



LIFEBAND: A Long-Range, Low-Power Wearable for Real-Time Aquatic Distress Detection

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1. Abstract

Drowning is a leading cause of accidental aquatic mortality worldwide, highlighting the need for robust emergency detection in infrastructure-constrained environments. **LifeBand** is an edge-computing wearable engineered for real-time aquatic physiological distress recognition, long-range emergency telemetry, and automated dispatch triggering. The device incorporates a multi-modal sensor array including a photoplethysmography (PPG) heart rate sensor, a 6-axis inertial measurement unit (IMU), a piezoelectric impact sensor, and a GPS module all managed by an ESP32 **system-on-chip**. By executing sensor fusion locally on the edge, LifeBand classifies submersion events using dynamic threshold analysis of photoplethysmographic variance, impact dynamics, sustained immobility, user profile and battery status. Upon distress, LifeBand constructs a standardized telemetry packet and broadcasts it over a 915 MHz LoRa network without reliance on cellular towers or Wi-Fi infrastructure. A gateway base station ingests the packet, logs the incident, triggers trimodal (auditory, optical, haptic) alarms, and provides victim locations and distress scores on a monitoring dashboard as well as on a mobile app. The scope of work includes a working prototype of the hardware and software components, reliability experiments and simulated telemetry results. The experimental results and the prototype implementation show that Lifeband is a reliable, affordable, safety solution that scales from swimming-pool facilities, to open water flood rescue operations, accelerating response to mitigate aquatic fatalities.

Keywords: Aquatic Safety, Wearable Technology, LoRa Communications, Edge Computing, ESP32, Drowning Detection, Flash Flood Response, Sensor Fusion

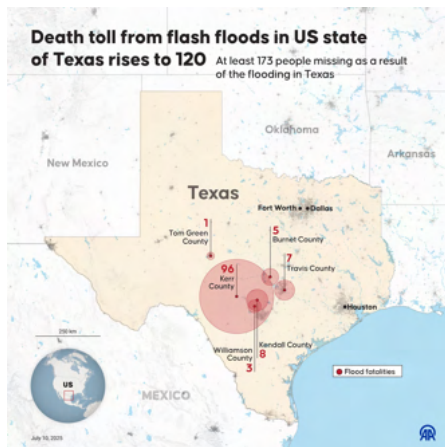
2. Introduction and Background

2.1 Problem Context and Regional Urgency

Drowning and inland flooding are major public safety threats across the United States. Drowning claims over 4,000 lives annually—a public health crisis compounded by recurring, severe inland flood events in vulnerable regions.

This threat is particularly pronounced in the Central Texas region located within "**Flash Flood Alley**"—one of North America's most flood-prone geographic corridors. While non-coastal flash flooding accounts for over 43% of all aquatic fatalities in Texas (with the state leading the nation in historical flood deaths at over 1,000 recorded casualties), recreational waters present an equally pervasive hazard. Statewide, over 80 residential and municipal pool drownings occur each year, often driven by quiet submersion, supervisor distraction, or delayed emergency response in rural facilities lacking dedicated network infrastructure.

The critical need for real-time tracking during aquatic disasters was brutally highlighted by the July 2025 flash flood at Camp Mystic along the Guadalupe River in Kerr County. Rapidly rising waters swept through the camp during early morning hours, resulting in the tragic loss of 27 young campers and staff. The sudden inundation destroyed local power grids and cellular towers, completely severing communication infrastructure and leaving rescue teams unable to locate or track individuals.



Central Texas flash flood risk map. Source: Anadolu / Anadolu via Getty Images

The disaster underscored a systemic vulnerability: whether facing a sudden flash flood or a silent pool submersion, when local infrastructure collapses, emergency personnel lose both critical communication channels and real-time situational awareness of victims trapped or swept downstream.

2.2 Technical Limitations of Existing Solutions

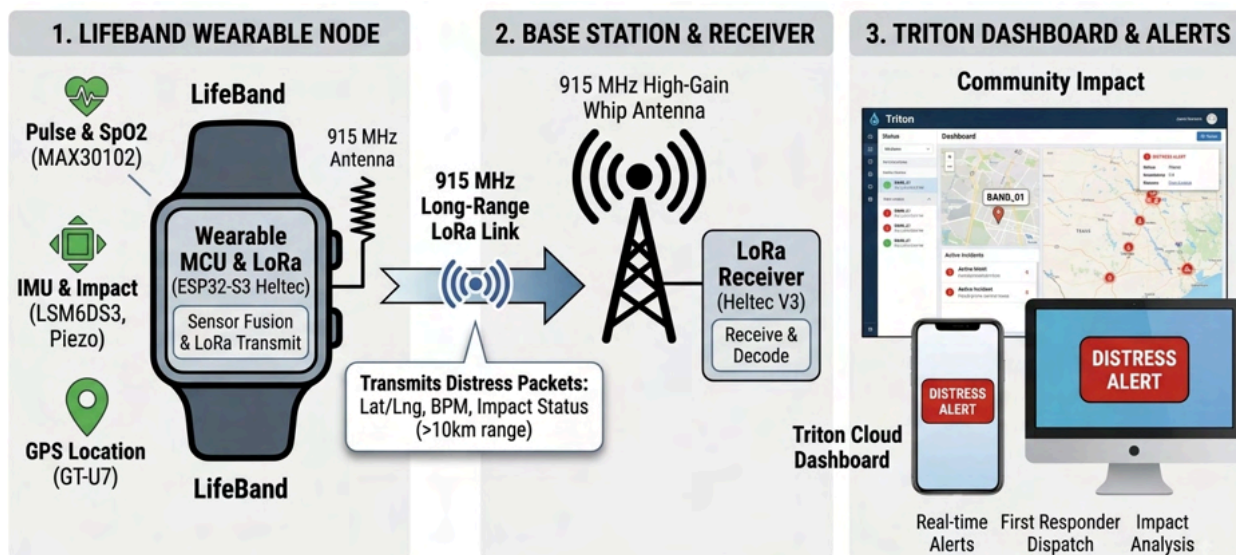
Despite the frequency of these emergencies, traditional emergency response systems fail to provide reliable protection in aquatic environments due to three key bottlenecks:

- **Signal Attenuation in Water:** Standard cellular and Wi-Fi signals operate at higher radio frequencies that suffer from severe signal degradation over open waters, dense foliage, and saturated atmospheric conditions common to flash floods.
- **Reliance on Manual Activation:** Traditional emergency alert devices rely on a manual trigger of SOS button, a paradigm that fails entirely during critical distress states like rapid aquatic submersion, sudden impact shock or fatigue.
- **High Cost and Infrastructure Dependencies:** Commercial aquatic safety monitoring and satellite-based distress systems require expensive recurring subscriptions or dense, power-heavy localized mesh networks—making widespread deployment expensive for municipal public parks, youth summer camps, and rural recreational waters.



