Review Article

Internet of Things: A Hypothetical and Prototyping Platform for CRASP Methodology

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Abstract:
The construction industry has always been considered one of the most dangerous industrial sectors. Construction workers are often exposed to considerable risks, including falling from heights, unguarded machinery, or being stuck by heavy construction equipment. The construction business employs both skilled and unskilled laborers susceptible to accidents and health hazards on the construction site. Numerous accidents occur at construction sites despite the existence of labor safety rules. A Korean case study statistics showed the significance of construction health and safety management. By adopting CRASP methodology and applying innovative methods such as the intervention of ICT and the IoT, i.e., the prototype development through the Arduino platform could implement the automated features of construction health and safety management features. This research concludes that the CRASP conceptual methodology could be adaptable that drives the manifestation of IoT-based prototyping. IoT-based prototype functional features showed the feasibility of implementing automated construction health and safety management on-site.

Keywords: Arduino implementation, CRASP methodology, Construction Health and Safety Management, Internet of Things, Prototyping Research Design

Citation: T.G.Vasista" Internet of Things: A Hypothetical and Prototyping Platform for CRASP Methodology". *Iota*, **2023**, ISSN 2774-4353, Vol.03, 02. https://doi.org/10.31763/iota.v3i2.619

Academic Editor : P.D.P.Adi

Received : March, 04 2023

Accepted : April, 14 2023

Published : May, 30 2023

1. INTRODUCTION

The CRASP management methodology concept was developed and suggested by AlSudairy and Vasista in 2014 at King Saud University, Riyadh, Saudi Arabia [6]. The basic premise of this methodology is the strategic sense-and-respond model as a generic business model suggested by [19]. This fundamental paradigm is subsequently modified with a CRASP (i.e. Customer-Response-Adapt-Sense-Provider) methodology view by [6] in passing. While innovative technologies and discoveries were constantly made through human historical findings and inventions, digital technologies are rapidly scaling up technological growth. Technological development is driven by human ingenuity, providing new environments and tools for creative production [28]. Given this reciprocal connection between creativity and technology, it is essential to explore the relationship between the Internet of Things (IoT) and CRASP methodology (i) in subjective or qualitative knowledge of methodological terms and (ii) in objective or technological terms.

If functional prototyping becomes possible while reflecting the subjective or qualitative terms, the hypothesis that IoT acts as a platform for CRASP methodology becomes accepted or rejected. For this purpose, the construction health and safety management domain has been selected to verify and test the hypothesis. CRASP methodology is an effort of Conceptual Creativity. According to [7], creativity may be considered a product and a process and is typically considered the product of valuable answers to difficulties or innovative and efficient concepts. Further, [28] cited that when an idea has novelty but it lacks value proposition and effectiveness to other individuals, it could not be considered "*creativ*e" in passing to [17].

Moreover, Ref. [4] cited that value proposition and value creation in electronic enterprise go beyond the e-business value that could be realized by configuring the value chain of activities. The value chain is the creation of strategic networks among companies. Electronic enterprise firms are often innovative through novel exchange mechanisms. E-business has the potential to establish unexplored wealth in the 21st century by exploiting new opportunities provided by the Internet [61]. But customer-side demand uncertainty could cause a Bullwhip effect [5]. According to management and technology experts, the IoT (Internet of Things) has the potential to drastically alter current supply chains in the 21st century [51]. Some of the several publications that described IoT's potential advantages and risks are: [11] and [50]. According to [8], the global forecast of internet-connected devices during the year 2030 will be almost three times 9.7 billion in the year 2020. The increase in safety concerns and productivity at construction sites and rapid urbanization in a developing country like India is driving the growth of the IoT market in the construction sector. While China and the USA are expected to have a big IoT market, Government of India, Malaysia, Hong Kong and Singapore are seriously considering making stringent laws to control construction accidents. Thus these countries are also expected to play contributory roles in IoT based construction market [67].

