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A novel Architecture for Sensor-based Rescue Management using Smart Band and Handheld Device Prototypes based on Low-Power Wireless Technology

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Abstract

Objective: This research aims to enhance search and rescue operations through the development of a Sensor-based Rescue Management System (SRMS). The objectives include proposing architectures for pre and post-disaster scenarios, designing prototypes for a Smart Band and Hand Held Device (HHD), and conducting experimentation, results analysis, and power consumption analysis. **Methodology:** The SRMS architecture enables timely assistance to end users and provides precise information to rescue teams. In pre-disaster scenarios, the smart band communicates the user's health status to a centralized server via the infrastructure. Notifications are sent to rescue teams for prompt response. In post-disaster situations, where the network infrastructure is damaged, rescue teams use HHDs to log sensor data from smart bands. The HHDs store the information offline and transmit it to the server when network connectivity is restored. Local HHD applications analyze the data for abnormalities, while server applications analyze sensor data to direct additional rescue teams. **Findings:** The SRMS utilizes low-power wireless mesh network technology with multi-hop communication. Field experiments demonstrated the system's affordability, scalability, and ability to generate alerts in medical emergencies. Power analysis indicated that the smart band prototype has a battery life of approximately 6 days with a 300 mAh battery, while the HHD can run for approximately 9 hours with a 5000 mAh battery. **Novelty:** This proposed system offers quick deployment, scalability, cost-effectiveness, and optimization of end node lifespan. It introduces novel architecture design, end node and HHD prototypes, and the use of low-power wireless technologies in various terrains. Additionally, the SRMS addresses offline connectivity by storing sensor data and transmitting it when network connectivity is restored. It significantly improves decision-making quality, efficiency, and effectiveness in disaster management activities.

Keywords: Disaster Management; Sensor Based Rescue Management System; Pre And Post Disaster Scenarios; Smart Band; Hand Held Device (HHD); Low Power Wireless Mesh Network; Offline Connectivity; Zigbee; Wirepas; Heart Rate Monitoring; Body Temperature Monitoring; Step Count; Wireless Sensor Network

1 Introduction

Rescue management systems rely on timely access to data and quick decision-making for successful outcomes. In this context, having knowledge of the health status of individuals in need of rescue is of paramount importance. Information such as heart rate, body temperature, and movement needs to be shared with rescue teams to facilitate efficient and effective assistance.

This research aims to address the challenges in rescue management by proposing a novel Sensor-based Rescue Management System (SRMS) that enables quick deployment, ensures long node life, and caters to the requirements of both pre-disaster and post-disaster scenarios. The key contributions of this study include the design and development of a smart band (or end node) capable of tracking the health status of the end user, which has been experimented with using both ZigBee and Wirepas technologies.

Additionally, a Hand Held Device (HHD) has been designed and developed specifically for rescue team personnel. The HHD receives alerts from the base station and allows rescue support to be offered to the end user without explicit requests. The SRMS also addresses the need for offline connectivity by implementing a solution where user sensor data is stored in offline storage and transmitted to the base station once the connection is restored.

Various applications have been developed to run on the smart band, HHD, network devices, and the base station for seamless functionality. These applications facilitate communication, process the sensor data, and analyze it wherever necessary. To validate the practicality and performance of the proposed system, extensive experimentation, cost analysis, and performance analysis have been conducted using industry-grade wireless technologies, specifically Wirepas. This wireless technology is widely known for its low-power machine-to-machine communication capabilities, mesh network topology, and interoperability in sensor networks. By addressing the challenges of data availability, decision-making speed, and health status tracking, the SRMS presented in this paper holds the potential to greatly improve the quality and efficiency of rescue management activities at all levels.

Wirepas Mesh is a wireless networking technology known for its robust mesh network topology and multi-hop communication capabilities. It offers reliable and scalable connectivity, making it well-suited for applications such as SRMS. Wirepas Mesh provides extensive coverage, moderate to high data rates, and optimized power consumption, ensuring efficient and seamless communication in challenging environments. ZigBee, another mesh networking technology, operates on a standardized protocol and is widely used for interoperability in sensor networks. While ZigBee offers moderate scalability and is suitable for indoor applications, its scalability and range may be limited for large-scale deployments encountered in SRMS. Additionally, ZigBee focuses on low-power operation, which may not meet the data rate requirements for real-time health monitoring in SRMS.