2.3 Proposed Solution and Community Impact

To bridge the critical gap between localized aquatic emergencies and rapid search-and-rescue efforts, this paper presents **LifeBand**—a long-range, low-power, low-cost, automated wearable safety framework for aquatic distress detection and alerting. By integrating continuous biometric monitoring with an offline, low-power LoRa (Long Range) radio transmitter, LifeBand bypasses traditional cellular infrastructure to broadcast critical location and physiological status alerts across extended distances during active submersions or power grid failures. Furthermore, this core architecture easily scales to recreational environments like community and commercial swimming pools, offering lifeguards an automated, continuous safety mechanism to detect and prevent accidental drownings.

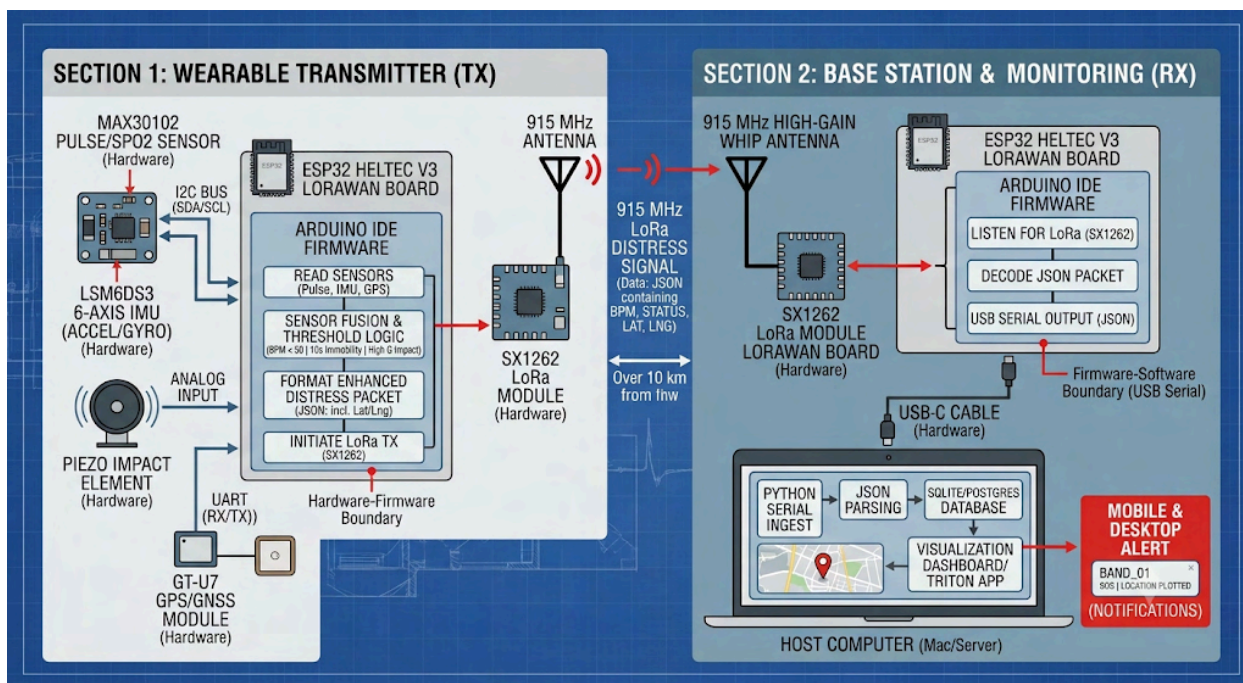


3. Methodology and Experimental Setup

3.1 Hardware Architecture and Embedded System Design

The framework integrates a compact wearable edge device with real-time biometric and physiological sensing, on-device edge computing for power optimization, and long-range (LoRa) radio communications. To complete the system architecture, transmitted telemetry is captured by localized receivers and pushed to web and mobile app dashboard. This enables search-and-rescue operators to visualize live location data, track victim status flags, and receive automated real-time alert notifications during aquatic emergencies.

LifeBand - System Architecture



- **Microcontroller Unit (MCU) and Core Architecture:** The system relies on an ESP32 microcontroller, selected for its low power consumption, processing efficiency, and versatile interface options (GPIO, SPI, and I2C) that enable real-time multi-sensor data fusion at the edge.
- **Embedded Sensor Arrays:**
 - **Biometric Optical Pulse Sensor:** Measures photoplethysmogram (PPG) signals to track heart rate fluctuations, providing real-time detection of physiological distress or impact shock.
 - **Mechanical Piezoelectric Sensor:** Registers rapid hydro-barometric pressure spikes and impact forces during sudden water entry.
 - **Kinematic 6-Axis Accelerometer / Gyroscope (IMU):** Tracks motion dynamics across three rotational and translational axes to detect orientation changes, rapid free-fall events, or active drowning.

- **Spatial GPS Module:** Captures real-time positioning coordinates (latitude, longitude, and altitude) directly on the edge node to embed precise geographical location data into outgoing distress payloads.
- **Long-Range Wireless Transceiver:** LoRa transceivers operating on sub-gigahertz frequencies (915 MHz) handle long-range, offline telemetry transmission—delivering live distress score, GPS positioning, and health metrics to search-and-rescue dashboards without requiring active cellular networks or Wi-Fi gateways.

3.2 System Control Logic and Autonomous Triggering

The firmware executes an autonomous detection algorithm implemented within the Arduino/ESP-IDF framework. Rather than relying on manual user intervention, the system continuously executes an autonomous distress detection algorithm that evaluates sensor telemetry against mathematically defined safe thresholds for each metric. An emergency event is triggered when the $f(t)$ exceeds a critical boundary:

$$f(t) = w_1 * \Delta HR + w_2 * (dP / dt) + w_3 * |dz / dt|$$

The decision logic evaluates:

- **Biometric Deviations (ΔHR):** Photoplethysmogram (PPG) pulse rate variance relative to resting baselines (detecting extreme tachycardia or sudden cardiac cessation).
- **Pressure Dynamics (dP/dt):** Transient mechanical pressure spikes indicating sudden hydrodynamic shock or water entry.
- **Depth Rate of Change (dz/dt):** Rapid vertical displacement calculated from hydro-barometric pressure shifts.
- **Kinematic and Spatial Offsets (ΔP and lat/long/alt):** Relative position shifts from the 6-axis IMU cross-referenced with absolute GPS coordinates to confirm displacement or uncontrolled drift.

