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LoRa-Connect: A Unified System for Flood Search and Rescue Operations

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ABSTRACT

This study developed and evaluated LoRa-Connect, a unified communication system designed to support flood search and rescue operations in Barangay Bulac, Minalin, Pampanga. The study responded to recurring flood risks caused by typhoons and heavy rainfall, particularly in areas where cellular signal and Internet connectivity may become unreliable during emergencies. Using applied, descriptive, and quantitative approaches, the system integrated EchoBand wearable devices for civilians and rescuers, a Raspberry Pi-based central node, a web application for command monitoring, and an Android mobile application for rescuer task coordination. Purposive sampling involved seven residents using EchoBands, eight rescuers and barangay personnel, and four technical experts in computer and electronics engineering. Data were gathered through system testing and a user acceptance survey and were analyzed using weighted means and descriptive interpretation. Results showed positive user acceptance, with civilian ratings for the EchoBand in ease of use, reliability, and effectiveness at 3.325, 3.425, and 3.250, respectively. Rescuers also rated the device, web application, and mobile application within the Agree category, while technical experts rated system architecture, compliance and security, performance and reliability, integration and maintenance, and overall system evaluation from 3.50 to 3.67, interpreted as Strongly Agree. The system met its intended functions by enabling SOS reporting, location tracking, task allocation, and offline mapping support, with reported localization accuracy of 30 to 40 meters and practical battery performance. The findings indicate that LoRa-Connect can strengthen barangay-level flood rescue coordination, although further enhancement in accessibility, emergency alerts, user training, and community-level deployment readiness is recommended.

Keywords: *LoRa communication, disaster response system, flood search and rescue, Internet of Things, embedded system, wireless sensor networks*

INTRODUCTION

The Philippines is highly exposed to tropical cyclones and flood hazards because of its geographic location and climatic conditions. PAGASA (2024) reported that an average of about 20 tropical cyclones enter or develop within the Philippine Area of Responsibility each year, and about eight or nine of these cross the country. In Central Luzon, Pampanga remains vulnerable to flooding because of river systems, low-lying municipalities, and repeated exposure to intense monsoon and typhoon rainfall. The Pampanga River Basin has been described as one of the major river basins in the country, and flood- and landslide-prone areas in the province continue to require preparedness, communication, and response capacity (Macalalad et al., 2021; Unson & Cariaso, 2024).

Barangay Bulac in Minalin, Pampanga represents a local setting where disaster communication is critical. During severe weather events, residents may experience poor cellular signal, Internet outages, and fragmented communication channels. These limitations can delay evacuation notices, make it difficult to locate civilians requesting assistance, and affect rescuer coordination. The experience of Super Typhoon Carina demonstrated the importance of quick and organized communication, particularly in communities where several families may require evacuation and where responders must act with limited time and incomplete information.

Communication infrastructure is therefore a central concern in flood search and rescue operations. The Sendai Framework for Disaster Risk Reduction emphasizes preparedness, risk governance, and effective response as core priorities for reducing disaster impacts (United Nations Office for Disaster Risk Reduction [UNDRR], 2015). In technology-based disaster response, long-range low-power communication, wireless sensor networks, and Internet of Things (IoT) systems offer potential solutions when conventional connectivity becomes unreliable. Wireless sensor networks can support monitoring and distributed information exchange, while IoT enables objects and systems to communicate and support decision-making (Akyildiz et al., 2002; Atzori et al., 2010).

LoRa-Connect was developed to address this communication gap by providing a unified system composed of wearable EchoBand devices, a central computing node, a web application, and a mobile application. Using LoRa communication technology, the system enabled SOS transmission, location tracking, evacuation messaging, and task allocation even in areas with limited cellular and Internet connectivity. The study evaluated whether the developed system could support flood rescue operations in Barangay Bulac through functional testing and user acceptance evaluation involving civilians, rescuers, barangay personnel, and technical experts.

Literature Review

Flood Risk, Local Disaster Preparedness, and Emergency Communication

Flooding remains a recurring disaster concern in the Philippines due to the frequency of tropical cyclones, monsoon rainfall, and the exposure of low-lying communities. Balita (2024) noted the continuing impact of natural disasters in the country, while PAGASA (2024) emphasized the regular formation and passage of tropical cyclones through the Philippine Area of Responsibility. For Pampanga, flood risk is intensified by river basin conditions and heavy rainfall, particularly in municipalities surrounding the Pampanga River Basin (Macalalad et al., 2021). These conditions underscore the need for community-based systems that can help residents and responders communicate rapidly during emergencies.

