An Edge-Based Architecture for Personal Safety System on Construction Sites

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ABSTRACT

This study presents an edge-based architecture personal safety device to detect electric charges on construction site and thereby avert site accidents through electrocution. Electrocution has been identified as a major source of human deformity and even death on construction sites. A number of existing personal safety gadgets introduced to reduce this calamity (electrocution) on construction sites are not intelligent enough to respond on time to avert accidents. This study seeks to propose an Edge Computing architecture to detect and avert electrical hazards for personal safety on construction sites. The system enables IoT (Internet of Things) devices on PPE (Personal Protective Equipment) detect electrical charges, process and trigger alert for safety on construction sites. We proposed a wearable edge-based architecture to support emerging personal safety systems to detect electrical charges on construction site for site safety. The electrical charges will be sensed in real-time with respect to the position of a site worker, the data will be processed at the Edge resource on the PPE. This will rapidly trigger appropriate warning signs to initiate response from the wearer. Thereafter data will be transferred to the distance cloud for further processing. The proposed system will provide a just-in-time response and subsequently avert electrocution of accidents on construction sites.

Keywords: IoT, Edge Computing, Health and Safety, Electrocution

1. Introduction

Accidents on construction site is a menace throughout the world (Navon and Kolton, 2006). The industry accounts for 19% of fatal occupational injuries in the US in 2017 and 26% of fatal accidents recorded in UK in 2018 (Arslan et al., 2019) . The Finnish construction industry accounts for 25% of fatal occupational accidents (Zhang et al., 2015) and even record a high rate of annual death in China (Guo et al., 2015). Despite being a major contributor to the economy, the construction industry is the least safe work sector (Stasiak-Betlejewska and Potkány, 2015) due to the harsh working environment (Hallowell, 2011) and the high safety risks involved (Rashid, & Behzadan, 2017). The construction site environment consists of different skilled workers carrying out different trades simultaneously given rise to a dynamic, unique and complex work site (**Gua, et. al, 2017**). The sites are constantly changing resulting in trip hazards from building materials, tools and cables around every corner. The accident death and injury on construction site is three and two times respectively higher than other industries (Sousa et al., 2014). Invariably, the construction sector presents the highest number of fatal accidents (Martinez-Aires et al., 2018). This leads to construction being classified as a high-risk industry **(Le, et al., 2014**).

The financial implication of site accidents is substantial. Site accidents cause delays in projects and also increase project overruns, as an injured worker or equipment may need to be replaced. Aside from this, there is also the social repercussions of site accidents which include disabilities and early retirement (Tüchsen et al., 2009). All these culminate into high compensation claims which are paid from the profit of Construction Companies. The entire construction industry chain; owners, architects, workers, insurance companies and manufacturers are liable when accident occurs in construction sites (Abderrahim et al., 2005). No doubt, site accidents constitute a substantial loss to the contractor, the workers and the society. Thus, adequate safety on construction sites will increase ROI for the construction industry and subsequently enhance the survivability of the industry.

Inefficiencies have long been established in the way of processing safety in the construction industry (**Abraham et al., 2004, Egan, 1998**) and despite the more attention paid to site safety management, the accident rate continues to be high (Zhou et al., 2015). Poor site safety management is largely responsible for the high accident rate on construction sites. Safety management in construction site involves identification of hazards, reacting promptly to avert danger and communicating to other stakeholders involved (**Guo, et al. 2017**). Smart Construction Site Safety monitoring applications require appreciable networking, processing and memory capabilities to instantly process data coming from sensors and also to provide necessary feedback and control loops for instant signalisation.

IoT devices for safety purposes on construction site generates a huge amount of contextual data (continuous video of equipment and men working on construction sites) which requires instant analytic computation (processing) request. These IoT applications generate data that are useful for construction site safety in many ways (Dastjerdi and Buyya, 2016). Emerging, almost interactive nowadays IoT real-time applications are not sustainable with the existing long-distance cloud communication, characterise by long latency (Wang et al., 2017). Also, the bandwidth, speed and instant analytics requirements of real-time IoT applications is beyond the centralised traditional cloud solutions (Shi et al., 2016). Therefore, effective personal safety systems on construction sites are real-time applications that should not be hampered by constraints and burden from the distant cloud infrastructure. A faster approach than the traditional cloud is thus required as the delay or failure introduced by the cloud infrastructure cannot be tolerated. A real-time safety application system that could process data at a close proximity to the data source is thus required, thus, the Edge computing (Ai et al., 2018).

