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LoRa enabled Real-time Monitoring of Workers in Building Construction Site

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ABSTRACT- In construction, the real-time monitoring of the worker is necessary for ensuring safety in terms of health and accidents. The technology advancement in the sensors and wireless communication technology has inspired to implement Internet of Things (IoT) real-time monitoring in construction site. With this motivation, in this study we have proposed a system that is powered with long range (LoRa) and IEEE 802.15.4 based Zigbee communication for real-time implementation. Worker health monitoring mote, helmet detection mote, shoe detection mote, and glove detection mote are the primary components of the proposed system. In addition to this, a local server is embedded to supervise all the primary components and interconnect with gateway to log the real-time data on the cloud server for real-time implementation. As proof of concept, one of primary component i.e., health monitoring mote is implemented in the construction site to measure temperature and pulse rate of the work. In future, the remain components will be implemented in construction site, for the implementation of complete system in real-time. The current study enables to monitor the worker in the construction site and assist to respond immediately in case of emergency.

General Terms: Construction, worker's health, LoRa

Keywords: Construction; real-time monitoring; IoT; wireless sensor network (WSN); Wi-Fi; Zigbee and LoRa.

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1. INTRODUCTION

The construction sector is identified as important economic backbone of a country due to multiple categories of construction projects along with the importance of huge end-users [1]. Construction projects are highly beneficial but they are usually vulnerable to a range of unknown hazards and remain one of the riskiest sectors to work with because of events at all occurrences [2]. If the risk analysis is not evaluated properly in the building project's lifetime, then these risky scenarios may lead to life-threatening [3,4]. Health and safety are two important factors that keeps the workplace essentially free from possible hazards of injury and provides the necessary protective equipment. It is concerned with the growth, advancement, and management of the working environment [5]. In traditional method, it is bit challenge to monitor the status of workers in the construction site. In order of enhancing the monitoring of the workers in real-time assists to minimize health related incidents and other kind of accidents. The implementation of wireless sensor network (WSN) in the construction industry enabled to connect the different elements of the construction site through wireless sensors and communication protocol [6] [30].

Currently the advancement in the sensory technology and wireless communication technology has empowered to implement real-time monitoring in any application. In order to implement real-time monitoring, IoT is one of prominent technology [7]. Sensors and communication technology combinedly assist to realize IoT in many applications. The communication protocols play a crucial role in implementing IoT enabled devices in real-time for the transmission of data to long-range with security and reliability. This study is inspired above facts and focused on implementing IoT with intelligent system for monitoring workers status in the construction site. Currently wireless communication is major component to implement IoT effectively [31]. There are different wireless communication protocols for transmitting the sensor data from one location to another location. However, the low power communication protocol is preferred in IoT devices as the it is consumed low power during transmission [32]. LoRa is one of the low powered wide area networks and Zigbee one of personal network based on IEEE 802.15.4 are gaining wide attention in the IoT due to its minimum power consumption during transmission. An IoT enabled local server-based architecture is proposed for monitoring and supervising the status of PPE kits including helmet, googles, gloves and shoes through IEEE 802.15.4 based Zigbee and 433 MHz based LoRa communication. In this study, we also focused on design the customized hardware for real-time implementation. The contribution of the study is as follows:

- IoT based automated system is implemented to enhance the safety and health monitoring of the workers at the construction site.
- Shoes detection mote, gloves detection mote, Worker Health Monitoring mote and helmet detection mote are the components that assists to realize the proposed system.
- Health monitoring mote is implemented on different

person of different age group for evaluation.

The organization of the study is as follows, *section 2* covers the background, *section 3* covers the system description; *section 4* covers the results and the conclusion of the article in the conclusion section.

2. PRIOR ART

Construction hand tools are widely utilized and may be found on construction sites all around the world. To carry, make, and install building components for their homestead, human ancestors created and used a variety of hand tools. Construction methods evolved and productivity rose with the introduction of hand tools, although workforce habits on the field altered as well [8]. However, data suggests that when hand tools, particularly power tools, are utilized in a variety of situations, they can cause a variety of injuries [9]. Investigation of construction operations concerns and discovered that practitioners regularly use powered and hand tools as a valuable asset, but they can also be risky [10]. The construction industry has always been considered of as an employment one, with hand tools being employed for a large portion of the work. New technology that assists construction workers, on the other hand, may have irreparable consequences if utilized incorrectly, recklessly, or in a harmful manner.

In 2007, manufacturing workers were the most frequently injured by hand tools, according to Hong Kong occupational injury statistics; nevertheless, construction workers were the most injured of all industrial sectors in 2015. The decrease in the number of injuries can be linked to the digital transformation, which includes the use of IoT in manufacturing [11,12]. Two popular recommendations for lowering the risk of tool-related injuries are to use personal protective equipment (PPE) and to upgrade hand tools [13, 14]. However, in practice, construction workers are unwilling to wear proper PPE, neglect to wear it, or wear the incorrect type of PPE for a variety of reasons, including: 1) the detrimental consequences of PPE on production; 2) the discomfort of wearing PPE, especially in high temperature weather; and 3) a lack of awareness on importance of wearing PPE and training to wear effective PPE. 4)negligence and not understanding the benefits of personal protective equipment (PPE) and a lack of information regarding the occurrence of frequent injuries and the possibility for death caused by improper use of hand-held equipment.

