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Research article

Occupational Safety and Health Support System for Telecommunication Tower Climbers

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Abstract: Telecommunication tower climbers are exposed to sunlight, delicate particulate matter (PM 2.5), and wind for extended periods daily, which unavoidably impacts their health and safety and may result in serious accidents. This study aims to (1) create an Occupational Safety and Health Support System for Telecommunication Tower Climbers to mitigate the risks associated with working on telecommunications towers and (2) assess the user satisfaction of those using the system. The system displays information like the heat index, PM2.5 levels, wind speed, body temperature, and heart rate on a monitor and the LINE app. It alerts with sounds and lights when values reach risky levels, helping safety executives take preventive actions. After the safety support system development was completed, the researcher tested and evaluated the system using the Black Box Testing method, involving 15 experts who assessed the system's performance in three areas. The Perception of Usefulness received an average score of 4.120, indicating a high level. System Efficiency had an average score of 4.333, which was also high, and Data Quality received an average score of 4.156, which was high as well. Additionally, 60 climbers used the system and provided evaluations. For Perceived Usefulness, the average score was 4.040, System Efficiency obtained a score of 4.167, and Data Quality scored 4.167, all indicating high levels. These results suggest that the system development met its objectives and can be effectively applied in the future.

Keywords: Occupational safety and health; Telecommunication tower; IoTs

1. Introduction

Telecommunication towers, including those for radio transmission and mobile phone base stations, are being developed and extensively utilized across Thailand. Tower climbers must wear durable clothing that can withstand abrasion, strain, and tears to protect themselves from scratches, wounds, or punctures. This attire must also comply with essential safety regulations. However, due to prolonged strenuous work under the sun, climbers generate substantial thermal energy and experience dehydration. Consequently, it is common practice to consume beverages high in sugar and caffeine, such as energy drinks or canned coffee.

Some tower climbers use marijuana or kratom to rejuvenate and reduce fatigue [1]. They face physical challenges like cramps, sunburn, dizziness, and heatstroke [2]. Extreme heat and PM2.5 exposure, especially in Thailand's summer and winter, lead to coughing, breathing difficulties, and long-term respiratory damage. These conditions impact workers' health and increase accident risks. While wind can help with temperature and dust reduction, it can also cause instability and complicate tasks [3].

The safety and occupational health system for telecom towers is essential. It transmits real-time data about the working environment and employees' physical conditions to management, assisting in informed decision-making. This helps identify measures to eliminate or reduce hazards, ensuring workers' safety. Eltahir, M. [4] studied a wearable insole system using IoT and sensors to detect poor postures, demonstrating improved results compared to previous methods. Eltahir, M. [4] concurs that wearable technology has significantly enhanced safety measures.

Research objectives

(1) Develop a Safety and Occupational Health Support System for Telecommunication Tower Operators.

(2) Measure the satisfaction level of this system among operators.

Research scope

This study examines tower climbers in Bangkok and its surrounding regions, including Pathum Thani, Nonthaburi, Nakhon Pathom, Samut Prakan, and Samut Sakhon.

2. Materials and Methods

Literature Review

1. Telecommunications towers

Telecommunication towers are steel or concrete structures designed for antennas to transmit and receive radio waves [4]. First used in 1901 by Guglielmo Marconi to send radio messages across the Atlantic Ocean, these towers enabled sound transmission via radio [5]. They vary from 100 to over 2,150 feet in height and come in three types: (1) monopoles made of tapered steel tubes, (2) guyed towers stabilized with wires, and (3) self-supporting towers, which are freestanding lattice structures [6].

Figure 1. Types of telecommunication tower

2. Safety and OSHA Standards related to working on telecommunications towers.

The researcher has examined several safety standards for tower climbers, including:

2.1 Occupational Safety, Health and Environment ACT B.E. 2554 (A.D. 2011)

Section 5, paragraph 1, and Section 8, paragraph 1 of the Safety Act, Occupational Health and Working Environment B.E 2554 outline specific duties. Employers are required to provide adequate training and prepare standard safety equipment. They must enforce and arrange to prepare, inspect, and maintain safety equipment to ensure safety protection. For instance, equipment should be checked for readiness before each use. Workers must wear safety equipment such as gloves, safety shoes, full-body harnesses, and lifebelts. Additional equipment may be necessary depending on the task. All equipment must meet established standards [7].