Disaster response depends not only on physical evacuation plans but also on reliable channels for collecting and transmitting information. In flood-prone barangays, rescue operations may be weakened when telephone calls, SMS, or Internet-based platforms become unavailable or overloaded. The Sendai Framework stresses that effective preparedness requires strengthening early warning, operational readiness, and local response capacity (UNDRR, 2015). In this context, a dedicated and locally deployable communication system can help ensure that urgent signals, location data, and rescue assignments remain available even when public communication networks are limited.

LoRa, IoT, and Wireless Sensor Networks for Search and Rescue

LoRa and LoRaWAN technologies have been widely explored for low-power and long-range communication in IoT systems. The LoRa Alliance (2020) describes LoRaWAN as a protocol optimized for battery-powered end devices, while The Things Network (n.d.) explains that LoRaWAN defines how LoRa hardware communicates at the network level. Comparative studies also show the relevance of low-power wide-area networks for large-scale IoT deployment, particularly when devices require extended battery life and longer communication ranges (Mekki et al., 2019; Marini et al., 2022). These features make LoRa suitable for disaster scenarios where responders require field communication over larger areas with limited infrastructure.

Previous search and rescue studies support the use of LoRa-based communication architectures. Bianco et al. (2020) evaluated LoRa LPWAN technology for mountain search and rescue, while Manuel et al. (2022) proposed a LoRa LPWAN-based communication architecture for search and rescue missions. Karthikeyan et al. (2024) also demonstrated the use of LoRa and IoT-based devices for disaster and fleet management. These studies indicate that LoRa systems can support location reporting, responder coordination, and communication continuity when conventional networks are unavailable.

System Integration, Offline Mapping, and Task Allocation

Search and rescue communication systems require more than signal transmission; they also need integrated interfaces that help responders interpret information and act on it. Poeschl et al. (2024) proposed an integrated 5G and LoRaWAN communication system for search and rescue applications in rural areas, suggesting the value of combining communication layers for operational continuity. Gu and Li (2023) presented a search and rescue device design using a magnetic compass, while Sirry and Patra (2024) emphasized that modern technological tools can enhance rescue mission coordination.

LoRa-Connect follows this direction by integrating EchoBand wearables, a Raspberry Pi-based central node, a web application, and a mobile application. Its central node receives location and status data, while its software layer supports offline mapping and task assignment. Routing and mapping tools such as GraphHopper and MapLibre supported offline location visualization, while the Munkres implementation of the Hungarian Algorithm was used to optimize task assignment. This integration reflects the broader movement toward IoT-enabled disaster systems that connect field devices, data processing, and responder interfaces.

Data Privacy, Usability, and Community Acceptance

Because the system collects and displays location and identity-related information, ethical and privacy considerations are important. The Data Privacy Act of 2012 requires the protection of personal information in government and private information systems (National Privacy Commission, n.d.). In disaster response systems, privacy protection must be balanced with the urgent need to locate and assist affected residents. This makes informed consent, confidentiality, limited access, and secure data handling essential components of system testing and deployment.

User acceptance is also necessary because disaster technologies are only useful when civilians and rescuers are willing and able to use them during stressful conditions. Ease of use, reliability, and perceived effectiveness determine whether a device or application can realistically support local operations. Thus, beyond technical performance, the evaluation of LoRa-Connect included civilian, rescuer, and expert feedback to determine whether the system was not only technically functional but also acceptable to the community and professionals who may rely on it during flood emergencies.