A study proposed an IoT-based system that uses trustworthy sensors to guarantee that people are wearing adequate PPE when utilizing both powered and non-powered hand-held equipment to minimize the risk posed by this equipment. Rapid building of smart construction sites is now possible because to recent advancements in electrical technology and computer science. Sensor-based safety management has provided designers, engineers, owners, and users with a variety of unique, automated, and smart services, making it one of the most interesting possibilities [15]. Safety management is more very crucial in preventing the occurrence of hazards than handling them after they occur. As a result, early hazard identification is critical for prevention, and large sensor-assisted safety management studies have proposed that a variety of sensors be used to identify hazards earlier on.

A haptic sensor like environmental sensors and biosensors, is directly placed on the object or included within the object that is to be monitored [16,17]. RFID readers and tags are integrated into the traditional construction supply system, dangerous tools and materials were effectively identified and traced from a safe distance [18,19]. Ultra-Wide Band (UWB) RFID was utilized to send huge amounts of data in a timely manner, implementing exact crane posture prediction and security space analysis [20,21]. Several other haptic sensors were also connected together simultaneously in order to extract a variety of building processes and improve safety management. To protect from falls and musculoskeletal disorders, the researchers used motion sensors to capture workers' muscular activity for workplace study [22,23]; Physiological sensors, such as eye trackers, electroencephalography (EEG) sensors, and electromyography (EMG) have lately been used to monitor physiological status for advanced occupational safety and health analyses [24,25].

2.1. Existing system for construction safety

General PPE on construction sites consists of many forms of protective clothing for the eye, head, hearing, hand, foot, breathing, and skin. Workers are prone to forgetting or using the improper protective equipment due to the range of protective equipment available. As a result, workers should be encouraged to pick appropriate PPE while on the job, taking into account the following criteria: 1) PPE should be chosen based on the recognized hazards during the building stage; workers. 2) PPE materials and specifications should be chosen in accordance with the detailed construction task. According to the Construction Site (Safety) Regulation, the obligatory PPE for certain activities is coupled with relevant hand tools in *Figure 1* [2]. Regardless of the construction operations, hand, head, skin, and boot protections are standard PPE for workers on most construction sites. PPE is selected for various safeguards based on task qualities such as the region and basic materials.

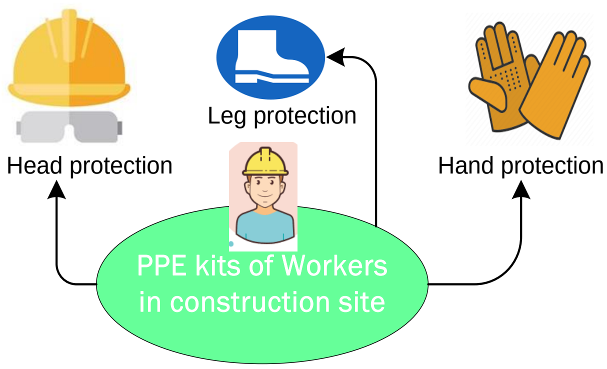

Figure 1: PPE tool pairs for construction safety

Figure 2 depict an automated pair system that ensures workers are wearing appropriate PPE before using hand tools to guarantee their safety. The system is empowered with wireless communication protocol and Wi-Fi protocol to provide the sensor data of the workers on the cloud server. This enables authorities to visualize the workers status from any remote location through internet connectivity.

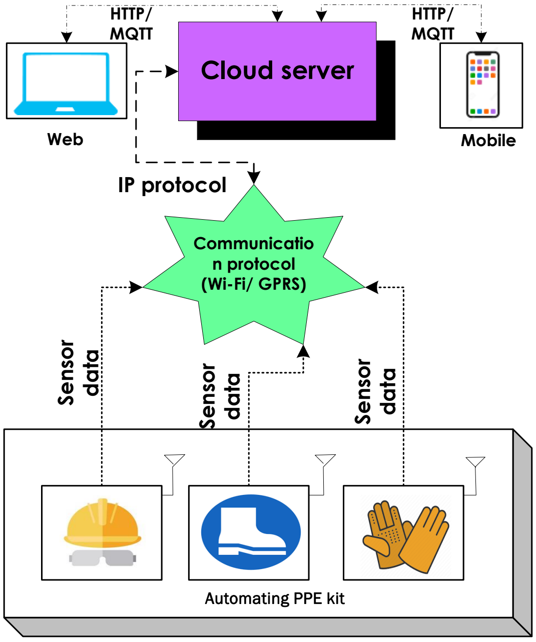

Figure 2: System framework of PPE-tool pair system

3. SYSTEM DESCRIPTION

The safety of the construction workers at the site is significant element for preserving the health of the construction workers. Here the monitoring the health status of every worker plays a vital role. As monitoring of health status is possible with the assistance of emergence technologies that are able to empower to establish a real time monitoring system through internet connectivity. However, the real time monitoring is only possible when the construction site is built with advanced infrastructure based on communication and sensor technology. To realize this kind of system, architecture is specifically proposed to construction site for the safety of workers with the assistance of advance wireless communication and sensors.