When the calculated score exceeds pre-programmed threshold limits ($f(t) > T_{\text{alert}}$), the system constructs an emergency distress broadcast payload containing bandID, distress score, timestamp, trigger type, physiological and location information to be transmitted to the base station.

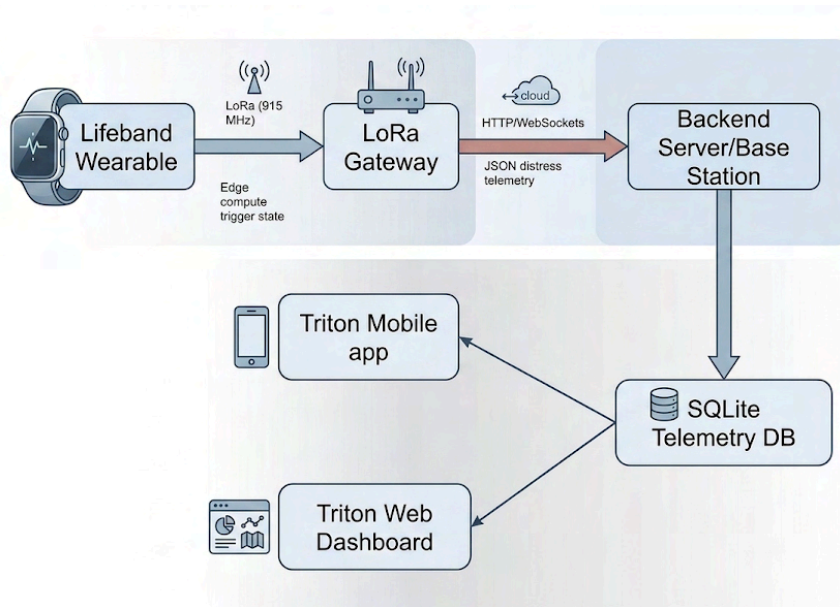
3.3 Hardware SOS Override

Alongside automated biometric, kinematic, hydro-barometric sensing, the wearable also includes a tactile Manual SOS button. The physical SOS switch provides an instantaneous override. Activating the switch forces the onboard ESP32 into an immediate alert state to immediately broadcast an emergency payload.

3.4 Dashboard Architecture and Multi-Modal Response Simulation

The base station server converts raw telemetry into actionable search-and-rescue (SAR) data and renders it as distress alert on mobile devices via a mobile app or on a centralized web monitoring dashboard. This system constantly monitors incoming packets, logs telemetry to

learn trends, and executes multi-modal alerting during active distress triggers or manual SOS activations.



3.4.1 Localized Backend and Telemetry

- **Asynchronous Server:** A lightweight, local Python **FastAPI** application serves as the core intake engine. It parses incoming packet streams, extracts JSON-formatted emergency payloads, and handles real-time, low-latency dashboard updates.
- **Database Schema (SQLite):** Telemetry data is stored in **SQLite** database. The structured schema logs key information including device IDs, timestamps, distress score, GPS coordinates, pulse rates, trigger source, and device battery life. The constant logging vs overwrite with most recent data allows better audit for any post-incident reviews.

3.4.2 Multi-Modal Emergency Alert Mechanism

Upon receiving a packet marked with a “Distress State” flag (including Manual SOS), the server immediately triggers a multi-modal alert that cascade across the monitoring interface:

- **Auditory Alarms:** An unmuted, high-frequency audio siren sounds at the mobile app/dashboard station to alert in crowded pool environments or severe weather conditions during flash floods.
- **Visual Mapping and Spatial Tracking:** An interactive Map view pins the precise GPS coordinates of the transmitting node. The map automatically centers on the distress location, displaying color coded pins based on distress scores to identify criticality and urgency.
- **Physiological, Age and Kinematic Tracking:** The dashboard displays real-time health data cards showing PPG heart rate trends, depth displacement rates, motion state, along with age and device battery life.

3.5 Experimental Protocol and Testing Methodology

To evaluate the operational viability and transmission reliability of the LifeBand prototype, empirical field testing was divided into structured phases:

3.5.1: Sensor Calibration and Signal Reliability

- **Objective:** Establish baseline threshold accuracy and eliminate false positive triggers.
- **Procedure:** The optical pulse sensor and piezoelectric unit were subjected to controlled breadboard simulations (simulated cardiac rate changes, light taps, and sudden rapid drops into water bowl).
- **Metrics Observed:** Sensor latency, any false positives, and triggers (spikes) caused by sudden change in depth or motion.

3.5.2: RF Transmission and Signal Attenuation

- **Objective:** Quantify LoRa radio signal strength and packet delivery performance across open air, open water and through dense environmental obstacles like wooded area and urban buildings.
- **Procedure:** The transmitter was positioned at water-level in the pool to mimic an active drowning or floatation scenario. Received Signal Strength Indicator (RSSI) and Packet Loss Rate (PLR) logged at varying distances ranging from 10m to 1km
 1. Open air environment (initial test)
 2. Line-of-sight open water environments (simulating lakes/pools).
 3. Dense tree canopy corridors (simulating rural flash flood environments).
 4. Community urban settings (simulating flash floods in dense urban environments).
- **Metrics Collected:** RSSI, successful Packet Delivery Ratio (PDR) and Packet Delivery Time (latency)

3.5.3: Power Model Simulations

- **Objective:** Measure operational battery longevity of the wearable to quantify edge computing vs cloud computing benefits.
- **Procedure:** Gather datasheet electrical characteristics for each hardware subsystem and compute average energy consumption across various operational states: low-power sleep mode, baseline periodic sensing, and distress transmission mode. Compare this energy profile against a continuous streaming model where raw sensor data is transmitted to the base station for remote processing and distress detection.
- **Metrics Collected:** Through mathematical modeling determine average energy consumption in both scenarios and determine device battery life.

