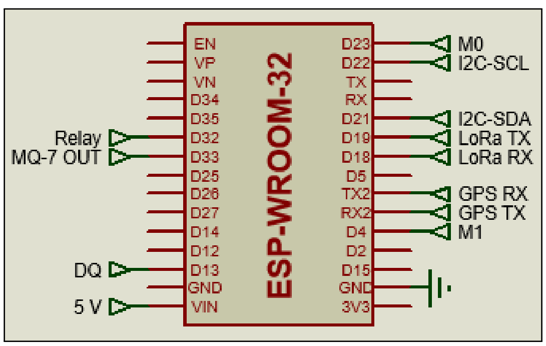

Fig. 5. Transmitter circuit microcontroller wiring diagram

B. Design of the Prototype

The SolidWorks design tool was used to create custom cases to protect the transmitter and receiver circuits of the smart firefighter helmet. A special case was designed for the transmitter circuit (see "Fig. 9"), where the modules and sensors were strategically distributed according to the nature of their functions (antennas and environmental sensors), and a clip for the pulse oximeter that the firefighter will wear. The latter will allow a firm and comfortable hold on the helmet wearer's earlobe to ensure a continuous and correct measurement of his heart rate and oxygen saturation. "Fig. 10" shows the isometric view of the clip designed for the ear pulse oximeter to be used by the firefighter.

The model prioritized functionality, ergonomics, and protection of components against adverse conditions of heat and humidity. To achieve this last objective, it was decided to use acrylonitrile butadiene butadiene styrene (ABS) as the material for the printed parts. ABS is a thermoplastic that stands out for its good impact resistance, structural rigidity, and durability