The proposed architecture is shown in the *Figure 3*, where the architecture is integration of four components namely: health monitoring mote, local server, LoRa gateway and main server. As discussed, that to implement real time monitoring system the integration of sensors and communication is required. So here the detection and health mote component are integration of helmet detection mote, worker health monitoring mote, shoe detection system and gloves detection system. Each detection system is embedded on the body of individual workers for monitoring the safety status frequently. This detection system is embedded with the Zigbee RF communication and specific sensors. Sensors and communication allow to sense the physical parameters of an individual worker and communicate it to the local server located at the nearby in the construction environment. The local server records and save the data in its memory storage during interruption of connectivity with LoRa gateway. Local server empowers to act as interconnectivity between the LoRa based gateway and detection system with reliable connectivity. Local server is feasible to communicate with the LoRa gateway as it is integrated with multiple wireless communication protocol namely Zigbee and LoRa. LoRa and Zigbee communication are integrated in the architecture as it provides the open licensed spectrum to communicate the data with low energy consumption. The local server transmits the status of each detection frequently to the LoRa based gateway

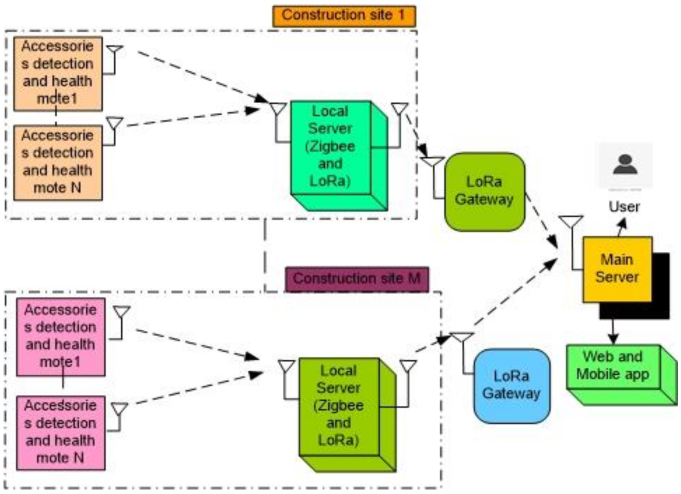

Figure 3: Proposed architecture for construction safety

LoRa gateway is also integrate with the multiple communication protocol, however here the gateway is additionally embedded with Wi-Fi modem for allowing the sensor data of detection system to log on the main server over internet protocol (IP). The reason behind integration of the Wi-Fi modem is, as the RF packets receiving from the detection system doesn't support for logging the data on the cloud server. The data is available in the main server, where the authority is feasible to monitoring the status of each individual worker at every construction site in real time. The authorities can request for the status of an individual through the web application and Mobile app based on main server. This architecture enables to identify the status of workers in terms of number of workers entered into the construction site and number of unauthorized persons tried to enter into premises are available to the authorities on the server. Finally, the complete architecture enables to implement wireless infrastructure and environment in the construction site. In addition, the description of detection system is illustrated below:

3.1. Accessories detection and health mote

The "accessories detection and health mote" consists of various modules to monitor the multiple accessories of workers in the construction site to ensure their safety. Helmet Detection Mote, Worker Health Monitoring Mote, Shoe Detection System and Gloves Detection System are the components that come under the accessories detection and health mote. Moreover, an identification detection system is placed at the entrance of the construction site for identifying the worker through RFID technology as shown in *figure 4*.

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This detection system enables to identify and restrict the unauthorized person entering into the construction site.

The circuit diagram for identification detection system is shown in *figure 5*. It consists of PIR Sensor, RFID Reader, Microcontroller, LCD, Power Supply Unit, Buzzer and 2.4GHz RF Transceiver. This circuit is placed at the entrance of the construction site to monitor if anyone is entering the site. PIR is a passive infrared sensor that continuously monitors the human movement and alerts the microcontroller whenever anyone enters the site, microcontroller read the data from RFID reader to check whether the person is a valid person or unknown person. If the reader reads the RFID card data, then it means person is wearing helmet otherwise he/she is not wearing the helmet. A buzzer is a output device used to alert through sound, it is connected to microcontroller. If a person without helmet or unauthorized person enters the site then the controller rings the buzzer and alerts the nearby people, simultaneously the same information is updated to the local server through RF transceiver.