3.5.4 Operational Incident Simulations

Simulation A: Managed Community Pool Incident (Manual SOS and Surface Distress)

- **Objective:** Evaluate edge-to-dashboard-to-mobile app transmission, multi-modal alert, visual spatial mapping precision, and lifeguard alerting response during a manual SOS in a managed aquatic environment.
- **Procedure:** A simulated user experienced sudden surface fatigue in a crowded pool environment and executed a tactile SOS. The wearable edge node formatted an



emergency packet, broadcasted telemetry via LoRa to a central gateway node connected to the local backend and dashboard triggering an alert on app on mobile device.

- **Metrics Collected/Observed:** Real-time distress alert, visual quadrant pinning accuracy on the app, and multi-modal audio/visual siren activation verification.

Simulation B: Off-Grid Rural Flash Flood Response

- **Objective:** Validate offline LoRa telemetry range, downstream GPS trajectory tracking, and topographic rendering capabilities during an off-grid flash flood evacuation scenario mimicking "Flash Flood Alley" conditions.
- **Procedure:** Mocked telemetry and active hardware relays simulated 50 victims swept downstream in an off-grid river corridor with non-functional cellular infrastructure. Few wearables initiated either manual or automated distress signals, continuously broadcasting GPS location, and key telemetry data over LoRa to a central Search-and-Rescue (SAR) gateway node.
- **Metrics Collected/Observed:** Real-time distress alert, precise GPS location and direction/distance information to get to victim, real-time vector coordinate update frequency on offline-cached topographic maps, victim vitals and age information to bucketize urgency of dispatch.

4. Results

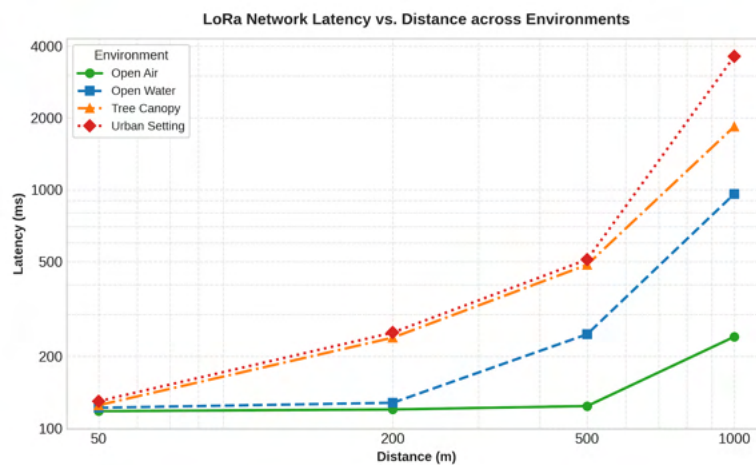
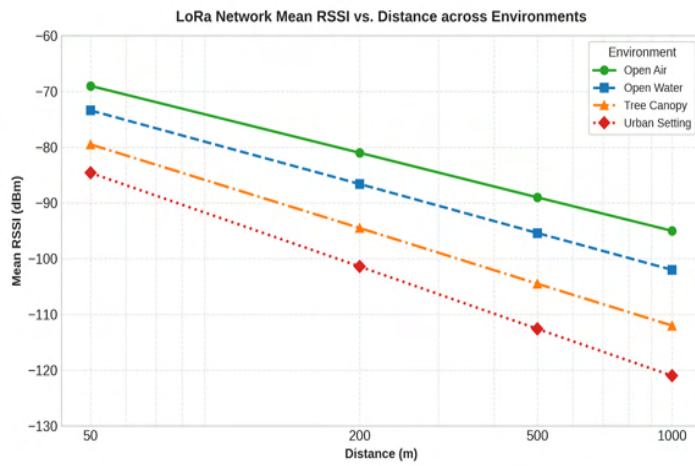
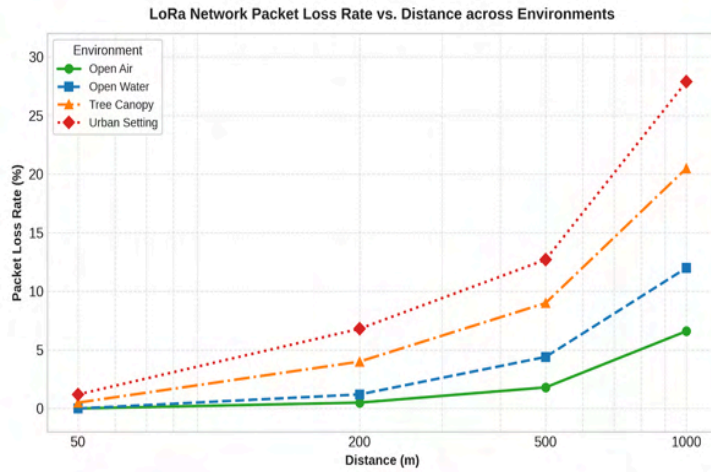
4.1 Signal Propagation and Network Range Across Varying Environments:

An empirical signal propagation analysis across the four evaluation environments highlights LoRa performance as a function of distance (50m-1000m) and varying environments (metrics evaluated: RSSI, PLR and Latency)

Distance (m)	Environment	Optimal Spreading Factor	Mean RSSI (dBm)	Packet Loss Rate (%)	Latency (ms)
50 m	Open Air	SF7	-69.0 dBm	0.00%	118 ms
	Open Water	SF7	-73.4 dBm	0.00%	122 ms
	Tree Canopy	SF7	-79.5 dBm	0.50%	125 ms
	Urban Setting	SF7	-84.6 dBm	1.20%	130 ms
200 m	Open Air	SF7	-81.0 dBm	0.50%	120 ms
	Open Water	SF7	-86.6 dBm	1.20%	128 ms
	Tree Canopy	SF8	-94.5 dBm	4.00%	240 ms
	Urban Setting	SF8	-101.4 dBm	6.80%	252 ms



500 m	Open Air	SF7	-89.0 dBm	1.80%	124 ms
	Open Water	SF8	-95.4 dBm	4.40%	248 ms
	Tree Canopy	SF9	-104.5 dBm	9.00%	485 ms
	Urban Setting	SF9	-112.6 dBm	12.70%	510 ms
1000 m	Open Air	SF8	-95.0 dBm	6.60%	242 ms
	Open Water	SF10	-102.0 dBm	12.00%	960 ms
	Tree Canopy	SF11	-112.0 dBm	20.50%	1,840 ms
	Urban Setting	SF12	-121.0 dBm	27.90%	3,620 ms



Observation: Across tested operational distances, LoRa signal attenuation and latency scale significantly as environmental obstruction increases from open air to dense urban structures. At short ranges (~200 m), the system achieves near-100% packet delivery ratios with <250ms latency across all terrains using low spreading factors (SF7–SF8).