LoRa, based on a star-of-stars topology, excels in long-range communication and is suitable for applications prioritizing power efficiency. It offers extended coverage over several kilometers but sacrifices data rates. In SRMS, where timely health status updates and quick decision-making are critical, the lower data rates of LoRa may not meet the requirements for real-time communication and alert generation. In contrast, Wirepas

Mesh addresses the specific needs of SRMS effectively. It provides extensive coverage, moderate to high data rates, and optimized power consumption, ensuring reliable and efficient communication. Its decentralized architecture allows for scalable deployments and seamless connectivity in diverse terrains encountered during rescue operations.

Considering these factors, Wirepas Mesh emerges as a highly suitable choice for SRMS implementation, offering the necessary capabilities for real-time health monitoring, quick alert generation, and coordination between rescue team personnel and the base station. Its strengths in scalability, range, data rates, and power efficiency make it a preferred option over ZigBee and LoRa in meeting the unique challenges of SRMS effectively.

Ahsan et al.[1] explores the use of wireless sensor networks (WSNs) and IoT technologies in disaster management. It discusses the challenges and opportunities associated with deploying WSNs and IoT devices in disaster-prone areas, and highlights their potential benefits in early warning systems, disaster monitoring, and post-disaster recovery. In[2], Kamal G. et.al discuss various aspects of WSNs in IoT, including architecture, communication protocols, data aggregation, security, and energy efficiency. They analyze the different techniques and algorithms used in WSNs for IoT applications, highlighting their advantages, limitations, and potential challenges. In[3], Islam et al. provide an overview of IoT devices in healthcare, including their capabilities, architectures, and communication protocols. They also discuss various smart applications that leverage IoT technologies to improve healthcare services and patient care. In[4], M. Nasr et al. presented an overview of AI applications in healthcare, highlighting the potential benefits and advancements in areas such as diagnosis, treatment, patient monitoring, and data analysis. They also address the challenges associated with implementing AI in healthcare and discuss future prospects for smart healthcare systems. These works in literature surveys on wireless sensor networks and IoT in disaster management, whereas SRMS focuses on addressing the specific challenges and requirements of pre and post-disaster scenarios. The SRMS proposes a novel architecture for quick deployment, design and development of a smart band for tracking the health status of end users, a Hand Held Device (HHD) for rescue team personnel, and offline connectivity support. SRMS emphasizes experimentation, power consumption analysis, and the development of applications tailored for SRMS. Unlike the survey paper, the SRMS provides a focused and practical approach to enhancing search and rescue operations in disaster scenarios.

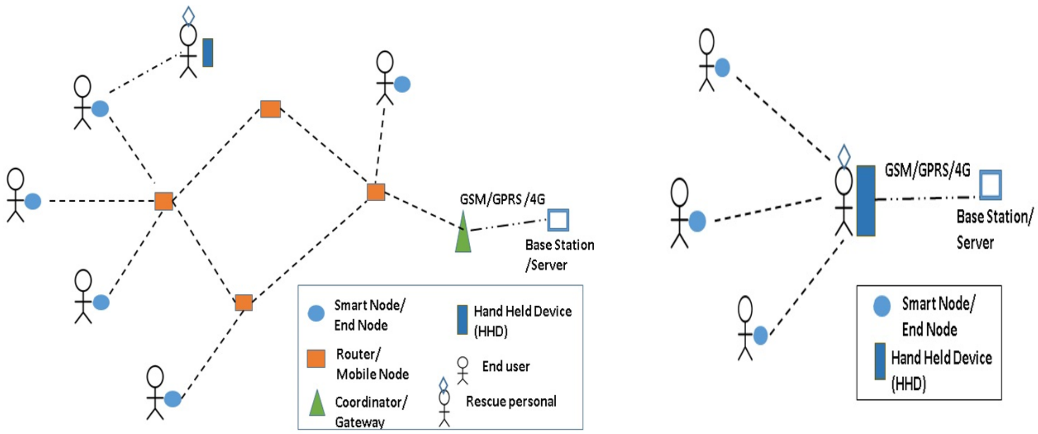
In[5], Dahlia Sam et.al present a system that utilizes IoT devices and sensors to monitor and collect health-related data from individuals remotely. The system allows for real-time monitoring of vital signs such as heart rate, blood pressure, and body temperature. It also incorporates data analysis and visualization techniques to provide insights into the individual's health status. In[6] Salem et al. focuses on personal health monitoring, providing individuals with access to their own physiological data. These works focus on remote health monitoring whereas the proposed SRMS has a broader scope in terms of search and rescue operations. The SRMS incorporates multiple components and functionalities specifically designed for rescue scenarios, such as emergency notifications, location tracking, and coordination among rescue team personnel.