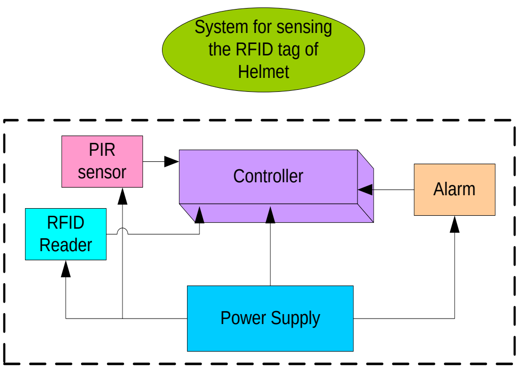


Figure 4: System at the entry point of construction site

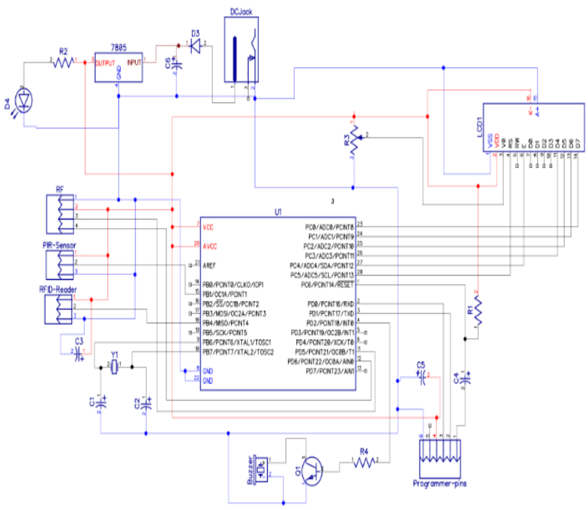


Figure 5: Circuit Schematic of Entry Node

3.1.1. Health detection mote

The purpose of this module is to check the whether the worker has worn the helmet or not using eye blink sensor. Workers might enter the site with helmet, but they may not wear it throughout their work at the site. Monitoring it continuously is very important to alert the worker and the management to reduce the risk. Googles are attached to the helmet to protect eyes and an eye blink sensor is embedded in to the googles to monitor the eye blink continuously, since helmet and googles are attached if the eyeblink sensor continuously detects the eye lid movement then it means the worker has worn the helmet otherwise the helmet is removed. Since each helmet has a RFID card it can be detected who has removed the helmet, to the worker a buzzer is placed that rings continuously when eye blink is not detected and the same informed is updated to management in the server through RF Transceiver. This mote is interconnected with shoe detection system and gloves detection system through RF communication as shown in the *figure 6*.

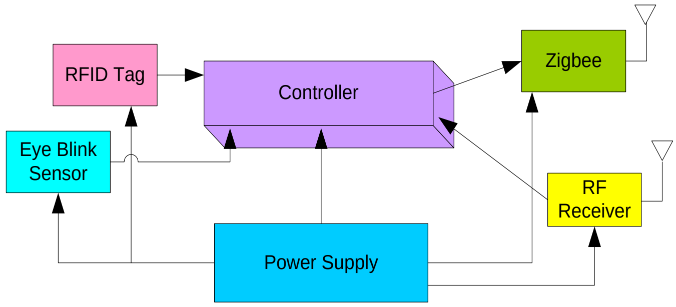


Figure 6: Helmet Detection Mote

An eye blink sensor integrated in this mote assists to authorize whether the helmet is worn by the worker or not. Moreover, the RFID tag integrated with this mote for confirming the identity during the entering into construction site. IEEE 802.15.4 based Zigbee module works on 2.4 GHz frequency is embedded in the detection mote allows to transmit the information to the local server with respect to programming instructions embedded during the firmware of it.

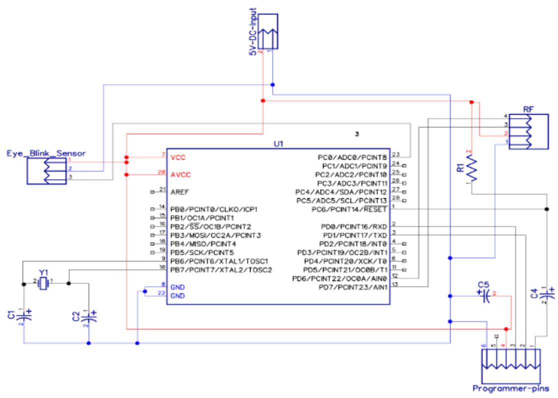


Figure 7: Schematic of Helmet Detection Mote

3.1.2. Worker health monitoring mote

Employees in construction site are usually adults and elders; because they work throughout the day rigorously monitoring their health parameters is very crucial in predicting any health issue. This mote checks the health parameters of the worker like body temperature and pulse rate continuously and updates the information through RF communication (Fig.8). The body temperature and pulse rate parameters empower the mote to confirm abnormality in the health of workers. This mote immediately triggers the events at the main server to react immediately and provide the assistance to the worker for avoiding the deterioration of the health condition. The triggered events are communicated to the helmet mote via RF transmitter and further the helmet mote transmits to the local server through Zigbee communication. The power supply provide to the mote is based on battery power and moreover the component embedded in the mote are feasible with the battery power supply as they are low consuming components.