Since construction workers mandatorily must wear some personal protective equipment (PPE) such as hard hat, safety boot, safety, vest, hand glove, and so on, incorporating sensors into the PPE for intelligence will no doubt maximise the usability of the site accessories (PPE) (Yan et al., 2017). No doubt the need to move towards autonomous or semiautonomous decisions made by systems, actuators and various controls requires the need to build intelligence into the PPE of construction workers to alert for personal safety. Thus, rendering PPE useful for a crucial role in Edge computing architecture. The inclusion of PPE in modern Edge computing IoT systems can accelerate the development of people-centric safety systems for construction industry. The integration of PPE into the personal safety management network will provide a robustly safe construction site. The emerging Personalised Edge Computing for Construction Site Safety will require real-time analytic results by processing data at low proximity to the data source.

1.1 Electrical Hazards in Construction Industry

Construction industry is known to be the highest sufferer of electrical accidents, as 52% of all fatal electrical accidents for the period of 2003-2010 (**US bureau of Labour Statistics, CFOI, 1991-2010**) were in the industry. Falls, electrocution, struck-by-objects, and caught-in-between were incident categories responsible for 59.19% of all worker deaths in 2014 and 7.3% of construction workers' death on site were from electrocution **(OSHA in Park, 2016).** If an electrician fell from a ladder, this is categorised as a 'fall' accident, whereas it was as a result of contact with electricity. So, in actual fact contact with electricity has been a major cause of injuries and accidents on construction site (Haslam et al., 2005). Sources of electrical hazards on construction site include, cuts or abrasions on cables, wires and cords, temporary lighting, open power distribution units, detached insulation parts on electrical cord, improper grounding of equipment and wet electrical equipment. Engineers, electricians and overhead line workers are known to be the professionals affected by electrical hazards. While in actual fact, other site workers like plumbers, and maintenance workers are also at risk of electrical hazards. Digging is a day to day activity in construction, be it a new construction or a maintenance job. Inadvertently digging may have damaged the insulation of an underground cable. A site worker that subsequently comes in contact with the exposed cable could sustain electric shock or death. Invariably, all site workers must be able to properly identify electrical hazards on site, as failure to recognize the potential hazards could result in electric shock or death.

DIAGRAM OF A DIGGING EVENT THAT COULD LEAD TO ELECTROCUTION

Hazards from electricity on construction site could be from overhead cables, underground cables, working close to power lines, or disorganised workspaces. Manual environmental assessment of power lines and cables and ensuring good practice in workplace has been the available means of reducing electrical hazards on construction site. Poorly arranged workplace can be recognized as unsafe working area by site manager and documented. Communicating all identified unsafe area to all site workers is currently cumbersome and ineffective. Meanwhile, electrical hazard is a personal accident from electrical hazardous area as the electrical charges usually affect the person that came in direct contact hence it requires a personal safety approach. The best approach will be for every site worker to be able to identify electrical dangerous area on site so as to be able to effect personal safety. Therefore, integrating a time-critical, early warning system to personal devices worn by construction worker will increase personal safety at the construction site, prevent disasters and save lives. This study seeks to propose an Edge Computing architecture for Electrical hazard to enable IoT devices on PPE detect electrical charges, process and trigger alert for safety on construction sites. We proposed a wearable edge-based architecture to support emerging personal safety systems to detect electrical charge on construction site for site safety. The electrical charges will be sensed in real-time with respect to the position of a site worker (detect the danger), the data will be processed at the Edge resource on the PPE. This will rapidly trigger appropriate warning signs to initiate response from the wearer. Thereafter data will be transferred to the distance cloud for further processing.The main contribution of the paper is in the design of an Edge based architecture to detect electrical charges on construction sites which will trigger an alarm system to warn of danger. Also, the system will send signals to the admin/safety system to log the incident.