Moreover, The applications of IoT in different industries are Health care, Precision agricultural farming, retail industry, transportation and energy, cities, building and homes, manufacturing, mining, oil and gas, and wearable. IoT helps in preventing delays in the construction industry [32]. Healthcare monitoring wearables like smart blood-pressure cuffs or knowing pulse rate can be possible remotely during different times of the day through IoT [62]. Sensor-based technology can be applied to enhance construction safety management [59]. IoT allows the creation of a real-time hazardous gas monitoring system that integrates wireless sensor networks with building information modeling technology [15]. Therefore the following goal and objectives are set for this research paper. The present study aims to develop a functional prototype using the Internet of Things platform with a mapping knowledge of CRASP methodology terms. Moreover, research objectives include: [1] Developing the functionalities of construction health management features using IoT platforms (i.e., Arduino or Raspberry Pi platforms), [2] Developing the functionalities of construction safety management features using IoT platforms (i.e., Arduino or Raspberry Pi platforms), [3] Thus develop a prototype to show the feasibility of implementing the functional features of construction health and safety management.

2. METHOD

Earlier works on this methodology include strategic perspective by [26] and [27], capturing the value in the network era by [12], and technical perspective by [35]; other works include: [46],[13], [10], [19], [42], [30], [49], [18], [29]. and [55]. Customer Relationship Management perspective as a key role in supply chain management and its predictive capability by [56]; Description of how CRASP method could be used to apply for process quality control in Oil and Natural gas project sites by [57] in passing. Moreover, Figure 1 is a Application of Modified CRASP Methodology.

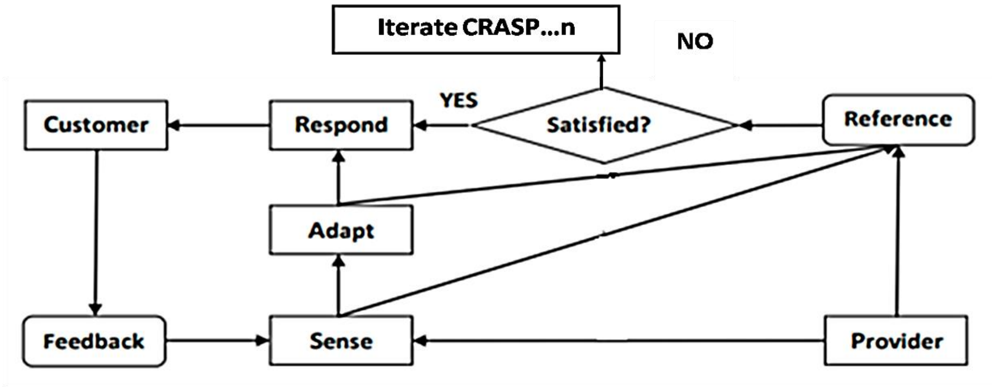

Figure 1. Application of Modified CRASP Methodology (Source: AlSudairi and Vasista, 2014, Redrawn) [6]

Furthermore, The advantages of the CRASP methodology are as follows: [1] Customer: It is about Customer Satisfaction. The term customer is polymorphic and synonymous and changes according to the context. The following two citations help us understand how the IoT environment helps construction workers with health and safety aspects.

According to a study of Spanish construction workers, employees' perceptions of their health may be influenced by their attitude toward their work, which may be satisfied or unsatisfied. The research was carried out between January 2014 and June 2015 on a sample of 302 people working for Andalusia-based businesses, using a stratified random technique to include businesses of all sizes and provinces. According to the data, workers over 55 are more content with their jobs than those between 35 and 45, which suggests that work experience in the industry raises overall contentment. Similarly, employees with 2 to 5 years of experience exhibit greater satisfaction levels than those with only 6 to 2 years. A positive relationship exists between health perception and job satisfaction and body pain and general health perceived [47]. An IoT-based healthcare system installation could routinely monitor patients' physiological parameters. As a result, IoT-enabled devices improve the quality of care through routine monitoring, lower the cost of care, and actively participate in data collection and analysis [38].