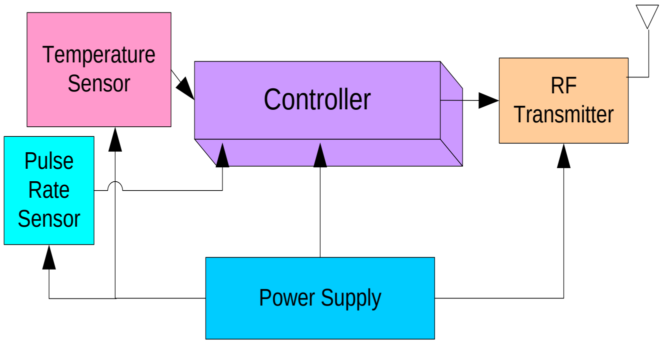


Figure 8: Worker Health Monitoring Mote

The circuit diagram for health detection of workers is shown in *fig.9*, to detect the temperature, an infrared temperature sensor MLX90614 is used and to monitor the heart rate pulse sensor is used.

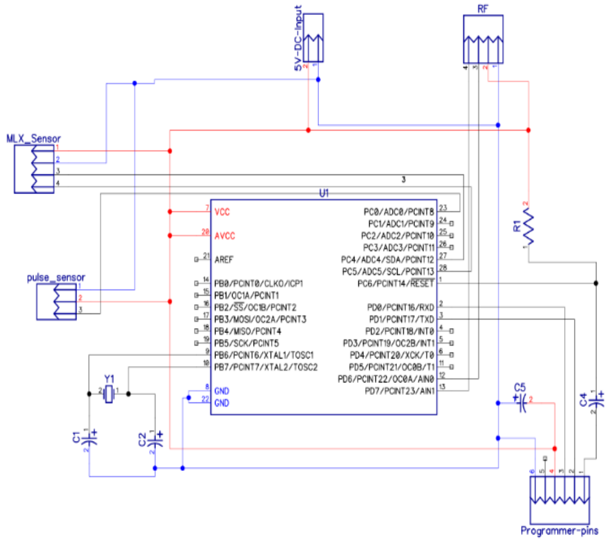


Figure 9: Schematic of Worker Health Monitoring Mote

3.1.3. Shoe detection system

Shoe detection system is to detect whether the worker has worn shoes or not using pressure sensor as shown in *figure 10*. The pressure sensor integrated on the shoe detection system empowers the system to authorizes the person is wearing the shoe or not. This indeed interconnects with the helmet mote through RF transmitter. The helmet mote will alert the person in the form of alarm to wear the shoes. The schematic diagram of shoe detection is shown in *figure 11*. To detect the pressure Force Sensing Resistor (FSR) Sensor is used and buzzer to alert the worker and RF module to communicate wirelessly.

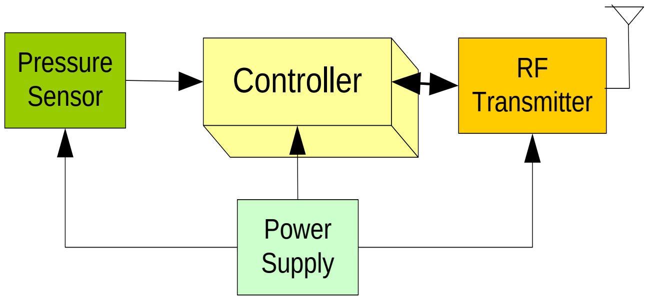


Figure 10: Shoe Detection System

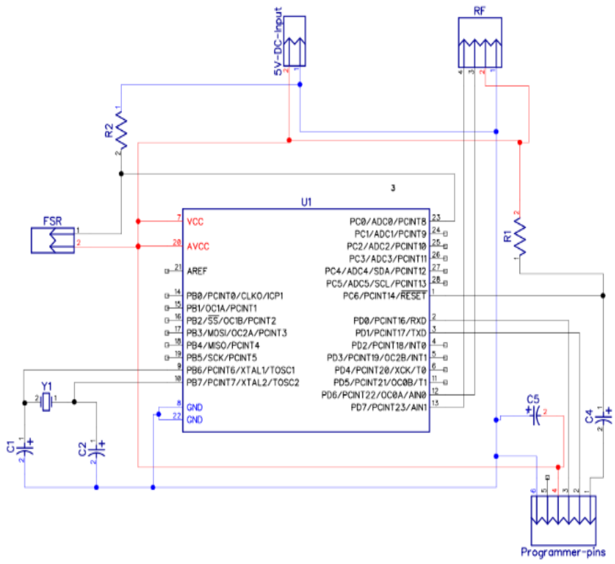


Figure 11: Schematic of Shoe Detection System

3.1.4. Gloves detection system

Gloves detection system is used to check whether the worker has worn Gloves or not using touch sensor. The detection system is also interconnected with the helmet mote through RF transmitter as shown in the figure 12. The touch sensor integrated in the detection system authorizes the person whether wearing gloves or not. Touch sensor is configured as digital sensor, logic 1 and logic 0 represents two states: wearing of gloves and not wearing of gloves, based on the logic received from the touch sensor, the microcontroller will take appropriate action (*figure 13*).