2. Related work on Construction site safety

According to Guo, et al. 2017, the three construction safety management methods are safety training (Son, H. & Lee, 2015), proper site monitoring (Cheng, et al., 2004) and identification of safety hazards (Abdelhamid & Everett, 2000). According to Haslam, et al., 2005, 49% of accidents on construction sites are as a result of workplace issues. Meanwhile, identification of safety hazards hinges/is largely dependent on identification of job hazard area (JHA) on site (Kasirossafar & Shahbodaghlou, 2012). A large number of JHA is undetected due to the dynamic, unique and complex nature of construction site (**Gua, et. al, 2017**). According to (Guo and Liu, 2015) proper identification of job hazards area on construction sites can significantly improve site safety and decrease associated cost. Meanwhile, Ku & Mills, 2010 has since established that technology can assist in prompt recognising of safety hazards on construction sites despite the dynamism of the jobsite, thus leading to a safer construction with less effort. The robust application of modern technology for efficient personalised construction safety management has been in existence but not fully utilized **(Cheng, et al., 2012)**

Riaz 2006 used GPS and smart sensors wirelessly connected to a PC on site to track and notify of movement towards an already identified hazard area. Abderrahim et. al., 2005 fixed a miniature positioning and communication instrument on helmet to track worker s movement relative to an already identified hazard area on site. **Lee et al, 2009** employed infrared and ultrasonic sensor connected to transmitters on a site PC to detect workers moving near a classified hazard area. The processing capabilities of these studies are dependent on the limited resources on the processing PC on site. To benefit from the scalability of cloud solutions **Park 2016** integrate the Blue tooth low-energy (BLE) based location detection technology with BIM on a cloud platform to evolve a system capable of identifying potential hazard area on site and notify stakeholders in a real time manner. In the same manner **Zou, et al., 2017, Tang, et al., 2019 and Li, et al., 2018** presented cloud-based safety systems on construction site. However, safety in construction sites is a mission critical operation that requires real time response (Kochovski and Stankovski, 2018) that could not be supported by the centralised cloud infrastructure. Speed of data processing is essential in any safety-based system. Safety systems requires a high degree of autonomous decision-making capability, as situations is usually critical. Autonomous system is a one of the goals of the Industry 4.0, hence for a reliable, remote and easily maintained system coupled with bandwidth, cost, a cheaper, faster and smarter approach to the traditional cloud-based system must be explored.

2.1 IoT for safety in Construction Industry

IoT encompasses array of web-enabled smart devices that can sense environmental pressures, temperatures or body biometric changes. They can interact and give insight to the next action. IoT has leveraged on its ability to connect all objects to the internet with minimum human intervention to impact in the different aspect of everyday life ranging from healthcare, transportation, agriculture, automobiles etc (Petrolo et al., 2015). IoT are being employed to identify risks in construction sites hence potentially increasing site safety; poor air quality, worker getting close to an equipment, etc. IoT devices on construction site continuously improve safety by analysing hazards, incidents, and near misses by providing actionable information hence increasing safety intelligence on construction sites. IoT devices for safety in construction sites generates real-time data points that needed to be processed on the fly by a data analytic program in order to avert injuries before they occur. The ultralow latency required to achieve the on the fly processing could not be accommodated by the centralised cloud computing infrastructure. IoT devices deployed on construction sites are mobile running their applications on the resource constrained gadgets while the core service and processing are performed on cloud servers. This process is characterised by high latency and mobility issues (Ahmed et al., 2015; Pace et al., 2019). Cloud being a major player in extending the IoT network capabilities is constrained in terms of latency and bandwidth requirements as number of IoT devices connected to the internet geometrically progresses.

Thus, cloud infrastructure will not be able to support especially mission critical operations and real time applications like safety in construction site (Morabito et al., 2018).

2.2 Edge Computing in Construction

Internet of Things (IoT) was first introduced in 1999 for supply chain management (Ashton, 2009), later the concept of "making a computer sense information without the aid of human intervention" became widely accepted in healthcare, home, environment, and transports (Gubbi et al., 2013). IoT applications generate unprecedented amounts of data that can be useful in many ways (Dastjerdi and Buyya, 2016).