The authors in[7] presented a system that utilizes LoRaWAN-based sensors to detect fire incidents in the Mina area during the Hajj pilgrimage. The system employs a network of wireless sensors that monitor temperature and smoke levels, enabling real-time fire detection and alerting authorities for immediate response. Here authors focuses on fire detection in a specific pilgrimage context, using LoRaWAN-based sensors. In[8], Anna Brodin et al. present an algorithm that utilizes accelerometer data from wearable devices to accurately count the number of steps taken by an individual. The algorithm is designed to be open-source, allowing for easy integration into various wearable devices and applications. Here the authors focuses on accurately counting steps for fitness and activity tracking purposes. On the other hand, the SRMS addresses the broader domain of search and rescue operations, including health monitoring, emergency notifications, and coordination among rescue team personnel.

The outline of the paper is as follows. The methodology and proposed architecture given in Section 2. outlines the approach taken to design and develop the SRMS. It discusses the integration of low-power wireless technologies, such as Wirepas mesh network and presents the proposed architecture that incorporates smart bands, handheld devices, and a centralized base station. The implementation section following Section 2 describes the practical implementation of the SRMS. It details the hardware and software components used, including the sensors, microcontrollers, communication protocols, and networking devices. The implementation details are presented in Section 3 provide insights into the technical aspects of the system. Section 4 presents the findings obtained from the experimentation and evaluation of the SRMS. The conclusion section summarizes the key contributions and outcomes of the proposed work. The conclusion also discusses potential future advancements and research directions to further improve the system.

2 Methodology

This section presents the methodology and proposed architecture for the development of the Sensor-based Rescue Management System (SRMS). By integrating the proposed architecture with the methodology, we present a comprehensive understanding of the approach taken to develop the SRMS. The proposed architecture and consisting of the key components is depicted in Figure 1.



a) Pre disaster scenario b) Post disaster scenario

Fig 1. SRMS Proposed Architecture

The primary objective of the SRMS is to provide a sensor network-based solution that enables timely assistance for end users and offers vital information to rescue team personnel for effective rescue services. To achieve this, a comprehensive approach was devised, encompassing both pre-disaster and post-disaster scenarios.

In the pre-disaster scenario as shown in Figure 1 a, the health status of individuals wearing smart bands is periodically communicated to a server through the existing infrastructure. Algorithms running on the server analyze the sensor data and trigger emergency notifications to the rescue team personnel when necessary, facilitating prompt response and assistance. In the post-disaster scenario as shown in Figure 1 b, where infrastructure may be damaged or unavailable, rescue team personnel utilize hand-held devices equipped with sensor data logging capabilities. They log information from the smart bands worn by the users and transmit it to a centralized server. Dedicated applications on the hand-held devices process the received data, identifying any abnormalities or emergency situations.