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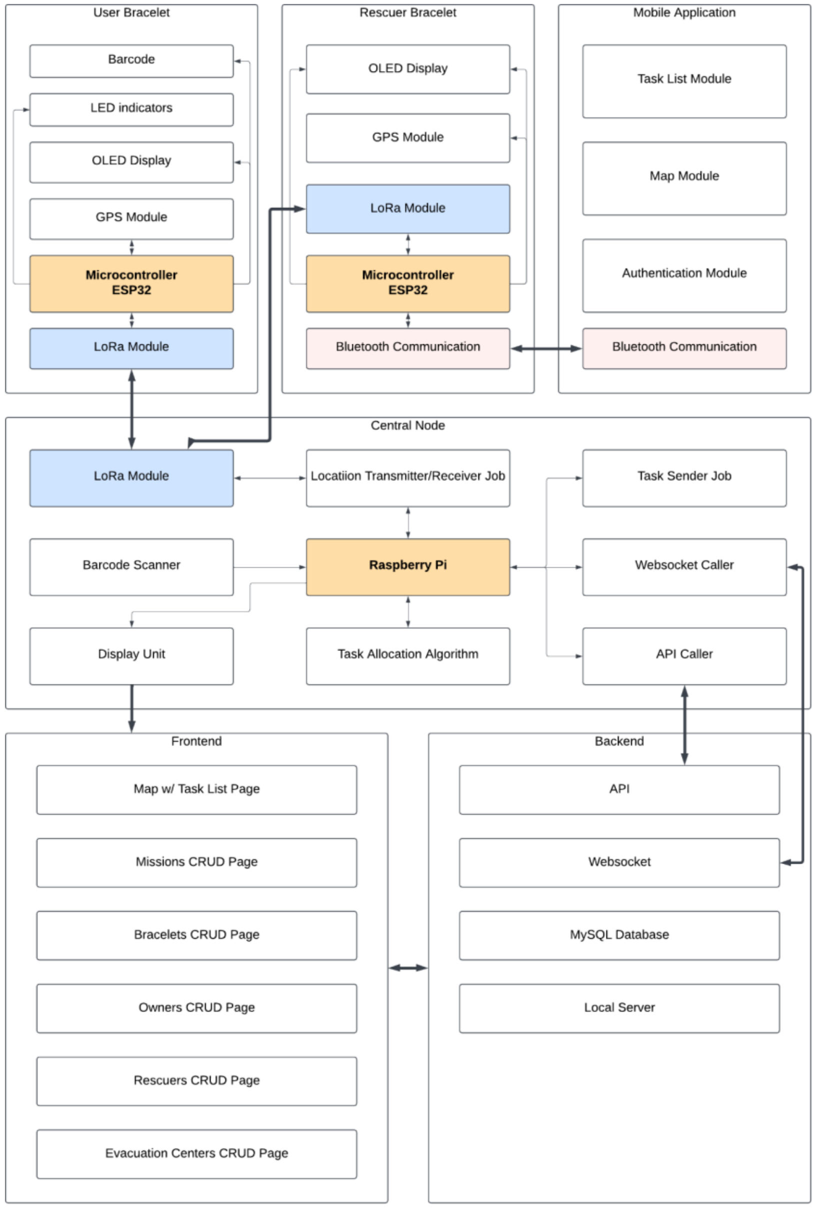
Figure 1. *System Block Diagram of the LoRa-Connect Unified Flood Search and Rescue System*



Note. The system framework shows the integration of user and rescuer EchoBands, LoRa communication, the Raspberry Pi central node, frontend and backend modules, task allocation, and mobile application functions used in flood search and rescue coordination.

METHODS

Research Design

The study employed applied, descriptive, and quantitative research methods. It was applied because it developed a practical system intended to address a local flood response problem in Barangay Bulac, Minalin, Pampanga. It was descriptive because it documented the functions, components, and deployment process of the system in relation to existing local disaster response needs. It was quantitative because user acceptance data were gathered through a Likert-type survey and analyzed using weighted means and descriptive interpretation.

Research Locale

The study was conducted in Barangay Bulac, Minalin, Pampanga. The location was selected because it is situated in a flood-prone municipality near the Pampanga River Basin and has experienced flood-related evacuation concerns during severe typhoons. The study focused on how a local communication system could support residents and responders during flood search and rescue operations.

Participants and Sampling Technique

Purposive sampling was used to select respondents who could provide relevant feedback based on residency in a flood-prone area, involvement in barangay response operations, or technical expertise. The non-technical end-users were composed of seven residents who used EchoBands and eight rescuers and barangay personnel. The technical expert group consisted of four professionals in computer and electronics engineering who evaluated the system components and technical design.

Research Instrument

The primary evaluation instrument was a user acceptance survey using a four-point Likert scale. Civilian users and rescuers assessed the system based on ease of use, reliability, and effectiveness. Technical experts evaluated the system in terms of system architecture and design, compliance and security, performance and reliability, integration and maintenance, and overall system evaluation. The interpretation scale is shown in Table 1.