Cisco Internet Business Solution group has since predicted that there will be 50 billion of Things connected to the Internet by 2020 (Evans, 2011). IoT devices runs on battery and do not usually have strong processor, whereas safety monitoring on construction sites requires heavy networking and processing support for its coordination and logistics operations. This necessitates the need for IoT devices to obtain higher frequency processors from nearby micro servers in order to perform effectively. Undoubtedly the emerging requirements for these vast IoT applications with the quantity of data generated by things immersed in our day to day life will be different; stringent latency, capacity constraints, resource-constrained devices, uninterrupted services with intermittent connectivity, and enhanced security (Chiang and Zhang, 2016) . This is pointing to a post-cloud era as centralised cloud computing might not be able to accommodate these challenges (Ai et al., 2018). The incapability of the cloud services and the affinity from IoT is suggesting that applications required to be deployed at the sort of edge of the network to consume these data. This is implying the devices on the network are changing from only data consumer to both data producer and data consumer.

Edge computing come to the rescue by bringing the processing to the edge of the network. Edge computing provides ultra-low latency, mobility support, location awareness and proximity to users (Ahmed and Ahmed, 2016). Edge devices like routers, access points, and base station host different services ranging from QoS, VPN, and Voice over IP (Zhang et al., 2019). These Edge devices act as a bridge that connects the smart mobile devices with the cloud. Considering the natural tactile and haptic sensations, human senses reactions have varied feedback and latencies, the most critical of which is the tactile control to visual feedback, which is as low 1 ms. In order to avoid a noticeable movement/displacement in human reaction feedback, the speed of getting the signal from the IoT device must be ready to match this **(Fetweiss, 2013**) .

2.3 Wearable Technology for Construction safety

The use of wearable technology in form of clothing and accessories with embedded sensors, computer, and the likes have received considerable acceptance across industries (Mann, 1998). Wearable Technologies are easily worn on human bodies and the inbuilt computing ability provide the competence and intelligence that makes them to be smart; smart shoe, smart hand band, smart vest etc (Jiang et al., 2015). The improved capability, wearability, portability and the affordability of wearable technology made them easily integrated into construction workers accessories (Özdemir, A. & Barshan, 2014). This render them usable (ideal for use) on construction site during work for occupational safety and health (Abdelhamid and Everett, 2002) . Since construction workers mandatorily must wear some personal protective equipment (PPE) such as hard hat, safety boot, safety, vest, hand glove, incorporating sensors in the PPE for intelligence will maximise the usability of the site accessories (PPE) (Yan et al., 2017). Safety and Health issues in the dangerous construction site has influenced the acceptance of wearable technologies by construction workers during work (Choi et al., 2017). FordjourAntwi-Afari, et al., in 2018 employed wearable insole pressure system to automatically detect and classify work-related musculoskeletal disorders that can lead to permanent disabilities (Bhattacharya, 2014) among construction workers. This background motivates this study to employ wearable technology (smart boot) for edge-based personal safety system for construction workers.

3. Architecture of Edge-based Site Personal Safety Systems

The architecture and the conceptual diagrams of the Edge-based Personal Safety System are as shown in Figure 1 and Figure 2 respectively. The system is divided into three parts namely: the Wearable Contactless AC Detector (WCACD), the Edge Node (or Cloudlet) and the Cloud. The WCACD is a wearable device that can be embedded into gloves or safety boots. It non-invasively senses the presence of Alternating Current in its surrounding. Whenever it detects this current, it activates an in-built buzzer and sends a frame through LoRa (short for Long Range) wireless link to the Gateway Node (GWN) of the Cloudlet. The message is forwarded to the Desktop Application through RS-232 protocol. The application then tokenize the message and stores the data in the database. Through the application, a warning message, which activate the buzzer three times, can be sent to the WCACD. Finally, alarm(s) raised are sent from the Edge Node to the Cloud, on a daily basis, through the internet for backup and reporting.