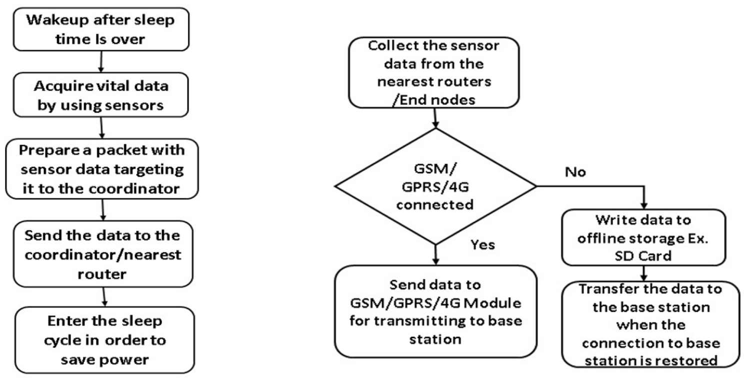
In SRMS, each user is provided with a smart node featuring accelerometers, temperature sensors, and heart rate sensors. The collected sensor data is wirelessly transmitted to the centralized system using the Wirepas mesh network and the Wirepas module. To facilitate data relaying over long distances, specific network nodes are designated as router nodes. These nodes assist in transmitting data from the smart nodes to the coordinator/gateway device, ensuring efficient data communication. The gateway device acts as the central hub for receiving and aggregating the sensor data. Communication between the sink node, router nodes, and end nodes forms a wireless mesh network, enabling seamless data routing and aggregation.

2.1 Smart node and coordinator node

The proposed architecture includes a flow diagram depicting working of the the smart node and coordinator, illustrated in Figure 2 a and Figure 2 b, respectively. These figures provide insights into the data flow and communication process within the system.

The smart band follows a procedure to periodically transmit the user's health status to the nearest router/coordinator, as illustrated in Figure 2 a. The coordinator node receives sensor data from the smart band/end node and attempts to transmit the data to the base station via the network connection. In the event that the network connection is unavailable, the data is stored in the SD card (offline storage) and will be transmitted to the base station once network connectivity is reestablished. The step-by-step process followed by the coordinator node is depicted in Figure 2 b.

On the other hand, HHD node comprises of Beagle Bone Black, wireless module and a LCD display. The detailed flow diagram of HHD is shown in Figure 3 . As illustrated in the flow diagram of the HHD, the scan module performs regular scans for smart band nodes within its proximity. It receives information from the smart nodes, locally processes and analyzes the data for abnormalities before transmitting it to the centralized server, provided network connectivity is available. In case of network unavailability, the data is stored offline and transferred to the base station once the network connection is restored. At the base station, algorithms analyze the received data and generate notifications to guide additional rescue team personnel to the field. This configuration facilitates the seamless transfer of data and ensures effective communication within the SRMS.



(a) Smart node (b) Coordinator node

Fig 2. Flow diagram of End node and coordinator

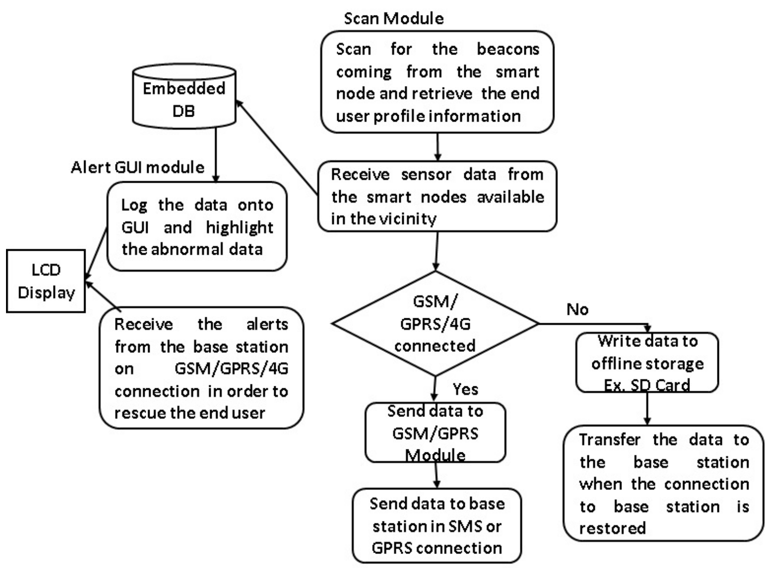
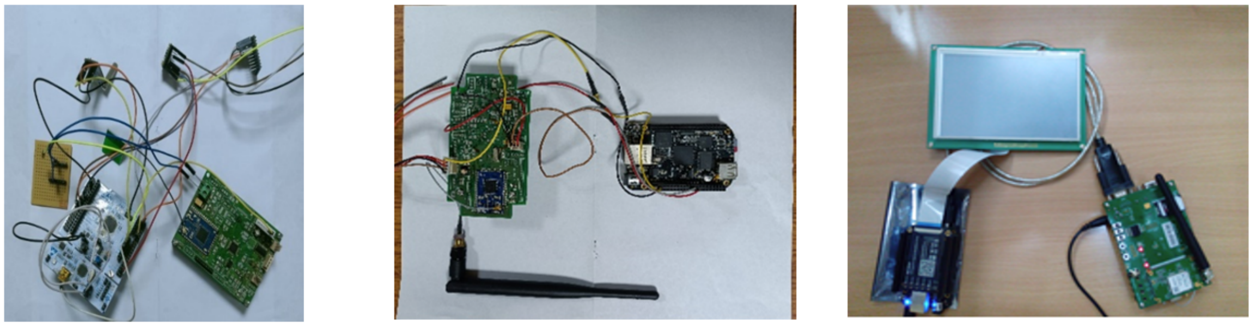