2.2 Communication Tower Best Practices The Occupational Safety and Health Administration and The Federal Communications Commission

Stakeholders in the industry and attendees of the DOL/FCC Joint Workshop on Tower Climber Safety on October 14, 2014, provided best practices in communication tower safety. It stated that every organization should set up a thorough safety and health management system that addresses every risk related to working on communication towers, and every business should make sure that its system complies with requirements set forth by other businesses in the contract chain. When weather circumstances risk workers' safety, all work crews should refrain from working at heights. They should also constantly monitor climbers' mental and physical health and remove unfit workers from climbing duty [6].

2.3 Communication Tower Best Practices by U.S. Department of Labor Occupational Safety and Health Administration and The Federal Communications Commission (OSHA 3877-06 2017)

Employees must annually show commitment to "100 percent tie-off", ensuring safety harnesses are always secured when ascending. Job site managers must enforce this strictly. Crews should avoid elevated work during unsafe weather conditions, and workers with compromised health should not perform tasks at heights. For instance, those on medications that cause drowsiness should not climb or work at high altitudes [8].

2.4 Reclamation Safety and Health Standards January 2023 Section 30: Tower Climbing Safety (RSHS 012) 04/17/2020 30-1 NEW RELEASE (Minor revisions approved 12/14/2022)

Tower climbers must always follow the 100 percent tie-off rule and thoroughly inspect their PPE, including fall protection gear, before each use per the manufacturer's guidelines. Before climbing, assess conditions that may affect safety, such as hazardous weather, health issues, infestations, damaged PPE, tower damage, or insufficient tie-off points [9].

2.5 NIOSH Alert: Preventing Injuries and Deaths from Falls during Construction and Maintenance of Telecommunication Towers [DHHS (NIOSH) Publication No. 2001–156]

This publication outlines the minimum requirements for tower workers, including height training, using certified hoisting equipment, trial lifts, proof-testing, pre-lift meetings, procedure documentation, environmental and physical condition assessments, and maintenance of hydraulic hoists and gin poles [8].

3. Theories related to occupational safety and health

3.1 Domino Theory

Heinrich's (1950) [10] theory likens accidents to a row of falling dominos. If one domino is removed, the chain reaction stops. He applies this concept to accident causation.

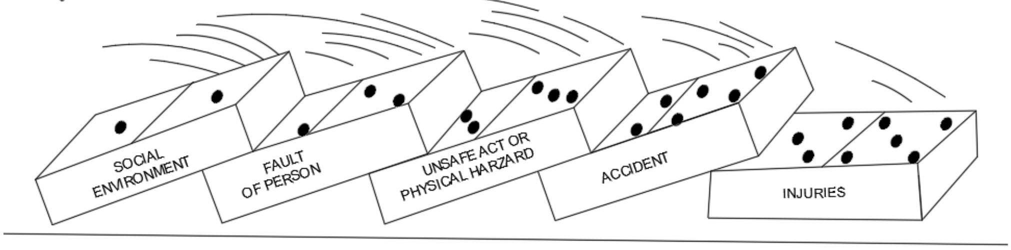

Figure 2. Domino theory
Source: Heinrich [10]

From the figure, the first stage, social environment and ancestry, covers factors that may lead to undesirable traits. A modern take would term this "inherited behavior," akin to inherited alcoholism or temperaments. The second stage, personal faults, includes traits like lousy temper or recklessness that can cause accidents. The third stage, an unsafe act or condition, marks the start of an incident through actions or inactions leading to accidents. The fourth stage is the accident, and the final stage is injury. The key policy implication is removing at least one of these stages through positive accident prevention training and seminars.