Wearable cameras may be used in mining sites for various tasks, including dust monitoring, safety monitoring, and supply chain management (SCM). Most of the time, cameras are valuable instruments for process control and site observation in outside contexts. However, adding some biosensors to miners' safety vests for radiation, health checks as well as gas sensors to the safety helmet, and a belt with proximity recognition functionality, as a result, can lead to improving jobs satisfaction even though there aren't any intelligent wearable jackets available on the market for mining sector workers [41]. [2] Responsiveness: Response under project-based decision-making under sustainable performance with compressed operations, precision force, and physical actuating the responses from the data sensed through sensors [21] with unique proximity identification features could lead to a healthier workforce [48] and offer a safer work setting. [3] Adapt: The IoT process significantly improves communications, gathers and transports data that enables quick decision-making, and improves supply chain performance. Thus, IoT has greatly enhanced typical challenges of SCM (Supply Chain Management), like chain visibility, and at the same time, it has improved the adaptability and agility of SCM, as mentioned in [20].

Furthermore, According to [58], a typical IoT network includes four main layers: (i) A sensing layer that could integrate different forms of things like Radio Frequency Identification (RFID) tags, actuators, and sensors; (ii) an information-transfer network layer that is compatible with wired and wireless networks (iii) a service layer that uses middleware to connect services and applications and (iv) a user interface layer that enables for system interaction and the display of information to the user IoT mechanics work with technologies that are used for achieving intelligent supply chain functioning can be divided into three layers: (I) Physical Sensing Layer and (II) IoT Middle Layer and (III) Application Layer. Figure 2 shows the complete IoT Basic Architecture.

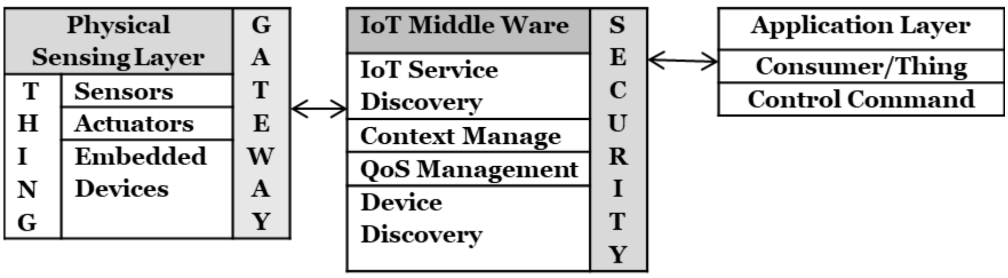

Figure 2. IoT Basic Architecture (Source: [53])

[4] Sense: In this section definition of sensors and sensing process is described:

A sensor is a device that reacts to an interesting physical input by producing a measurable, functionally relevant output, either electrical or optical [33]. A sensor is typically described as a device that transforms a physical measurement into a signal that can be read by an instrument or an observer [16]. A sensor gathers data from the outside environment, whereas a transducer converts energy between different forms [36]. The sensing process [Figure 3] can be depicted in a pictorial form:

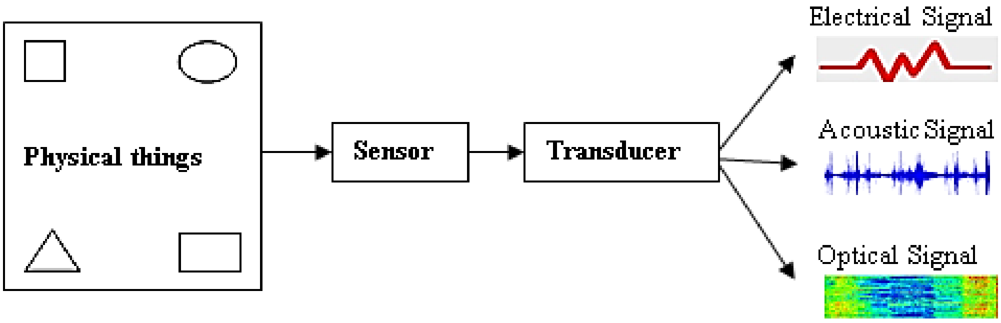

Figure 3. Process of Sensing (Redrawn Source: [43])

5) Provider: It is about supply chain management, value chain management, and supplier relationship management [58]. A provider might be a product or service provider, and it is often a virtual network of independent enterprises working together to jointly exploit a particular economic opportunity based on similar values and a frequent business objective. Specifying every partner's business model, organizational and technical coordination, and the proper criteria for agreements helps address the challenge of integrating partners' skills. It represents a virtual e-chain concept and presents a framework for supply chain collaboration in a virtual setting [40].