Fig 3. Flow diagram of Hand Held Device

3 Results and Discussion

The designed prototypes of smart node, coordinator/gateway node and Hand Held device are shown in the Figure 4. The smart node interfaces three sensors to the NUCLEOL073RZ board, and the sensor data is read through the I2C protocol. As shown the microcontroller unit (MCU) on the NUCLEOL073RZ board processes the data, which is then shared with the STM32F0CC board using the UART protocol. This enables seamless communication between the sensors and the STM32F0CC board, facilitating data transfer and processing. Subsequently, the data from the STM32F0CCT6 board is shared with the Wirepas module using the UART protocol. Acting as a host microcontroller, the STM32F0CCT6 board stores the Wirepas mesh stack application and processes data based on the communication signals received from the STM32L073RZ board and the network. The Wirepas module, configured as an end node, transmits data into the network. In the proposed architecture, the router is implemented using the STM32F0CCT6 board with the Wirepas module, specifically configured as a router. The router node is responsible for routing the data received from the end nodes, contributing to the network's overall efficiency. The HHD node comprises of Beagle Bone Black, wireless module and a LCD display.



(a)Smart Node prototype (b) Coordinator Node (c)Hand Held Device

Fig 4. Prototypes developed in SRMS

The detailed steps followed in calibration for retrieving step count, heart beat and body temperature by the end node are discussed.

3.1 Step count sensor

MPU-9250 sensor is a digital sensor used for step count has the data registers which can be configured for the required operations by following procedure given below:

1. Initiate the sensor configuration register and sets the self-test and off-set value.
2. FIFO buffer starts to keep the sensor data.
3. Sensor data was used by reading operations using I2C protocol. The sensor data samples are averaged.
4. Acceleration along 3-axis was considered for the step count calculation.
5. The threshold value is used to determine the valid step.
6. System starts considering the walk after a valid number of steps.

3.2 Heart rate sensor

The MAX-30102 sensor is low power digital sensor, which works on the reflection method. When finger is placed on the LED, light will be reflected and it will be collected by the photo diode in sensor. The steps followed in calibration of the heartrate sensor are shown here.

1. The sensor registers should be initialized.
2. Setting up the wavelength and selecting the required LED. Initialize the FIFO buffer
3. Keeping the data in a temporary buffer
4. Averaging the samples
5. Finding the beat using threshold value (if reflected light collected at the photo diode is greater than threshold value, then it is considered as valid sample).
6. Calculating the time for valid no beats.
7. Calculating heartbeat per minute.

3.3 Temperature sensor

The Max-30205 is a body temperature sensor that accurately measures temperature and sends out an overheating alert signal. The procedure followed in calibration of temperature sensor are is given below.

1. Initialize the configuration register, which stores 8 bits of information and is used to start individual translations, set data format.

2. The higher limit is set via the THYST register
3. Data saved in temperature register is read by using I2C protocol. It is multiplied with step size value to get the temperature.