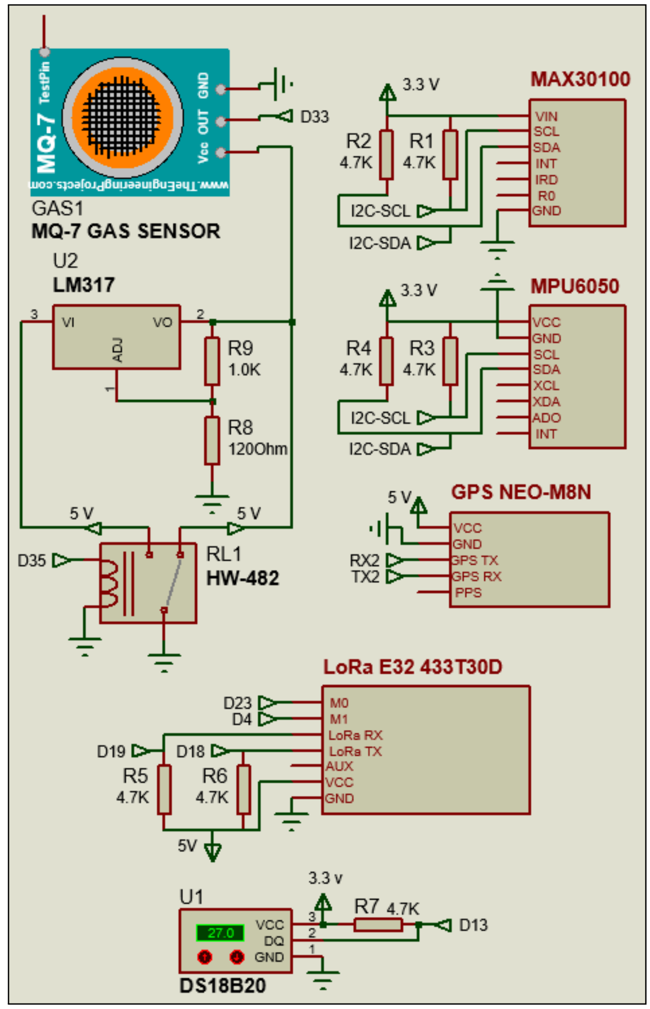

Fig. 6. Transmitter circuit component wiring diagram

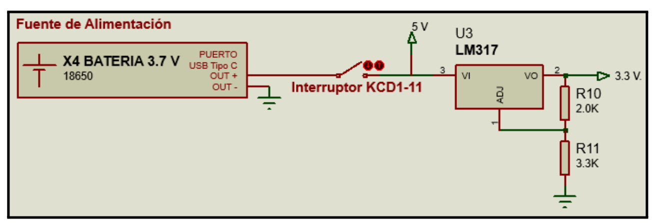

Fig. 7. Transmitter circuit power supply wiring diagram

against moderate chemical agents. In terms of thermal resistance, ABS withstands high temperatures compared to other general-purpose plastics, with a glass transition temperature (Tg) close to 105°C and a heat deflection temperature (HDT) that can vary between 85°C and 105°C under load [13]. Regarding its behavior in relation to humidity, ABS shows low water absorption (about 0.2 % of its weight in water in 24 hours at 23°C), which allows it to maintain its mechanical and dimensional characteristics in humid environments [14]. In addition, a silicone rubber insulating tube was used to protect the connections between the power supply and the

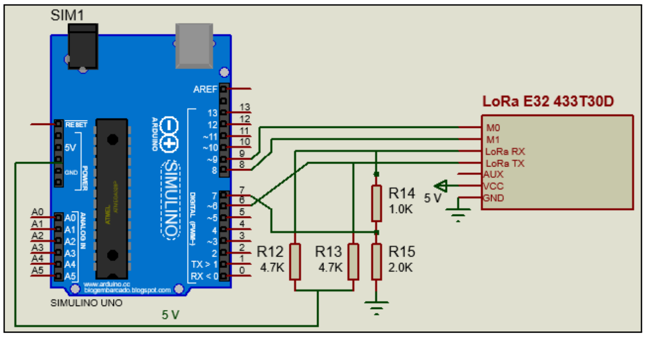

Fig. 8. Receiver circuit diagram

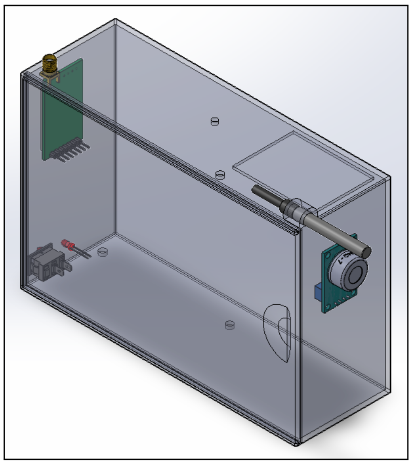

Fig. 9. Isometric view of the transmitter circuit housing

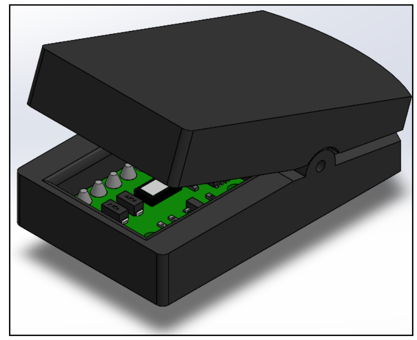

Fig. 10. Isometric view of the ear pulse oximeter designed in SolidWorks

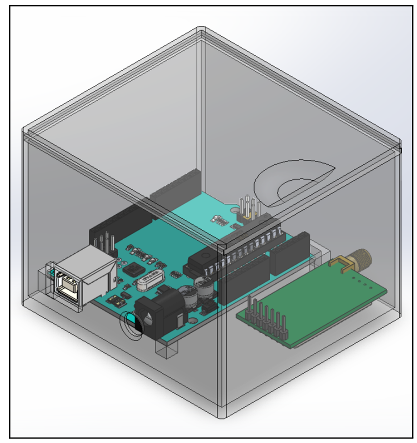

Fig. 11. Isometric view of the receiver circuit housing

transmitter circuit and the transmitter with the pulse sensor, which withstands temperatures from -50°C to 125°C, is flame retardant and waterproof [15]. In this way, the entire emitter circuit was protected against heat and humidity.