Construction sites are complex and dynamic systems. Due to the ever-needed information to better manage the construction site, worker health, and safety management has been conducted under challenging conditions. A new generation of approaches for enhanced construction health and safety management are reportedly provided by sensor-based technology. It is a successful method for gathering, identifying, and processing data to conduct real-time monitoring with high effectiveness and accuracy [59]. A novel cement-based piezoelectric composite sensor may be put in the foundation of reinforced concrete frames during construction to track damage to concrete structures in civil engineering projects [25]. Thus, IoT systems can be enhanced with Analytics and Artificial Intelligence capabilities [60].

Therefore, in the era of IoT, the CRASP approach represents a new perspective on agile project management. And the prototyping research design. At all levels of software project management, new intelligent gadgets are showing significant influence. The CRASP technique aims to increase efficacy and maximize factors, including teamwork, data analysis, stakeholder involvement, project development, resource planning, and feedback speed by evolving a project management solution across IoT networks. Then, it is necessary to provide an Agile-based project management approach to the problem, incorporate the relevant objects with their features into the project management process, and adapt to the IoT network [23]. Moreover, Table 1 shows the Mapping of CRASP Methodology and IoT platform process.

Table 1. Mapping CRASP Methodology and IoT platform process

Sl. No.	CRASP Methodology	Application Domain	IoT	Remarks
1	Customers are Building Owners/ Facilitators	Construction	Seeking the functional behaviors of Smart Gadgets	Sensors as Input data providers and articulation as output information providers
2	Response	Construction Health	Actuator	B. P. and Pulse Rate Environment Data
3	Adapt	Supply Chain	IoT Middleware	Acts as Data Integrator
4	Sense	Construction Health & Safety	Pulse Rate Sensor and Button Sensor	To Gather data on Pulse Rate and Whether a helmet is worn or not
5	Provider	Construction Health and Safety	Provider of Sensors and Actuators for Smart Homes and Building Functional Features through Wearable Jacket	Smart Wearable Jacket Providers for Construction Projects

According to Kim (2019) [38], prototyping is required in response to the demand of the Industry 4.0 revolution. It is a quick technique to influence user wants and strategies in building design. A process known as prototyping has to be established to adapt to changes in current requirements and to obtain the outcomes. One method for lowering design errors and removing failure causes during the early design phase is prototyping. Prototyping is a technique that uses prototypes to test, modify, and complete designs. But here, it is also essential to check if it means quality criteria according to ISO 15686 in terms of performance. For example, to test whether performance is achieved, the question can be posed, "*Will the design satisfy the end user's requirement*"? Therefore, a design technique established on prototyping is suggested in this study. This design technique seeks to improve the test's usability by setting it apart from the prototyping often done in architectural design projects [38]. The aim of the research is not only to study reference cases that enable designers to maximize the usage of the functionality of both digital models case studies but also to develop an IoT prototype model to realize the feasibility of IoT-based implementation to realize the functional features and their contribution to construction health and safety.

1. H01: Achieving the functional features of construction health management is possible by implementing it using an IoT platform (for example, selecting Arduino platform)
2. H11: Achieving the functional features of construction health management is NOT possible through implementing it using an IoT platform (for example, selecting Arduino platform)
3. H02: Achieving the functional features of construction safety management is possible by implementing it using an IoT platform (for example, selecting Arduino platform)
4. H12: Achieving the functional features of construction safety management is NOT possible through implementing it using an IoT platform (for example, selecting Arduino platform)

The construction business employs skilled and unskilled laborers, vulnerable to construction site accidents and health hazards. Safe working conditions need good coordination between contractors, clients, and employees, which Indian construction enterprises severely lack. Even though there are labor safety standards in place, building sites have a large number of incidents. It appears managerial care for employees' health and safety is also failing [34].