3.4 Hand Held Device prototype

Beagle Bone Black is used in HHD prototype development for communicating with smart nodes via wireless module interfaced. HHD also uses a LCD display for providing graphical user interface (GUI) to the rescue team personnel and GSM/GPRS modem to communicate the smart node sensor data to the centralized server. HHD may also be interfaced with GPS transceiver to retrieve location precisely. The steps followed in building HHD prototype are shown below:

3.5 Procedure for configuring the Hand Held Device

1. Preparing the SD card
2. Download bone Debian image
3. Tool chain download
4. Updating the kernel image
5. Enabling the UART1 on the Beagle Bone Black
6. Cloning C-Mesh-api (code for Wirepas mesh network)
7. Compile with updated tool chain using Make file of C-Mesh-api.
8. Interfacing the LCD cape
9. Interfacing GSM/GPRS, GPS modules

3.6 Performance Evaluation and Analysis

3.6.1 Power Analysis

Smart node power consumption analysis is performed based on parameter values reported in Tables 1 and 2 are taken from the respective components data sheets.

Table 1. Smart Node power analysis

Component	Active Current	Sleep Current	Active time per cycle (sec)	Cycles per hour	Total Current (mAh)
STM32F030	22 mA	5 μA	10	12	0.7338
MAX30205	925 μA	3.5 μA	2	12	0.0101
MAX30112	308 μA	50 μA	2	12	0.0517
ICM20948	3.11mA	4 μA	10	12	0.1075
Wirepas	30 mA	120 μA	10	12	1.116
Battery Charger IC	55 μA	55 μA	10	12	0.0549

Considering the data shown Table 1, assuming 5 minute duty cycle every hour smart node in active mode is 120 seconds and sensor active mode is 24 seconds approximately. Total current consumption by smart node using Wirepas module per hour is 49.88 mAh approximately and with a 300 mAh battery the smart node can run continuously approximately 6 days. A Smart Node prototype developed with CC2538 module instead of Wirepas consumes 149 mAh approximately and with a 300 mAh battery the smart node can run for 2 days approximately. Hence, SRMS preferred to use Wirepas as wireless technology solution for communication and prototype building and network setup.

3.6.2 Hand Held Node Power Consumption Analysis

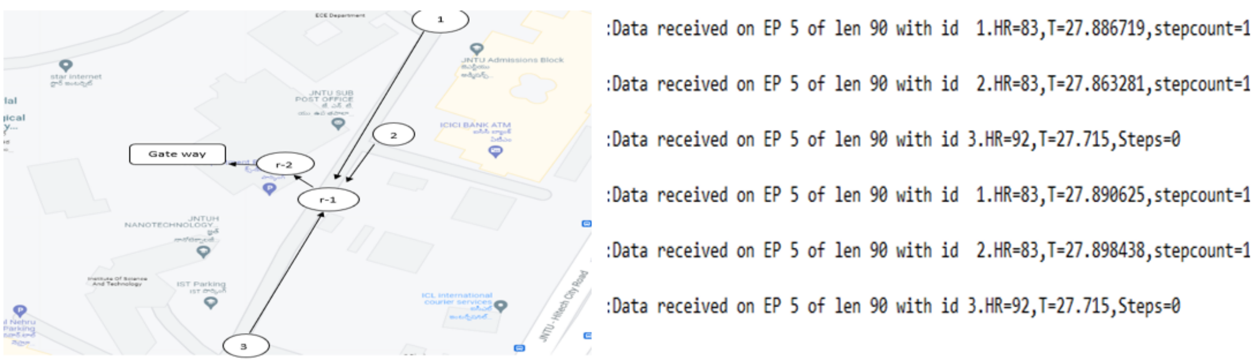
As given in Table 2, HHD LCD display duty cycle assumed as 20% per hour so the display current is 120 mAh. Total current consumption will be 575.3 mAh per day approximately. Considering 5000 mAh battery in powering HHD we can get up to 9 hours continuous search operation. Rescue team personnel can carry spare batteries and continue operations without interruptions.

Table 2. HHD power analysis

Component	Active current (mA)	Total current per hour(mAh)
Beagle Bone Black	430	430
LTE Modem	3.3	3.3
Wireless module	22	22
Touch LCD	600	600

3.7 Outdoor experiment and analysis

For outdoor experiments, the three end nodes in different positions in our work and observed the data received at the sink node. We have four test cases for monitoring the behavior of wireless sensor networks. In each test case, end nodes are placed with different scenarios like (i) within a line of communication with gateway, (ii) without a line of communication with gateway, (iii) using the router in case of no line communication to enable the data transmission to gateway and (iv) outdoor experiment to observe the range of communication distance.