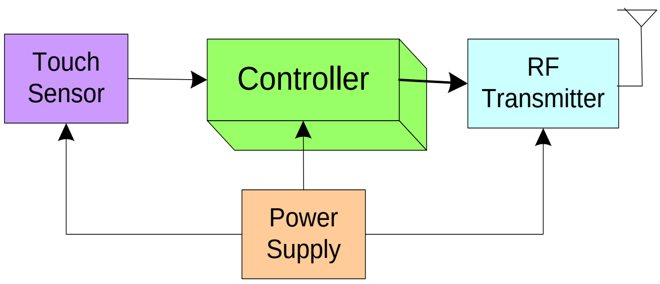


Figure 12: Gloves Detection System

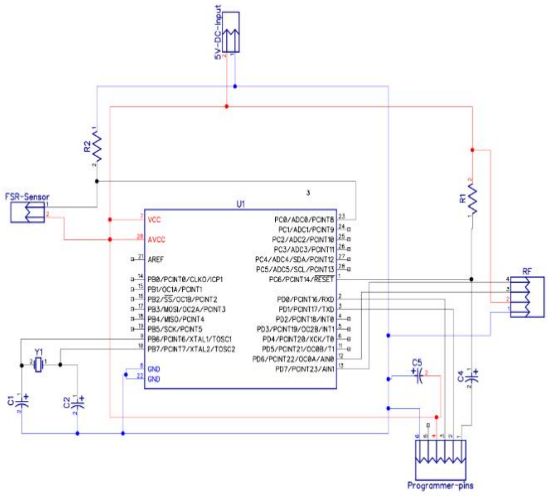


Figure 13: Schematic of Gloves Detection System

3.2. Local server

Local server is integrated in the architecture for enhancing the connectivity for maintaining stable communication in between accessories health and detection mote and gateway. It comprises of two distinct wireless communications i.e., IEEE 802.15.4 based Zigbee module and 433MHz based long range (LoRa) as shown in the *figure 14*. Moreover, it supervises the all the detection system of the individuals and route the sensor information to the gateway. Local Server schematic diagram is shown in *figure 15*, it consists of RF transceiver, Microcontroller, LoRa Module and power supply unit

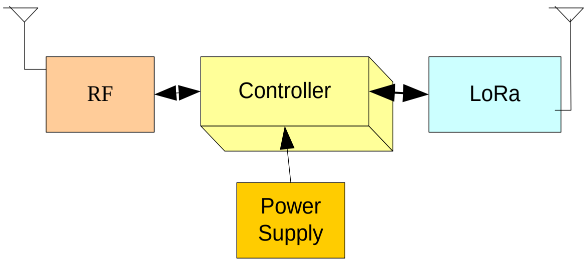


Figure 14: Local server

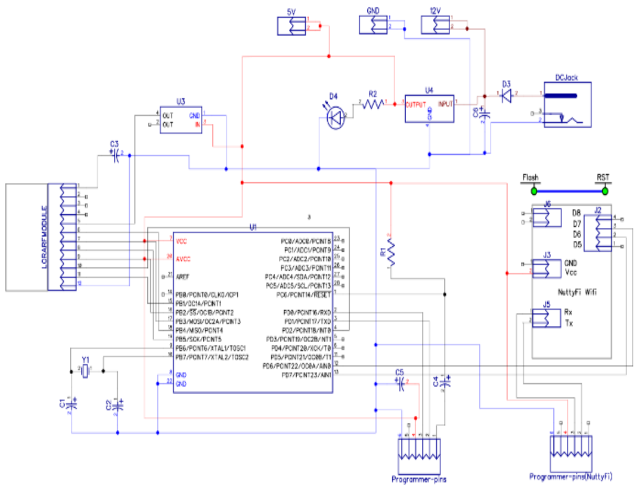


Figure 15: Schematic of Local server

3.3. LoRa based gateway

LoRa based gateway empowers to log the sensory data of the mote on the main server. In the main server, the sensory data is visualized with respect to Identification allotted to each detection system of the individual. Moreover, the gateway handles the multiple communication protocols. Basically, the sensory data need to convert into internet protocol (IP) packets for logging on the main server. So here the gateway integrates the IEEE 802.11 based Wi-Fi module for transmitting the data received from the 433MHz LoRa to the main server as shown in *figure 16*.