Table 1. *Processed Data Descriptions Used in Interpreting User Acceptance Results*

Weighted mean range	Description / Interpretation
1.00-1.40	Strongly Disagree / Very Dissatisfied
1.50-2.40	Disagree / Dissatisfied
2.50-3.40	Agree / Satisfied
3.50-4.00	Strongly Agree / Very Satisfied

System Development Procedure

The hardware development followed the prototyping model, which included requirements gathering, design, prototyping, testing, and deployment. The system required LoRa armbands for civilians and rescuers, a central node, sufficient battery life, location tracking, and practical form factors for emergency use. The final EchoBand prototype used the Heltec V3, ATMega328p, SX1262 LoRa chip module, ATGM336H GPS module, 0.96-inch OLED display, SP3T switch, LEDs, and a LiPo battery. A Raspberry Pi with a LoRa module and a 12dBi antenna served as the central node.

The software development followed the waterfall model. EchoBand algorithms were written in C using the Arduino IDE and later migrated to PlatformIO in Visual Studio Code. The central node used Python with libraries for SPI communication, WebSockets, and GPIO control. The web application was developed using Next.js with TypeScript, Socket.IO, Prisma.js, MySQL, MapLibre, GraphHopper, Munkres.js, Shadcn UI, and Tailwind CSS. The mobile application was developed in Kotlin using Android Studio and Jetpack Compose and also used MapLibre for offline mapping.

Data Gathering Procedure

The researchers deployed and demonstrated LoRa-Connect in Barangay Bulac, Minalin, Pampanga. Civilians, rescuers, barangay personnel, and technical experts were oriented about the system and its intended functions. The proponents tested the EchoBands and the central node for time-to-first-fix, battery life, communication range, and GPS accuracy. The web application was also assessed using the Lighthouse extension in Google Chrome. After the demonstration and testing process, respondents completed the user acceptance survey.

Data Analysis

Quantitative survey data were analyzed using weighted mean. The resulting means were interpreted using the study's four-point descriptive scale. For system functionality, the proponents also used formulas to examine time saved percentage, distance saved percentage, GPS distance using the Haversine formula, and cost reduction mean for task allocation performance. These analyses helped determine the system's usability, reliability, effectiveness, and technical suitability for supporting search and rescue operations.

Ethical Consideration

Ethical procedures were observed throughout the study. Respondents were informed about the objectives, purpose, and possible risks of participating in the evaluation. Informed consent was obtained before participation. In accordance with Republic Act 10173 or the Data Privacy Act of 2012, respondent data were kept confidential, were accessible only to authorized personnel, and were used only for purposes related to the study. Participants were also informed of their right to withdraw at any time without penalty.

RESULTS AND DISCUSSION

System Deployment and Functional Performance

LoRa-Connect was deployed and demonstrated in Barangay Bulac, Minalin, Pampanga to local first responders and previously recorded evacuees. The system transmitted SOS signals, showed civilian location and urgency status, allocated operations to rescuers when an SOS signal was received, and supported monitoring through a control center interface. Its web application allowed administrators to manage civilians, rescuers, obstacles, evacuation centers, locations, and SOS data, while its mobile interface enabled rescuers to view locations and monitor assigned tasks from the central node.

The system's architecture demonstrated the value of integrating wearable devices, a central node, and application-based interfaces in one flood response platform. The EchoBand enabled location-based alerting, while the central node managed communication and task allocation. The study reported practical battery performance and a localization accuracy target of 30 to 40 meters. These functional results support the claim that LoRa-based systems can help maintain emergency communication where cellular or Internet connection may be weak or disrupted, aligning with prior findings on LoRa-based search and rescue communication systems (Bianco et al., 2020; Manuel et al., 2022; Karthikeyan et al., 2024).

User, Rescuer, and Professional Acceptance of LoRa-Connect

The user acceptance results showed that civilians, rescuers, and professionals generally evaluated LoRa-Connect positively. Civilian users rated the EchoBand as Agree in ease of use, reliability, and effectiveness. Rescuers similarly rated the device, web application, and mobile application within the Agree category. Technical professionals gave stronger endorsements, rating system architecture and design, compliance and security, performance and reliability, integration and maintenance, and overall system evaluation as Strongly Agree. These results indicate that the system was considered usable, reliable, and technically acceptable for flood response operations.