A cover was also designed to securely contain the receiver circuit. This includes orifices for the USB type B port and the female Arduino barrel power connector for connection to the device that will run the helmet operating interface program and power the circuit, an orifice through which the LoRa module antenna will be exposed to receive the signal from the transmitter module, and a sliding cover for easy access to the circuit, as seen in "Fig. 11". The receiver is intended for use indoors or in any place with standard environmental conditions, so this housing did not require any special degree of protection against heat and humidity, and so it was made of PLA filament.

C. Final Test

Once the circuit was found to function properly, it was mounted in the designed case. The transmitter circuit was soldered to a soldering board to ensure a firm hold of its components at all times. Screw terminals were included for easy installation, in case any components needed to be examined or replaced. The transmitter circuit was powered by a 5 V power bank connected to a boat-type switch, and this in turn to the soldering board, while the receiver circuit was powered by a USB type B cable connected from the Arduino to the computer where the operating interface will be displayed."Fig. 12" shows the final prototype of the intelligent firefighter helmet. "Fig. 13" shows the design of the operating interface where all the data collected by the sensors and modules will be displayed. This was divided into 4 sections, in which vital signs (heart rate and oxygenation), posture, environmental conditions (temperature and CO concentration) and location (latitude and longitude) will be presented.

VI. Conclusions

The original prototype of the smart firefighter helmet has been redesigned to enhance its functionality in three key areas: first, by improving the location system with a high performance GPS module and antenna capable of quickly acquiring satellite signals; second, by integrating a carbon monoxide (CO) detection system to alert firefighters to hazardous gas levels and prompt timely protective actions; and third, by increasing the resistance of the device to heat and humidity using an ABS enclosure and insulating tubes to protect electronic components and wiring. This project aims to improve the occupational safety of Honduran firefighters during the response to wildfires and to support emergency management by providing real-time data for informed decision making.

Fig. 12. Isometric view of the improved intelligent firefighter helmet prototype

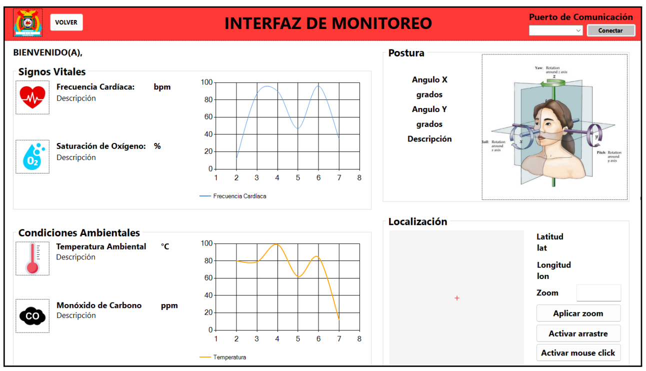

Fig. 13. Design of the operating interface

VII. Recommendations and Future Work

- Toxic Gas Detection System: Evaluate other types of CO sensors that are not susceptible to moisture and are capable of measuring continuously rather than in cycles. The current MQ-7 sensor is vulnerable to splashing or immersion in water and operates on 90-second sensing and 60-second purge cycles, making it an unsuitable sensor for this application.
- Heat and waterproofing enhancement: Apply a protective coating on the outer surfaces of the firefighter's helmet parts to improve their resistance to UV radiation, as ABS is not a naturally solar radiation resistant material and will be exposed to the sky all the time. Adding gaskets to the circular orifices in the emitter circuit box can improve the seal against moisture and dust. Since the orifices do not follow standard sizes, the gaskets could be manufactured by 3D printing with high-temperature TPU (HT-TPU), which is a modified version of traditional TPU that withstands up to 150
- Additional features: Consider integrating more features such as an audible alarm (to inform the firefighter about dangerous conditions of pulse, oxygenation, temperature or CO), a SOS button (so the firefighter can press when assistance is required in case of danger), a voice communication system (so the firefighter can communicate with his colleagues and the command center to coordinate his work request assistance), or even a video system (to transmit real-time images to the command center of the operation in progress carried out by the firefighters).
- Firefighter operations network: Consider scaling the smart firefighter helmet to an interconnected system in which multiple firefighters are monitored, can communicate with each other and the command center, and receive physiological, environmental, and location readings from their peers. This could be a future evolution for the project that could be developed in phases.