A. Major Health Issues that Labour Face in Construction

(i) pain and injury from over-exertion (ii) repetitive manual tasks under uncooperative postures (iii) exposure to molds, fungi, or rodent dropping (iv) exposure to toxic substances, chemicals, paints, lead and dust from wood or cement and soil, etc. (v) Working under extreme temperatures and under Ultra Violate radiations (vi) Working with hand tools, powered tools and heavy machinery equipment. Improper handling of any of these will lead to injuries and fatalities (vii) Working night shifts under low lighting conditions and poor visibility [44].

B. Some of the safety issues in construction might emerge from the following broad aspects

(i) Safety Policy and Procedures; (ii) Safety training and program (iii) Safety record keeping (iv) Safety measures (v) Cost related to safety (vi) Awareness towards safety (viii) Lack of safety regulations (ix) Not having an emergency plan (x) improper relationship between management and workers (xi) Extensive use of subcontracting (xii) Extensive use of temporary and unskilled labor (xiii) Unable to supply personnel protective equipment by micro and small construction companies. Details of the work process of this system can be seen in Figure 4, namely Flowchart for Pressed Button Sensor (Worn Helmet) and Figure 5 Flowchart for Heartbeat (Human Pulse) Sensor.

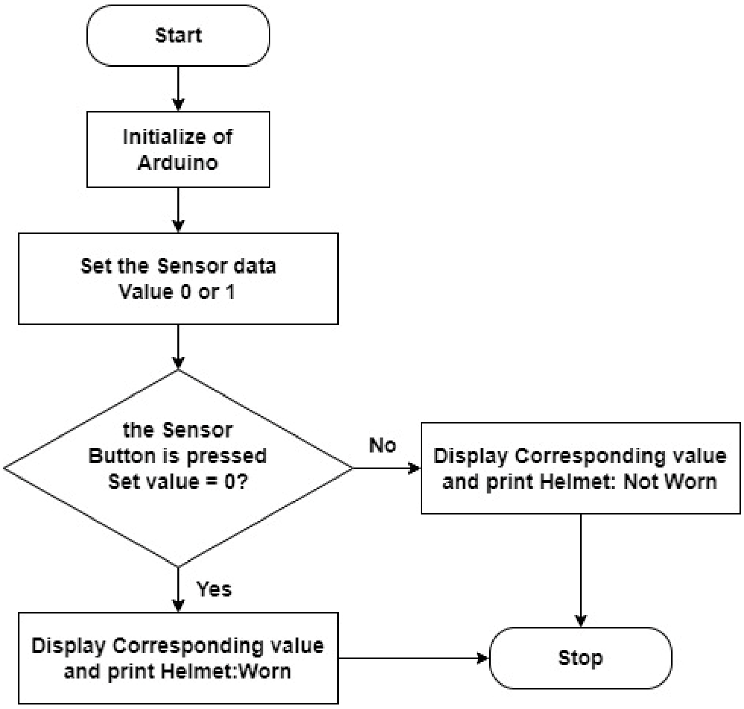

Figure 4. Flowchart for Pressed Button Sensor (Worn Helmet)