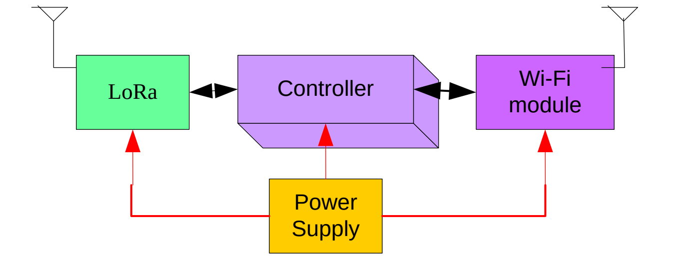


Figure 16: LoRa based gateway

4.EXPERIMENT IMPLEMENTATION

In this section, we present the implementation of the proposed system at construction site by evaluating the performance of the certain components like the health monitoring mote. In the health monitoring mote, the two major sensors integrated are the temperature sensor and pulse rate sensor. The pulse rate sensor works on the basis of photoplethysmography. It monitors the change in blood volume via any organ of the body that results in a change in light intensity through that organ. The MLX90614 is a high-precision temperature sensor with an output voltage that is proportional to the temperature in degrees Celsius. It works with I2C protocol and very reliable sensor for accurate temperature reading. It is 4-wired sensor 2 wires are connected to power supply namely Vcc and Ground and the other two pins are SDA and SCL (serial data and serial clock) Any form of calibration or trimming is not necessary in the LM35 series sensor to give accuracy of 1/4°C at room temperature and 3/4°Ccover a full temperature range of -55 to +150 °C. Control circuitry is simplified by the LM35's linear output, low output impedance, and reliable calibration. *Figure 17* illustrates the mechanism of the worker health monitoring mote with temperature and pulse rate sensor. During the firmware embedding in the health monitoring mote, the threshold temperature value and pulse rate of the worker are preset. This threshold value assists to conclude whether the worker health status is normal or abnormal. Moreover, the normal pulse rate of the healthy person in the *table 2* are also considered for setting the threshold value.

As shown in the *figure 17*, initially the sensor initiates the temperature sensor and pulse rate sensor for sensing the temperature and pulse rate value of the worker with certain interval of time. If the temperature and pulse rate of the worker are above the threshold level, then the health mote alerts the person on helmet detection mote to initiate immediate action for avoiding serious condition. Moreover, through the Zigbee communication, the helmet detection mote sends the alerts to authorities on main server through local server and gateway. If the temperature and pulse rate are normal, then the temperature and pulse rate sensor come to normal state.

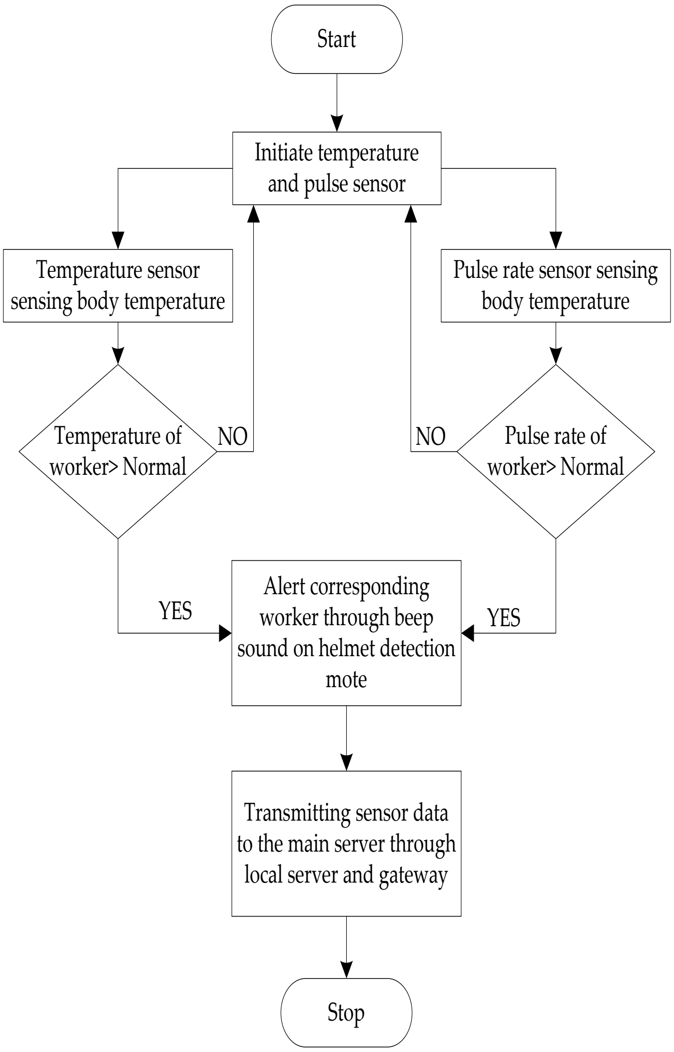


Figure 17: Mechanism of health monitoring mote

5. RESULTS

Table 2. illustrates the results of the health monitoring mote and the corresponding graph is *figure 19*, x-axis represents the age of the worker and y-axis represents the value of body temperature and heart rate measured through the health mote. Here we integrated the health monitoring mote on 8 different workers with different age groups. We have evaluated the pulse rate values of the workers with the normal pulse rate as shown in the table 1 and the corresponding bar chart graph is shown in *figure 18*. The values conclude that the pulse rate sensor and temperature value of the health monitoring mote is obtaining the pulse rate values and temperature values are in the normal range only. It is concluded that the proposed health monitoring mote is able to obtain the precise sensor values of temperature and pulse rate of the construction workers.