Table 2. *User, Rescuer, and Professional Survey Results for LoRa-Connect*

Role	Component	Category	Grand Mean	Interpretation
User	Device	Ease of Use	3.325	Agree
User	Device	Reliability	3.425	Agree
User	Device	Effectiveness	3.250	Agree
Rescuer	Device	Ease of Use	3.100	Agree
Rescuer	Device	Reliability	3.300	Agree
Rescuer	Device	Effectiveness	3.200	Agree
Rescuer	Web Application	Ease of Use	3.125	Agree
Rescuer	Web Application	Reliability	3.325	Agree
Rescuer	Web Application	Effectiveness	3.325	Agree
Rescuer	Mobile Application	Ease of Use	3.250	Agree
Rescuer	Mobile Application	Reliability	3.050	Agree
Rescuer	Mobile Application	Effectiveness	3.000	Agree

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Professional	System Architecture	Design and Scalability	3.67	Strongly Agree
Professional	System Architecture	Compliance and Security	3.50	Strongly Agree
Professional	System Architecture	Performance and Reliability	3.50	Strongly Agree
Professional	System Architecture	Integration and Maintenance	3.50	Strongly Agree
Professional	System Architecture	Overall System Evaluation	3.63	Strongly Agree

Implications for Flood Search and Rescue Operations

The results suggest that LoRa-Connect can help improve barangay-level search and rescue coordination by offering a dedicated system for SOS reporting, location transmission, and rescuer task assignment. Civilian ratings show that the EchoBand was acceptable for end-users, which is critical because residents must be able to activate the device during flood emergencies. Rescuer ratings further show that the system can support field operations through web and mobile interfaces, although the slightly lower mobile application ratings for reliability and effectiveness indicate areas requiring refinement.

The professional evaluation reinforces the technical soundness of the design. Strong agreement in architecture, security, reliability, integration, and maintenance indicates that the system has potential for real-world deployment. However, the study also identified areas for improvement, particularly accessibility, user training, emergency trust, and more immediate alerts. These points are important because technology adoption during disasters depends on repeated orientation, simple interfaces, reliable field testing, and community confidence. The findings therefore support continued enhancement and scaled testing of LoRa-Connect as a local disaster communication tool.

CONCLUSION

The study concludes that LoRa-Connect successfully achieved its objective of developing an integrated and user-accepted flood search and rescue communication system using LoRa technology. The system combined EchoBand wearable devices, a Raspberry Pi-based central node, a web-based monitoring interface, and a mobile application to support SOS signaling, location tracking, offline mapping, and rescuer task allocation. Field testing in Barangay Bulac, Minalin, Pampanga showed that the system met important functional requirements, including reliable GPS tracking, practical battery performance, and a localization accuracy target of 30 to 40 meters.

The user acceptance results further indicate that civilians and rescuers generally agreed that the system was easy to use, reliable, and effective, while technical experts strongly agreed that the system architecture and performance were suitable for deployment. These findings demonstrate that LoRa-Connect can support local rescue operations by addressing communication gaps in flood-prone communities. At the same time, the results point to the need for improvements in accessibility, training, emergency alerts, and trust-building to ensure that the system can be used effectively in actual disaster conditions.

Recommendation

Barangay disaster risk reduction and management offices may consider pilot-testing LoRa-Connect in wider flood-prone areas to determine its performance under different weather, terrain, and communication conditions. Regular community drills should be conducted so residents and rescuers can become familiar with the EchoBand, mobile application, and central monitoring interface before an actual emergency occurs.

System developers should improve the accessibility of the web and mobile applications, strengthen alert visibility and sound notification features, simplify user interface elements, and continue enhancing the durability and waterproofing of the EchoBand. Additional testing should also be conducted on battery endurance, communication range, GPS accuracy, and task allocation performance during simulated flood rescue scenarios.

Local government units and disaster management agencies may explore partnerships with universities, engineering experts, and communication technology providers to support system refinement, maintenance, and possible adoption. Future researchers are encouraged to expand the number of participants, include more barangays, compare LoRa-Connect with other disaster communication systems, and evaluate its performance during real-time emergency drills or actual flood events.

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