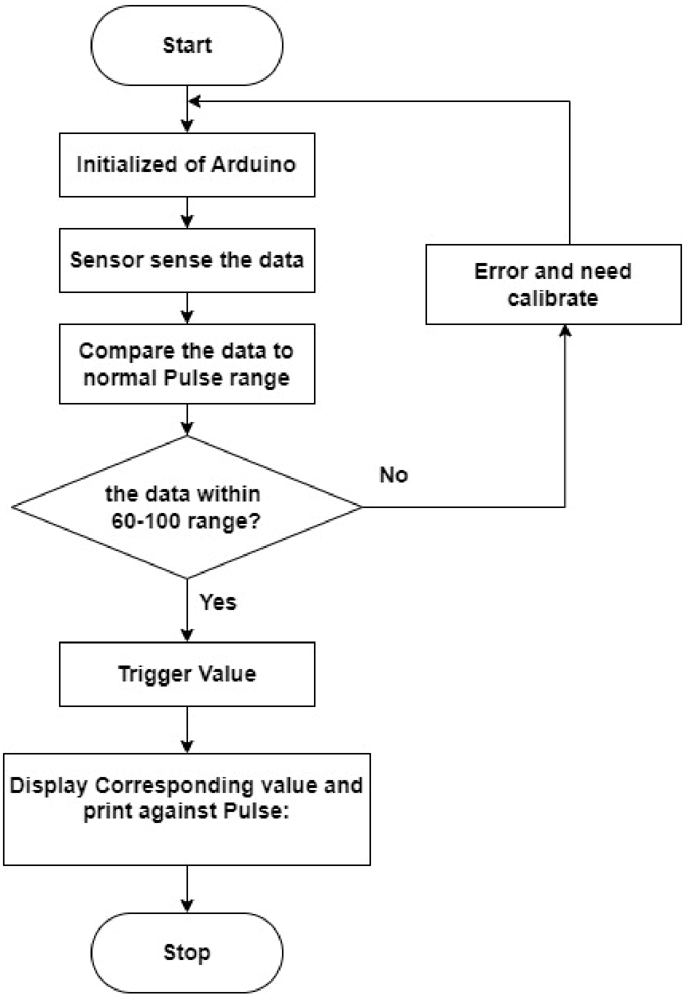

Figure 5. Flowchart for Heartbeat (Human Pulse) Sensor

3. RESULT AND DISCUSSION

The research conducted by [37] on construction worker safety shows that industrial accidents in the year 2016 were the cause of accidents as per the Korean "*Occupational Safety and Health Agency*" (OSHA). Out of the total of 90,656 people were involved in industrial accidents, of which about 29.3%, i.e., about 26,570, were in construction accidents. The following table shows different types of construction accidents. In addition, the distribution of construction accident types is shown in Figure 6. Moreover, Table 2 is a Distribution of Types of Construction Accidents.

Table 2. Distribution of Types of Construction Accidents (*Source*: Kim et al., 2018) [37]

Sl. No	Type of Accident	Percentage of Accidents
1	Fall	33%
2	Slip	15%
3	Object Strike	13%
4	Amputation, Cut, Slab	10%
5	Collision	9%
6	Crushing	8%
7	Occupational Illness	3%
8	Run Over	3%
9	Other	6%

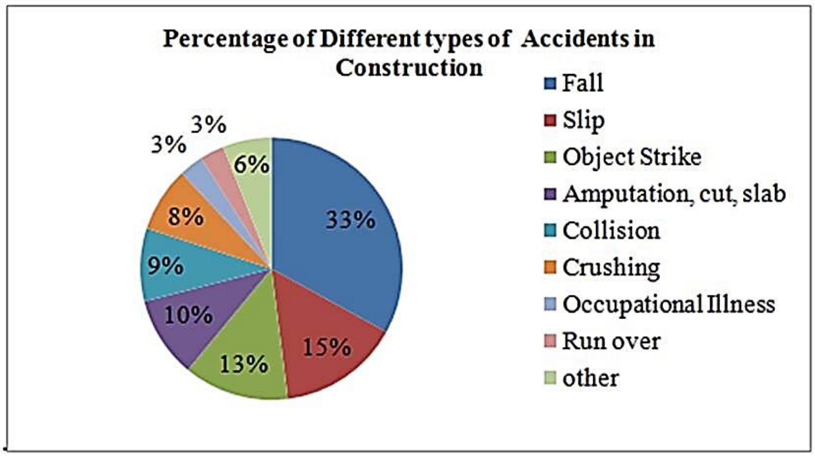

Figure 6. Distribution of Types of Construction Accidents (Redrawn)

The following table shows different types of construction accidents for other body parts. Of the 826 people who suffered body parts injuries in industrial accidents, 391, i.e., about 47.3%, were construction industry accidents. Moreover, Distribution of Types of Construction Accidents of worker body shown in Figure 7. And table 3 is a Distribution of Types of Construction Accidents of worker body.