However, at longer ranges (~1,000 m), environmental obstacles demand dynamic Spreading Factor adaptation (SF10 in open water and SF12 in urban areas) to maintain PLR<30%; this shift trades bandwidth for signal penetration, while increasing mean latency from ~120 ms to ~3.6 seconds.

4.2 Power Model and Battery Longevity:

Operational Mode	Sub-System / Hardware State	Current Draw / Metrics	Duty Cycle	Estimated Battery Life (1,000 mAh)
Deep Sleep	MCU (Deep Sleep)	~15 μ A	100% sleep state	~4.5–5.5 years
	LoRa Radio (Sleep)	~1.5 μ A		
	Sensors (GPIO Gated)	0 μ A		
	Total System	~16.5–20 μ A		
Standby	MCU (Deep / Light Sleep)	~15–30 μ A	99.9% idle state	~1.8–3.6 years
	LoRa Radio (Sleep / Standby)	~1.5–10 μ A		
	Sensors (Power Gated)	~5 μ A		
	Total System	~25–50 μ A		
Normal Monitoring	MCU (ULP / Light Sleep)	~0.8–1.5 mA	Continuous passive sampling	~10.4–22.2 days
	IMU / Piezo Active (10-20 Hz)	~0.5–1.2 mA		
	LoRa Radio (Standby)	~0.2 mA		
	Total System	~1.5–3.2 mA		
High-Frequency TX	GPS Module (Continuous Tracking)	~25 mA	Periodic burst every 30s	~64 hours ($\approx$ 2.6 days)
	MCU (Active Processing)	~40 mA (Peak)		
	LoRa Radio (TX, SF8 every 30s)	~80 mA (Peak)		
	Total System (Time averaged)	~12.5 mA		



Emergency Distress (flood)	MCU (Full Active, 240 MHz)	~50–65 mA	100% continuous dispatch	~7.2–9.4 hours
	GPS Module (Continuous Tracking)	~25 mA		
	LoRa Radio (TX, SF10-12, +22 dBm)	~120 mA (Peak)		
	Total System (Avg)	~85–110 mA		
Emergency Distress (pool)	MCU (Active sensor fusion)	~40–50 mA	Rapid burst every 2-5sec	11.8-14.5 hours
	GPS Module (Continuous Tracking)	~25 mA		
	LoRa Radio (TX, SF8, +17 dBm)	~80 mA (Peak)		
	Total System (Avg)	~55-68 mA		

Observation: LifeBand shifts down from SF12 (long-range flood rescue) to SF8 for localized aquatic environments (swimming pools within 300 m). This reduces packet ToA (latency) by over 80%, reduces packet loss, and extends battery operational life from 7.2 hours to over 11.8 hours.

4.3 Web dashboard and app testing with simulated data

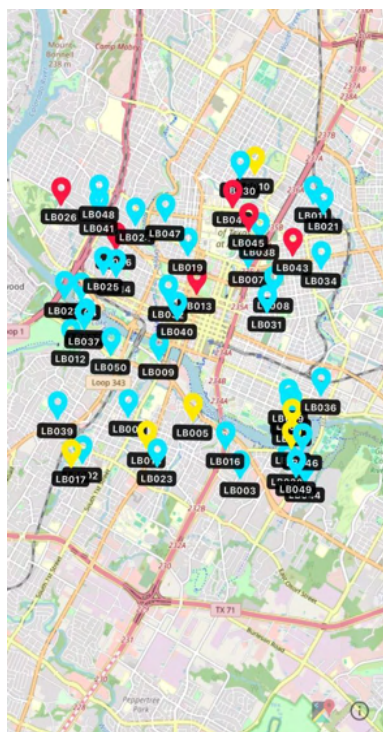
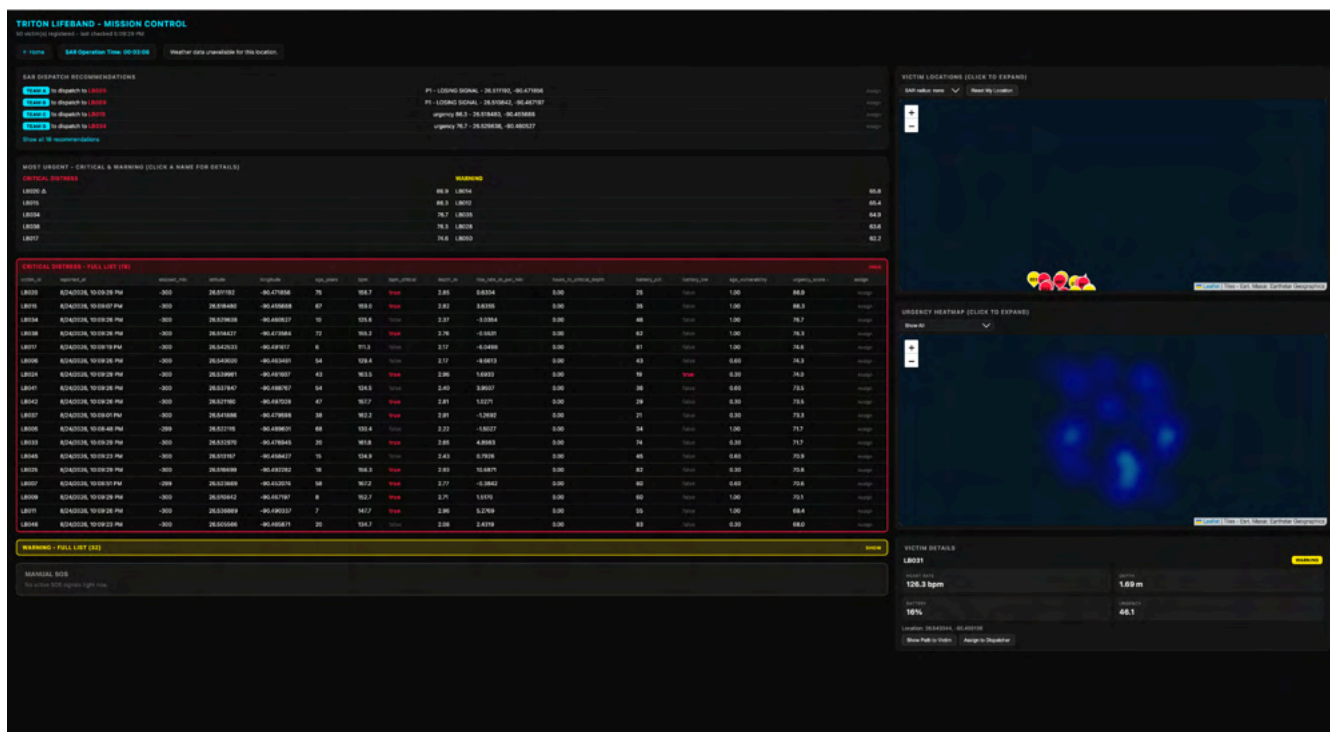
JSON Payloads transmitted from 2 LifeBands to BaseStation (mock data)