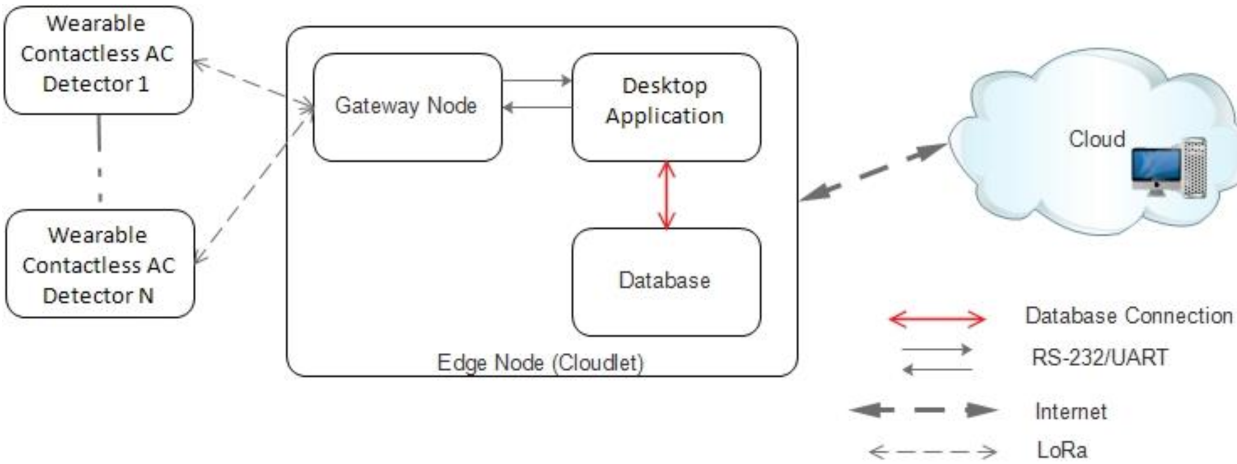

Figure 1: Architecture of the System

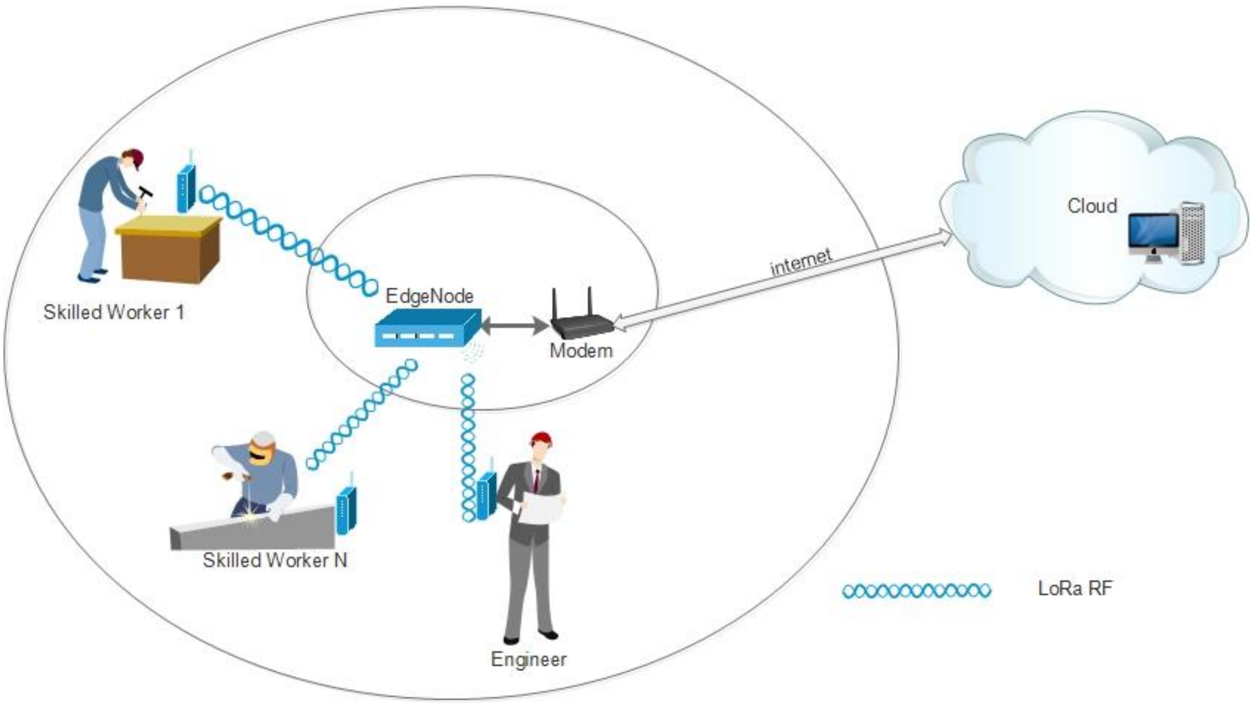

Figure 2: Conceptual Diagram of the System

Figure 3 depicts the circuit diagram of the WCACD. The circuit consists of an Arduino UNO board (host of the microcontroller), LoRa Transceiver module, GPS module, buzzer and a 5 stage Johnson Decade Counter. A copper wire (serving as an antenna) of 10 cm length, wounded as a coil is attached to the clock input (pin 14) of the decade counter. This antenna is the input to the circuit. It senses the electromagnetic waves surrounding an AC carrying wire. The counter **has** 10 outputs that become high one by one when the input pin 14 gets positive pulses. Pin 3, which is the first output pin of the counter is connected to digital pin 8 of the Arduino board. Pin 8 of the Arduino board is configured as an input pin and therefore, listen to incoming signal. Whenever it becomes HIGH, a control program running on the microcontroller will send a HIGH logic to pin 7 to activate the buzzer and then fetch the coordinate (longitude and latitude), that is location, of the device. This data is concatenated to the device identity and then forwarded to the GW node through the LoRa transceiver module. The Tx and Rx pins of the LoRa module are connected to digital pin 2 and pin 3 respectively. These two pins are configured as serial port using SoftSerial library.