Table 3. Distribution of Types of Construction Accidents of worker body (*Source*: [37])

Sl. No.	Body Part	Percentage of Accidents
1.	Head	41%
2.	Multiple body parts	31%
3.	Whole body	12%
4.	Chest, back	7%
5.	Others	9%

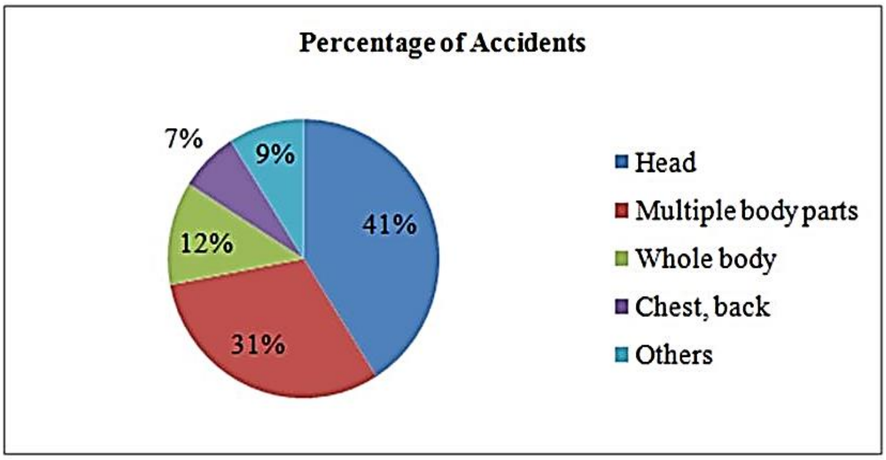

Figure 7. Distribution of Types of Construction Accidents of worker body

The rise of ubiquitous systems such as IoT devices and their enabling technologies are being developed, and their progressive adoption is taking place in the construction industry. IoT was found to have substantial potential in high-risk EHS ("*Environment, Health, and Safety*") businesses. Human lives are at risk in these sectors. IoT-based uses are well-positioned to provide safe, dependable, and efficient solutions because of their capacity to work at a fine-granular abstraction level. Applications of IoT have already experienced reasonable success in healthcare services, infrastructure monitoring, etc. Several factors and needs have prompted to use of IoT in the health care industry, such as: (i) increasing chronic diseases, (ii) lack of availability of critical patient information, especially in an integrated manner, (iii) RFID technology as well as wearable technologies (iv) lack of adequate training as well as assist to users (v) inadequate user education and assistance (vi) absence of data security and privacy considerations(vii) availability of wearable technologies in multinational construction companies in India [46].

For example, a Raspberry Pi-based platform with IoT integration can be used to monitor the structural health of buildings and identify the extent of damage (Abdelgawad and Yelamarthi, 2017). The gathering and collaboration of patient data obtained from hospital sensors utilizing IoT technology are called health monitoring systems. The sensor data will help the doctor gathered to enhance and improve patient health [1] in an emergency. The concept may be implemented using a Raspberry Pi 3 model B as the hardware platform to allow internet and smartphone communication with the doctor [63].

Wearable devices, sensors, and warning systems: Wearable sensing devices enhance hazard recognition and detection. It enhances safety planning, communication, or awareness and mitigates safety or health problem. Sensors improve hazard identification and recognition. It improves safety planning, brings awareness or communication, and enhances physical workplace settings; Warning systems enhance hazard identification and recognition. It enhances safety planning awareness or communication [65].

A. Implementing Construction Health and Safety Management Feature using Arduino

In this research, the Arduino platform is used for prototyping interactive objects using electronics. An open-source microcontroller termed Arduino may be quickly programmed, reprogrammed, and erased at any time. Like other microcontrollers, it can take inputs and control outputs for various electrical devices to act as a minicomputer. Arduino employs a hardware component called the Arduino development board and the “Arduino IDE” program to write code. Arduino can communicate with the environment by transforming signals into sensors. It is plugged straight computer’s USB port or powered with an AC-to-DC adapter or battery to get started [65]. Arduino consists of both hardware and software. It has 14 digital pins, an LCD with a 16-character X2 line display as the Figure 8, Figure 9, and Figure 10, and also a Wi-Fi module of ESP8266 socket with an integrated TCP/IP protocol stack. Wi-Fi direct (P2P soft-AP, +19.5dBm O/P power in 802.11b output mode [66].