- Automatic distress, Manual SOS distress, Routine device healthcheck

```
{
  "device_id": "LBID-005",
  "msg_type": "DISTRESS",
  "timestamp": "2026-08-22T15:42:10Z",
  "trigger": "AUTOMATIC_SUBMERSION",
  "location": {
    "latitude": 30.448520,
    "longitude": -97.784228,
    "altitude_m": 220.1
  },
  "telemetry": {
    "heart_rate_bpm": 165,
    "spo2_percent": 88,
    "submersion_depth_cm": 110.0,
    "submersion_duration_sec": 12
  },
  "radio": {
    "spreading_factor": 8,
    "rssi_dbm": -76.8
  },
  "status": {
    "battery_percent": 88,
    "state": "CRITICAL_DROWNING"
  }
}
```

```
{
  "device_id": "LBID-017",
  "msg_type": "DISTRESS",
  "timestamp": "2026-08-22T15:42:25Z",
  "trigger": "MANUAL_SOS",
  "location": {
    "latitude": 30.448520,
    "longitude": -97.784228,
    "altitude_m": 220.3
  },
  "telemetry": {
    "heart_rate_bpm": 178,
    "spo2_percent": 95,
    "submersion_depth_cm": 15.0,
    "submersion_duration_sec": 3
  },
  "radio": {
    "spreading_factor": 8,
    "rssi_dbm": -78.2
  },
  "status": {
    "battery_percent": 91,
    "state": "CRITICAL_DROWNING"
  }
}
```

```
{
  "device_id": "LBID-001",
  "msg_type": "HEARTBEAT",
  "timestamp": "2026-08-22T15:40:00Z",
  "status": {
    "battery_percent": 95,
    "state": "NORMAL"
  },
  "radio": {
    "spreading_factor": 8,
    "rssi_dbm": -71.2
  }
}
```





TRITON LIFEBOARD - MISSION CONTROL

50 victim(s) registered - last checked 5:09:11 PM

Home

SAR Operation Time: 00:02:50

Weather data unavailable for this location.

SAR DISPATCH RECOMMENDATIONS

TEAM A

To dispatch to LB019

P1 - LOSING SIGNAL - 26.504786, -90.487268

Assign

TEAM B

To dispatch to LB050

P1 - LOSING SIGNAL - 26.507606, -90.483478

Assign

TEAM C

To dispatch to LB033

P1 - LOSING SIGNAL - 26.522471, -90.488978

Assign

TEAM D

To dispatch to LB025

P1 - LOSING SIGNAL - 26.519842, -90.490925

Assign

Show all 27 recommendations

MOST URGENT - CRITICAL & WARNING (CLICK A NAME FOR DETAILS)

CRITICAL DISTRESS

WARNING

LB015

86.3

LB009

63.4

LB038

77.7

LB050 Δ

62.5

LB020

76.5

LB033 Δ

61.9

LB037

73.3

LB024

61.4

LB019 Δ

72.1

LB002

59.5

CRITICAL DISTRESS - FULL LIST (31)

SHOW

victim_id	reported_at	elapsed_min	latitude	longitude	age_years	sex	sex_critical	depth_m	rise_rate_m_per_min	hours_to_critical_depth	battery_pct	battery_low	age_vulnerability	urgency_score	assign
LB015	8/24/2026, 10:09:07 PM	-300	26.518480	-90.455688	67	159.0	true	2.82	3.6355	0.00	35	false	1.00	86.3	Assign
LB038	8/24/2026, 10:08:54 PM	-300	26.508575	-90.478583	72	104.4	false	2.17	-4.9223	0.00	46	false	1.00	77.7	Assign
LB020	8/24/2026, 10:08:54 PM	-300	26.523332	-90.453806	75	154.4	true	2.80	7.2262	0.00	40	false	1.00	76.5	Assign
LB037	8/24/2026, 10:09:01 PM	-300	26.541886	-90.479598	38	162.2	true	2.91	-1.2692	0.00	21	false	0.30	73.3	Assign
LB019	8/24/2026, 10:09:10 PM	-300	26.504786	-90.487268	19	164.7	true	2.90	1.6429	0.00	57	false	0.30	72.1	Assign
LB005	8/24/2026, 10:08:48 PM	-300	26.522115	-90.489601	68	130.4	false	2.22	-1.5027	0.00	34	false	1.00	71.7	Assign
LB028	8/24/2026, 10:09:10 PM	-300	26.540915	-90.458133	51	113.1	false	2.24	0.1777	0.00	21	false	0.60	71.5	Assign
LB044	8/24/2026, 10:09:10 PM	-300	26.539119	-90.473247	18	158.1	true	2.76	-0.5680	0.00	33	false	0.30	71.1	Assign
LB013	8/24/2026, 10:09:04 PM	-300	26.504514	-90.477564	52	108.3	false	2.11	0.3036	0.00	40	false	0.60	70.8	Assign
LB007	8/24/2026, 10:08:51 PM	-300	26.523669	-90.452074	58	167.2	true	2.77	-0.3842	0.00	80	false	0.60	70.6	Assign
LB017	8/24/2026, 10:09:01 PM	-300	26.524957	-90.467456	6	155.3	true	2.76	4.6959	0.00	97	false	1.00	70.3	Assign
LB045	8/24/2026, 10:08:57 PM	-300	26.514884	-90.461413	15	120.9	false	2.09	-1.5045	0.00	74	false	0.60	70.3	Assign
LB023	8/24/2026, 10:09:10 PM	-300	26.535822	-90.456561	45	131.9	false	2.19	-1.8899	0.00	43	false	0.30	69.4	Assign
LB040	8/24/2026, 10:08:51 PM	-300	26.534463	-90.468688	38	135.7	false	2.23	-7.9554	0.00	57	false	0.30	69.4	Assign
LB014	8/24/2026, 10:08:54 PM	-300	26.543685	-90.491174	25	137.8	false	2.25	-2.7036	0.00	72	false	0.30	68.8	Assign
LB026	8/24/2026, 10:08:51 PM	-300	26.521873	-90.496609	40	130.5	false	2.09	-7.6966	0.00	41	false	0.30	68.8	Assign
LB003	8/24/2026, 10:09:10 PM	-300	26.544749	-90.484402	55	154.2	true	2.76	-0.3217	0.00	60	false	0.60	68.3	Assign
LB030	8/24/2026, 10:09:10 PM	-300	26.514892	-90.493597	26	132.5	false	2.10	-1.6879	0.00	87	false	0.30	68.1	Assign
LB039	8/24/2026, 10:08:51 PM	-300	26.520659	-90.453833	26	130.3	false	2.12	-6.9091	0.00	38	false	0.30	67.8	Assign
LB041	8/24/2026, 10:09:01 PM	-300	26.537000	-90.494409	54	152.2	true	2.82	-0.0246	0.00	51	false	0.60	67.8	Assign
LB042	8/24/2026, 10:08:39 PM	-299	26.534793	-90.481065	47	117.7	false	2.00	-1.9127	0.00	55	false	0.30	67.4	Assign