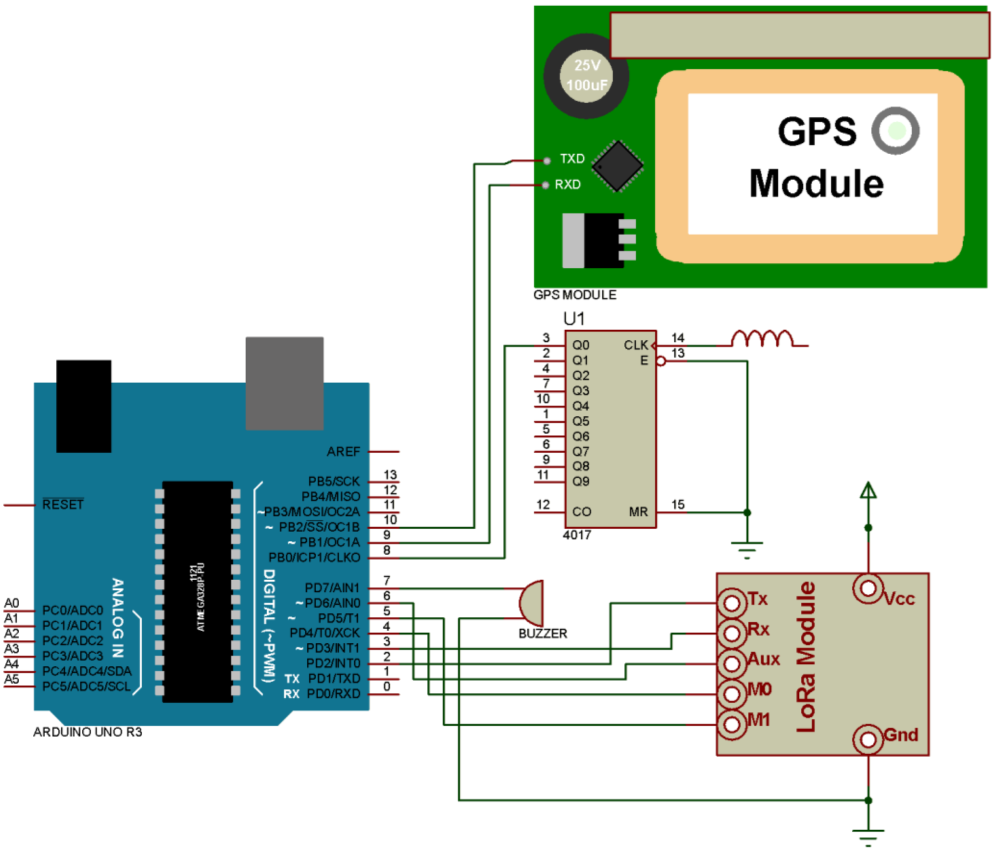

Figure 3: Wearable Contactless AC Detector Circuit

Figure 4 depicts the circuit diagram of the GW node. The circuit consists of an Arduino UNO board, a buzzer and a LoRa Transceiver module. The connection of the buzzer and the LoRa module to the Arduino board is similar to the WCACD. The LoRa listen to the same channel where the LoRa of the WCACD transmits its data. On receiving of a data frame containing the device identity and the location of the device, it sends a HIGH logic to pin 7 to activate the buzzer and forwards the data to a MySQL database through a desktop application.

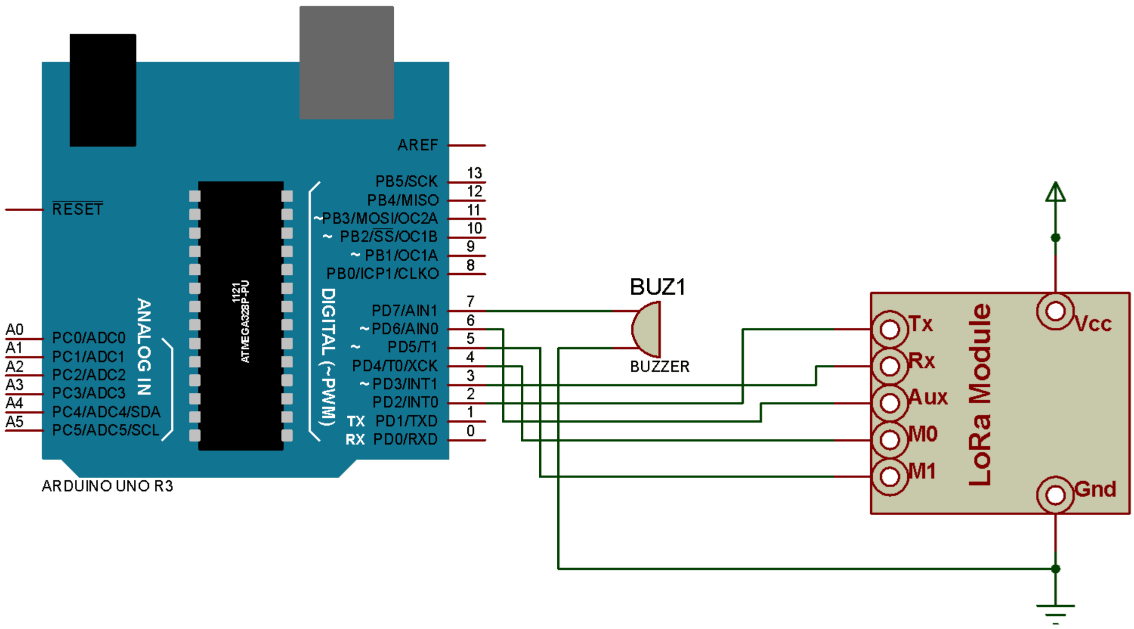

Figure 4: Gateway Node Circuit

4. CONCLUSION

The construction industry is one of the most risky industries with a dangerous working environment. This is evident in the injuries, and fatality and fatality records of the industry which inadvertently affect the productivity and efficiency. As such, there are different regulations and approaches towards improving the health and safety management of the industry, however, accidents and injury persist. This study proposes a faster response system issuing alert from real-time data to give real-time response that will avert site accidents. This is a reliable system that is not affected by intermittent internet connectivity and cost-effective solution- as use of bandwidth is limited. The proposed system would contribute to effective management of health and safety in the construction industry and positively affect productivity and efficiency. In addition, the proposed system can be deployed by the Small and Medium-Sized (SMEs) as it is cost-effective and easy to use. Limitations of the study which are lack of validation and evaluation provide fertile ground for further studies. Lastly, the study would be of benefits to stakeholders in the construction industry.

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