1) *Pulse Sensor*: One of the most frequently read vital signs is the human pulse. It could be utilized to identify ranges of emergency conditions like vasovagal syncope, pulmonary embolisms, and cardiac arrest. Pulse could be read from the fingertip, earlobe, wrist, and chest. However, the fingertip and earlobe provide high accuracy but are not highly wearable [9]. Biore biosensors make real-time measurements of the environment and the wearer’s health possible (pulse rate and body temperature sensor to track the miner’s fundamental physiological parameters). The finger-clip heart rate sensor is an optical biosensor with exceptional performance that monitors changes in blood flow in the body [41].

2) *Helmet Button Sensor*: It is essential to create technologies to monitor whether safety helmets are being worn because wearing them is one of the main contributors to the rise in accidents. However, incorrect use has not been seen, like when the chinstrap and harness fastening of the safety helmet is not correctly fastened. Experiments were performed using the Arduino platform based on the IoT concept and CRASP methodology, in which the sensing data was captured and displayed in ThingSpeak Cloud, and the values were sent to mobile through ThingSpeak Cloud App for Android Mobile. It classifies whether the safety helmet has been worn correctly or not worn [37].

Figure 8. Display board for Arduino

Figure 9. Display of Sensor Values (Note: Read Wore as Worn)

Figure 10. Updating Cloud

Many laborers work for the completion of the construction project on construction sites. Since laborers work in the construction site scattered, it becomes difficult for the supervisors to closely monitor them and even round the clock if needed occasionally. Some laborers might not be wearing safety helments and supervisors might be unable to watch them. In constructing a high-rise, multi-storied building, locating these labors at a given specific time and communicating with them to inform them about safety is not possible. Therefore it is essential to design automated and innovative safety mechanisms to protect the worker's safety and prevent accidents on construction sites. Wearable jackets that monitor and ensure construction worker safety can be adopted in this scenario, which send out warnings whenever a hazardous zone is approaching and notifies site managers by sending cloud-based mobile messages. Thus, accidents can be avoided, and labor productivity can be improved by constantly monitoring the ir-reasonable idle time some laborers spend using Passive Infra-Red (PIR) sensors in passing [31]. A wearable sensor jacket uses advanced knitting techniques to hold sensors in position so that upper limb and body movements can be measured. These sensors supply adaptable information to the central computer on the current worker activities who wear the jacket. Subsequently, it gets logically processed to take appropriate actions through actuators of other wearable jackets or computers in passing 22]. For example, many wearables such as hats, vests, and glasses hold sensors, GPS, and smart devices to achieve the safety goals of reducing or combating accidental risks. Usually, wearable jackets are designed to avoid significant causes of construction accidents such as falls from heights, caught-in/between objects, and electrocution [3].

4. SUGGESTION

Though there are pro-factors associated with wearable jackets for protecting construction worker safety, the cons and challenges should also be thoroughly researched to tackle them. A brief list of issues and challenges include IoT system efficiency, reliability, and un-remarkableness; workers as humans need privacy, so its associated legislation; interoperability; cost issues for reimbursement against insurance, end-user training, social inclusion, ethical usage issues, etc. To fully realize the potential of intelligent wearable jackets, researchers are expected to work more on adopting these technologies with a comprehensive approach, as mentioned in passing [14].

ACKNOWLEDGMENTS

My sincere acknowledgments to my previous and current organizations' environment in India, i.e., Narasaraopeta Engineering College, Narasaraopeta, Pallavi Engineering College, Hyderabad, and Ashoka Women's Engineering College, Kurnool, where I perceived the knowledge and prototype development efforts using Arduino. I apologize for the unavoidable picture taking with a mobile that has cracks on display glass, and such a picture is now used to become part of a publication.

AUTHOR CONTRIBUTIONS

Conceptualization; Tatapudi G. Vasista [T.G.V], Methodology; [T.G.V], validation; [T.G.V], formal analysis: [S.S],[M.S.L],[S.G.Z],[S],[A.D], investigation; [T.G.V], data curation; [T.G.V], writing—original draft preparation; [T.G.V], writing—review and editing; [T.G.V], visualization; [T.G.V], supervision project administration; [T.G.V], funding acquisition; [T.G.V], have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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