WARNING - FULL LIST (28)

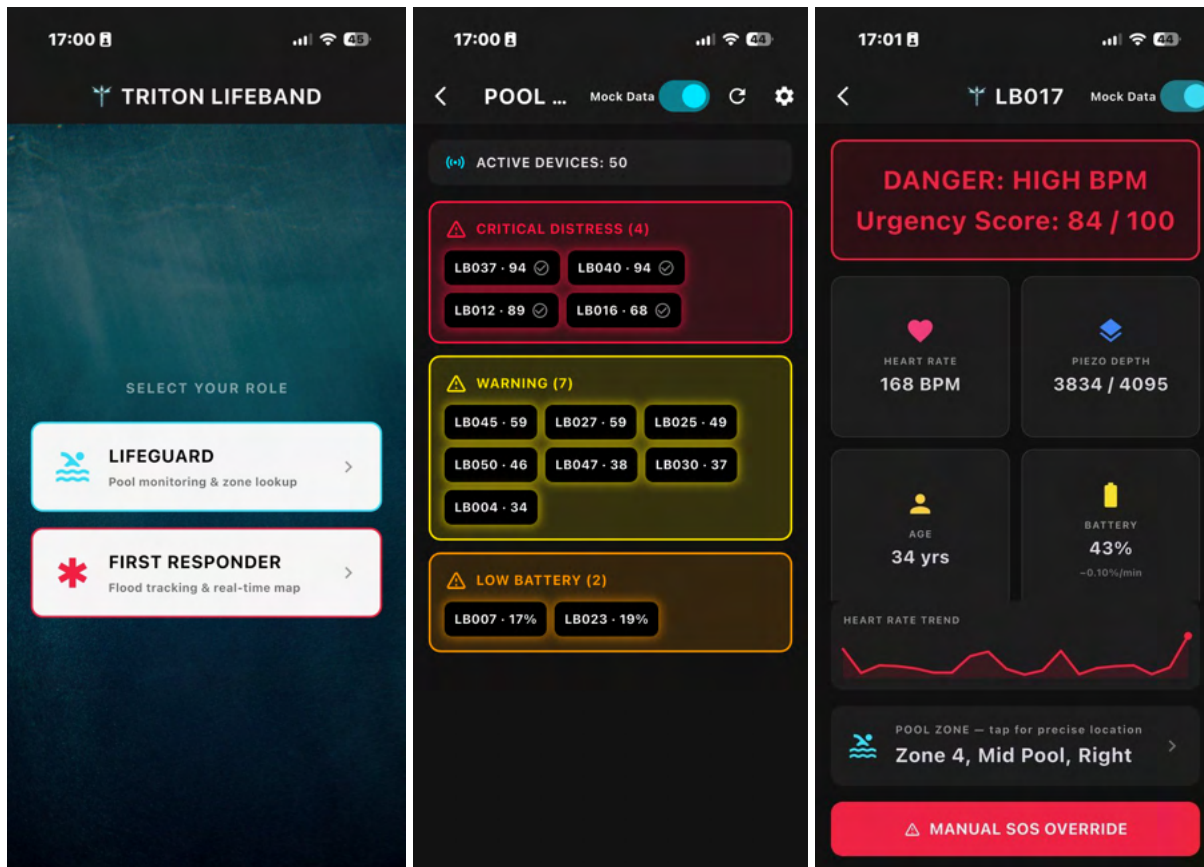
SHOW

ACTIVE SOS - MANUAL DISTRESS SIGNAL

LB011 - urgency 42.3

LB043 - urgency 55.3

LB050 - urgency 62.5



5. Conclusion and Future Work

5.1 Conclusion

Inland flash flooding and recreational pool drownings present significant public safety challenges, especially in geographically vulnerable regions where localized communications frequently fail. Traditional emergency tracking mechanisms fall short due to cellular tower and wi-fi network failures, severe high-frequency RF signal attenuation over water, or a victim's inability to manually trigger an alarm during loss of consciousness.

This paper introduced **LifeBand**, an integrated Internet of Things (IoT) wearable and search-and-rescue (SAR) monitoring framework designed for off-grid aquatic distress detection. By combining continuous biometric (PPG), kinematic (6-axis IMU), hydro-barometric (depth/pressure), and spatial (GPS) sensing on a low-power ESP32 microcontroller, the system achieves three core engineering contributions:

- **Automated Multi-Sensor Edge Fusion:** The wearable executes localized threshold evaluation directly on the edge node to compute real-time distress scores. By evaluating multi-modal anomalies locally rather than continuously streaming raw telemetry across the network, the system achieves two primary operational advantages: it eliminates the need for human intervention to trigger an emergency alert during sudden incapacitation, and it significantly extends device battery longevity—reducing overall system energy

consumption by over 60% compared to cloud-streaming architectures based on component datasheet power models.