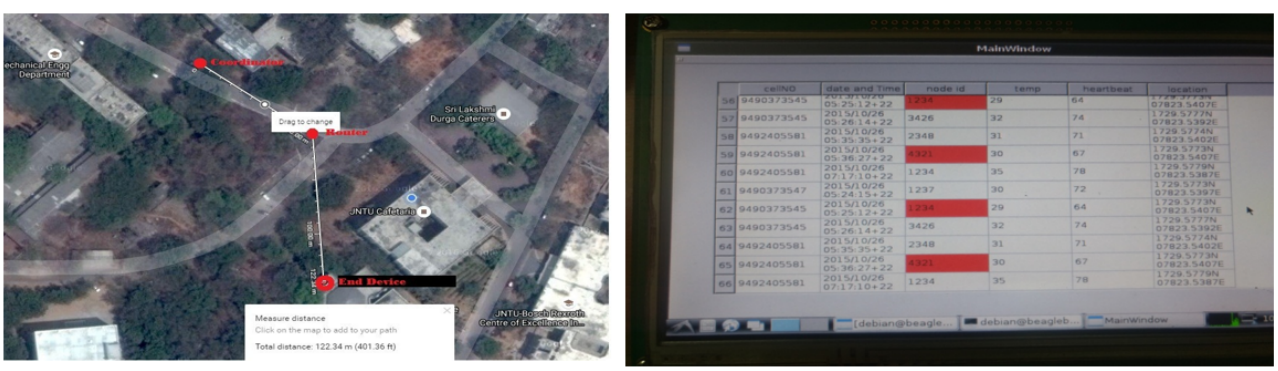


(a)Sample field experiment scenarios

(b) Data received in different scenarios at the coordinator node

Fig 5. Smart node field experimentation

Figure 5 depicts a google map showing the positions used in outdoor experiment scenarios. 1, 2, and 3 represent three scenarios of end nodes positions, and r-1 and r-2 represent router nodes



(a) Outdoor experiment carried out

(b) The received data is displayed on GUI

Fig 6. Outdoor experimentation with Smart node and HHD

When all the three smart nodes are placed in the line of communication with the gateway inside a building without routers. The data is successfully received at the coordinator node. In the output, HR means heart rate per minute; T means body temperature, and step count is the number of steps the person moves. Since we have used three nodes, there are three strings of data. The output received at the gateway is shown in figure 5b. When all the nodes are placed very far, without a line of communication with the gateway node it is observed that no signal is received at the gateway. On placing two routers r-1 and r-2 in appropriate positions it observed that the smart node's data is communicated to gateway node through multi-hop communication.
In our experimentation, it is observed that communication inside the building is difficult for far distances because of concrete wall obstruction. Multiple routers are required for data transmission in the network. In outdoor experiments, transmission is possible for longer distances with help of multi-hop communication.

Figure 6 demonstrates the experimentation carried out in our JNTUH university campus and data captured by HHD. The Data received by the HHD is displayed on the GUI developed in Qt. The captured data beyond the threshold is highlighted for the attention of rescue team personal.

4 Conclusion

The SRMS presents an innovative architecture for sensor-based rescue management, leveraging smart bands and handheld devices powered by low-power wireless technology. This system revolutionizes emergency response by enabling real-time monitoring of user health status and prompt notifications to rescue personnel. The integration of Wirepas mesh ensures seamless data transmission, even in situations where network infrastructure is damaged or unavailable. Advanced algorithms for data analysis enhance anomaly detection and facilitate appropriate actions. The collaboration between smart bands, handheld devices, and the base station optimizes information flow, enabling proactive monitoring and swift response to diverse emergency scenarios. Experimental results validate the feasibility and effectiveness of the proposed architecture, showcasing its potential for revolutionizing rescue management. Future improvements, such as compact design and efficient algorithms, can further enhance the prototypes. Additionally, incorporating drones as carriers for handheld devices can expand the reach of rescue teams. Continued research and development in this field hold promise for more efficient and effective search and rescue operations.

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