References

[1] Madrigal, J.D. (2024) Estado de País Cambio Climático - 2024, Estado de País. Available at: https://estadodepais.asjhonduras.com/wp-content/uploads/2024/CAMBIOCLIMATICO/Boletines%20y%20PPT/Estado%20de%20Pa%C3%ADs%20Cambio%20Clim%C3%A1tico%20-%202024.pdf

[2] Romero, A., Flores, R., & Nunez, F. (2024). Prototype of an Intelligent Firefighter Helmet for Health Monitoring and Location in Forest Fire Situations.

[3] L. G. K. Jose, "Propuesta de un sistema de detección de accidentes y localización para bomberos usando tecnología LoRa" Nov. 15, 2024. http://hdl.handle.net/10757/683889

[4] V. Pham, Q. Le, D. Nguyen, N. Dang, H. Huynh, and D. Tran, "Multi-Sensor data fusion in a Real-Time support system for On-Duty firefighters," Sensors, vol. 19, no. 21, p. 4746, Nov. 2019, doi: 10.3390/s19214746.

[5] InvenSense, MPU-6000 and MPU-6050 Product Specification, Revision 3.4, Aug. 2013. [Online]. Available: https://invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf

[6] Maxim Integrated, DS18B20: Programmable Resolution 1-Wire Digital Thermometer, Datasheet, Rev. 6, May 2015. [Online]. Available: https://datasheets.maximintegrated.com/en/ds/DS18B20.pdf

[7] u-blox AG, NEO-M8N Data Sheet: u-blox M8 concurrent GNSS modules, Document UBX-15031506 - R05, Sep. 2020. [Online]. Available: https://content.u-blox.com/sites/default/files/NEO-M8_DataSheet_%28UBX-15031506%29.pdf

[8] Hanwei Electronics, MQ-7 Gas Sensor Datasheet, [Online]. Available: https://www.sparkfun.com/datasheets/Sensors/Biometric/MQ-7.pdf

[9] Ebyte, E32-433T30D Wireless Module Datasheet, Version 1.6, [Online]. Available: https://www.ebyte.com/en/downpdf.aspx?id=1016

[10] Maxim Integrated, "MAX30100: Pulse Oximeter and Heart-Rate Sensor IC for Wearable Health", Datasheet, 2014. [Online]. Available: https://datasheets.maximintegrated.com/en/ds/MAX30100.pdf

[11] K. Piechnik, L. Heydick, A. Hofmann, and A. Klippel, "Comprehensive laboratory study on smoke gases during the thermal oxidative decomposition of forest and vegetation fuels," Fire and Materials, Nov. 2024, doi: 10.1002/fam.3253.

[12] Occupational Safety and Health Administration (OSHA), Dangers of Carbon Monoxide (CO) and Inhalation Hazards, SH-27666-SH5, 2015. [Online]. Available: https://www.osha.gov/sites/default/files/2018-12/fy15_sh-27666-sh5_OutlineforCOInhalationHazards.pdf

[13] Wevolver, "Understanding ABS Heat Resistance: A Comprehensive Guide," 2023. [Online]. Available: https://www.wevolver.com/article/understanding-abs-heat-resistance-a-comprehensive-guide

[14] M. Głowacki, A. Mazurkiewicz, M. Słomion, and K. Skórczewska, "Resistance of 3D-Printed Components, Test Specimens and Products to Work under Environmental Conditions—Review," Materials, vol. 15, no. 17, p. 6162, Sep. 2022, doi: 10.3390/ma15176162.

[15] N. H. Qian and N. B. Jiang, "Silicone resin Applications for Heat-Resistant Coatings: A review," Polymer Science Series C, vol. 65, no. 2, pp. 206–219, Dec. 2023, doi: 10.1134/s1811238223700443.