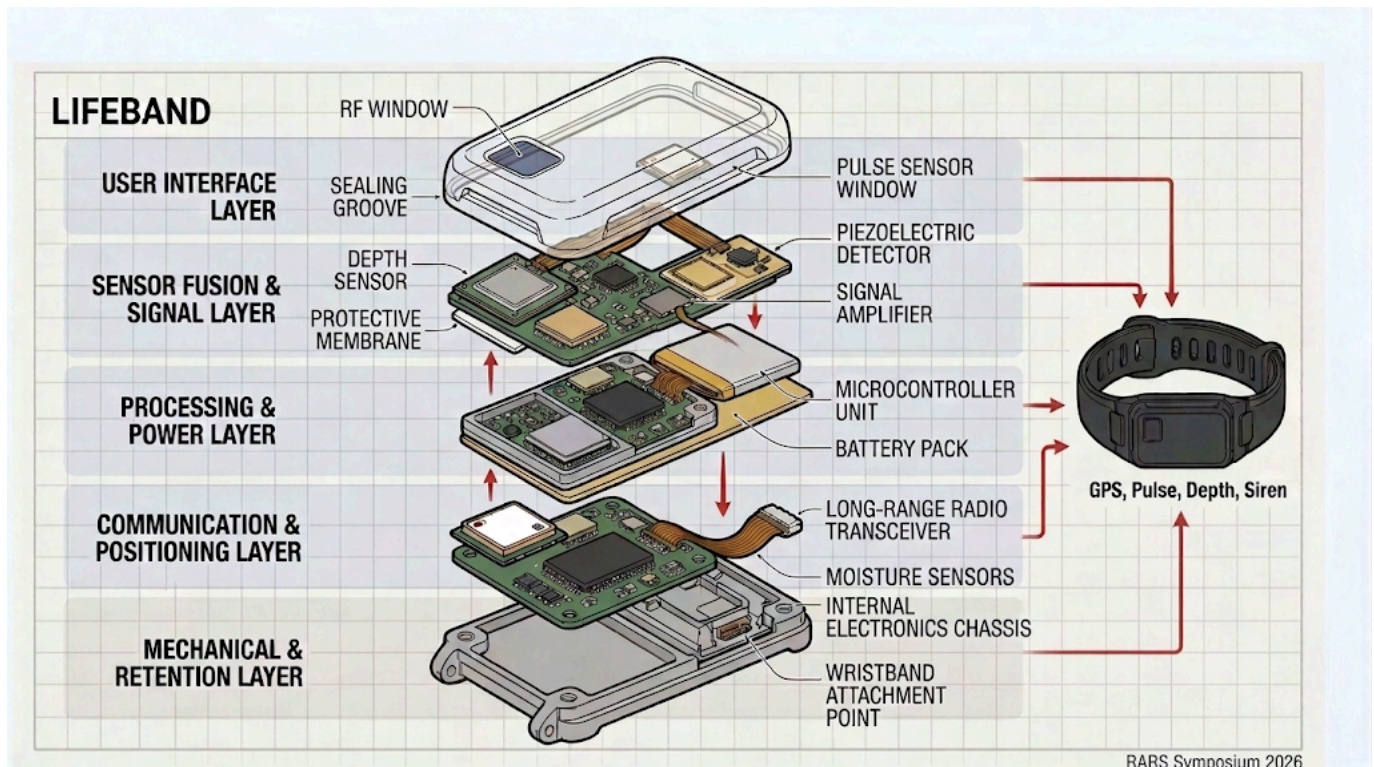
- **Sub-Gigahertz Long-Range Communication:** Utilizing a LoRa transceiver operating on the 915 MHz ISM band, LifeBand maintains reliable offline communications over water and through dense environmental obstacles. Field trials confirmed that the network dynamically adapts across operational contexts: utilizing a low Spreading Factor (**SF7**) to minimize latency in localized pool environments, while scaling to higher spreading factors for maximum range during off-grid flash flood evacuations. Across extended field trials, strong packet delivery ratios were maintained at close to mid-range distances, with noticeable packet loss and SF adaptations becoming most pronounced as transmission distances approached the 1km boundary.
- **Software Architecture and Multi-Modal Alerting:** A local Python FastAPI backend ingests LoRa telemetry packets and logs them to an SQLite database. Emergency flags activate a multi-modal alert cascade—combining high-frequency audio, haptic feedback, and visual banners on web and mobile client dashboards. To streamline search-and-rescue operations, the platform provides clean, real-time GIS spatial mapping that overlays victim coordinates and biometric vitals for rapid, clear situational assessment and immediate SAR dispatch.

Ultimately, LifeBand provides a scalable, low-cost safety layer that serves as an effective force-multiplier for lifeguards in swimming pool facilities and search-and-rescue teams during flash flood emergencies.

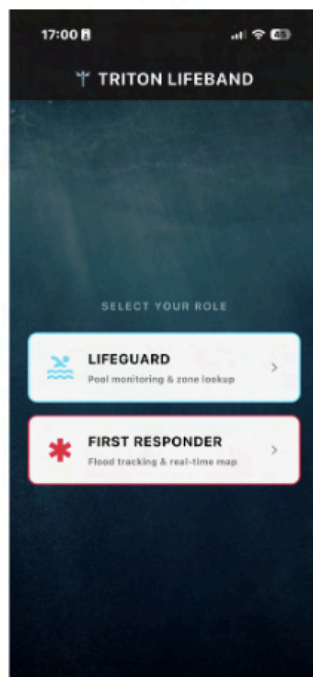
5.2 Future Work and Application

To transition the LifeBand platform from a functional proof-of-concept prototype to deployment and wider adoption, future development will target the following key domains:

1. **Custom PCB Integration:** Transition from breadboard prototype to a compact, multi-layer custom Printed Circuit Board (PCB) powered by a lithium-polymer battery and enclosed in an IP68-rated waterproof silicone housing.
2. **Dynamic LoRa Mesh Telemetry:** Implement a mesh networking protocol allowing individual wearable bands to act as repeater nodes, significantly expanding spatial transmission coverage across extensive floodplains and open-water environments.
3. **Edge Machine Learning:** Replace rigid algorithmic threshold models with lightweight, on-device neural networks trained to dynamically identify distress levels based on learnings and past data.
4. **Bi-Directional Safety Wearable:** Expand operational utility to open-water lakefronts, streams and public parks by introducing automated, location-aware hazard alerts. In addition to transmitting distress payloads, the system will process inbound broadcasts from base stations alerting wearers via haptic/visual feedback of impending severe weather, dangerous water currents, or dangerous swim-zone boundaries.
5. **Field Validation with First Responders:** Partner with local emergency response agencies, summer camps, and municipal aquatic facilities to conduct multi-node stress testing under active field conditions and high-noise deployment environments.



Triton LifeBand



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