Table 1: Optimal range of pulse rate of healthy person

Age	Pulse rate (Per minute)
20-29	68-100
30-39	68-85
40-49	65-85
50-59	60-80
60-69	60-80
Age	Pulse rate (Per minute)
20-29	68-100
30-39	68-85
40-49	65-85

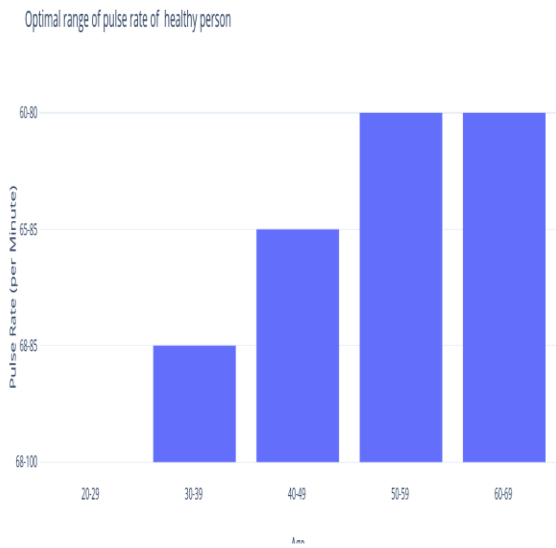
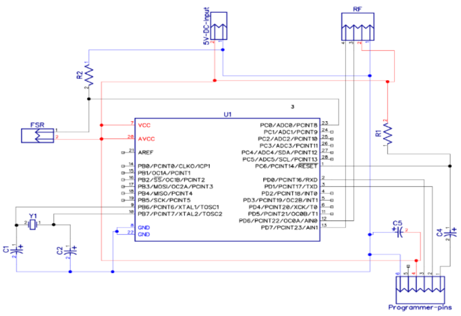


Figure 18. Optimal pulse rate of healthy person

Table 2: Results of health monitoring mote

Age	Pulse rate (Per minute)	Temperature (°C)
22	72	36.1°
		37.2°
		37°
		37°
		37.2°
		37°
		37°



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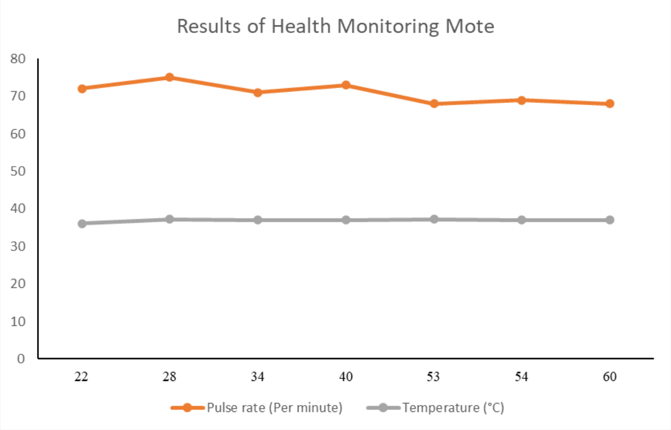

Figure 19. Results of health monitoring mote

6. DISCUSSION

This study is mainly focused on implementing the IoT network based on LoRa, Zigbee and Wi-Fi module for real-time monitoring of the construction of workers and construction site. Table 3 illustrates the comparison of present study with previous studies. As a part of real-time monitoring, this study aims to implement the customized hardware that is limitedly identified in the previous studies. In addition to this, this study implemented of the one the important component of proposed architecture i.e., health monitoring mote along with gateway for the monitoring health of construction workers. This health monitoring mote obtained the real-time temperature and pulse rate sensor value of the eight different construction workers.

Table 3. Comparison of our study with recent studies

Ref	Communication	Parameters	Real-time	Worker's health	Hardware Implementation
[26]	GSM modem	Fall detection	Only SMS based monitoring	Only fall detection is evaluated	Yes
[27]	RFID and Internet	PPE	Not implemented	Only PPE is monitored	Not implemented
[28]	RF	Dangerous Zone	RF based communication	Dangerous zone detected	Yes
[29]	Internet	Occupational Safety	Not Implemented	Questionnaire based evaluation of IoT System	Not implemented

7. CONCLUSION

The safety and health monitoring of the workers at the construction site is crucial role for avoiding the accidents. Unfortunately, the limited workers are wearing safety equipment during the work at construction site. In this article, an IoT enabled automated PPE kit is proposed for detecting the status of worker (i.e., Wearing PPE kit or not). The proposed system monitors the health status and the identification of the worker through sensory system and communication protocol like IEEE 802.15.4 Zigbee and Long Range (LoRa) communication. The sensory data available in the main server can be accessed through web application and mobile application through internet protocol (IP). As a proof of concept, a few of the key components, a health monitoring mote, is installed on a construction site to record the temperature and pulse rate of the job. The other components will be deployed on the building site in the future, allowing for real-time execution of the entire system. In future, the entire system will be deployed in the construction site to obtain real-time data of construction site, and workers health. In addition to this applying machine learning algorithm on real-time data to suggest safety guidelines in order of minimizing the casualties in the construction site.

List of Abbreviations -

EEG: Electroencephalography
EMG: Electromyography
FSR: *Force* Sensing Resistors
IEEE: Institute of Electrical and Electronics Engineers
IoT: Internet of Things
IP: Internet Protocol
I2C: Inter-Integrated Circuit
LCD: Liquid Crystal Display
LoRa: Long Range Radio
WSN: Wireless Sensor Network
PIR: Passive Infrared
PPE: Personal Protective Equipment
RF: Radio Frequency
RFID: Radio Frequency Identification
SCL: Serial Clock
SDA: Serial Data
UWB: Ultra-Wide Band
Wi-Fi: Wireless Fidelity

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