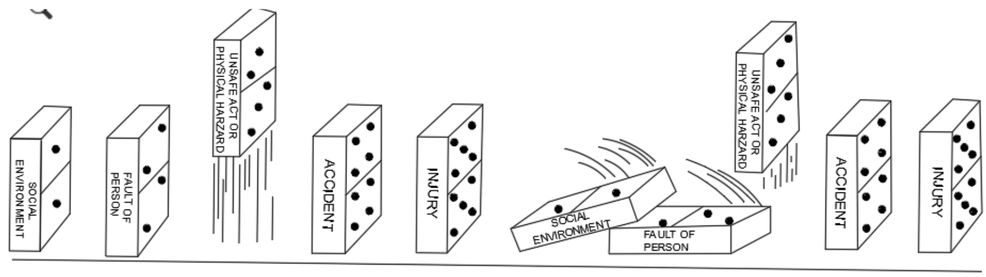

Figure 3. The unsafe act and unsafe condition constitute the central factor in the accident sequence
Source: Heinrich [10]

Ferrell's Human Factor Model

Unlike Heinrich, who explained accidents with a single chain reaction in vague terms, Ferrell's model incorporates multiple causes and is very specific about these causes [10]. Additionally, Ferrell defines accidents in terms of being the result of an error by an individual. As such, he explains his theory using the assumption that accidents are caused by one person.

Ferrell identifies three general causes of accidents: overload, incompatibility, and improper activities. Each of these are broad categories that contain several more specific causes. Improper activities are perhaps the simplest of the concepts, as it encompasses two straightforward sources of accidents. First, it is possible that the person responsible did not know anything better. Alternatively, he or she may have known that an accident may result from an action but deliberately chose to take that risk. The cause of incompatibility is slightly more complex than that of improper activities. It encompasses both an incorrect response to a situation by an individual as well as subtle environmental characteristics, such as a workstation that is incorrectly sized.

The remaining cause, overload, is the most complex of Ferrell's causes. It can further be broken down into three subcategories. First, the emotional state of the individual accounts for part of an overload. These states include conditions such as unmotivated and agitated. Second, the capacity refers to the individual's physical and educational background. Physical fitness, training, and even genetics play a part in this. Situational factors, such as exposure to drugs and pollutants, as well as job-related stressors and pressures, also affect one's capacity. Finally, the individual's load can also contribute to overload. This includes the difficulty of the task, the negative or positive effects of the environment (noise, distractions, etc.), and even the danger level of the task. Separate from each other, overload, incompatibility, and improper activities can all cause a human error, which can lead to an accident.

Petersen's Accident/Incident Model

Petersen's model is largely an expansion upon Ferrell's Human Factor Model [10]. The notion of an overload caused by capacity, state, or load is very similar to Ferrell's work. However, a few changes and refinements do exist. First, Petersen conceptualized the environmental aspect of incompatibility (workstation design and displays/controls) as a different part of the model, calling them ergonomic traps. Additionally, Petersen separated the decision to err from the overload cause. Further, Petersen also specified separate reasons for choosing to err. These reasons include a logical decision due to the situation (primarily for financial cost and temporal deadlines), an unconscious desire to err (psychological failings), and a perceived low probability of an accident occurring. The latter of those reasons, the perception of low accident probability, can include both actual instances of an accident being extremely unlikely, as well as the natural inclination of a human to disregard his or her own mortality. This aspect of Petersen's model is akin to criminology's rational choice perspective (see the criminological theories chapter), as it makes the same assumptions of human rationality and hedonistic calculus.

Another noteworthy contribution is Petersen's recognition that human error is only part of a larger model. A system failure, the inability of the organization to correct errors, was added as a possible mediator between errors and accidents. These failures have a range of possible occurrences. The failure of management to detect mistakes and a lack of training are but two examples of systems failures. Even poor policy itself can lead to a systems failure that does not prevent an accident from occurring following a human error.

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3.2 Ferrell's Human Factor Model

Ferrell's model identifies several specific causes of accidents [10]. Furthermore, Ferrell attributes accidents to individual error, positing that one person causes them. He categorizes the general causes of accidents into three main groups: overload, incompatibility, and improper activities. Each category encompasses various, more specific causes [11].

4. Internet of Things

The Internet of Things (IoT) uses the internet network and data from nearby devices or objects to make them functional. "Internet" refers to a computer network system that connects and communicates with other computer networks. The term "thing" includes all objects or equipment, such as air conditioners, televisions, tables, chairs, pens, pencils, clothes, and shoes.

The Internet of Things (IoT) has gained significant traction in recent years [14]. According to Yeo, Yu, and Kang [13], IoT applications in the construction industry are instrumental in preventing accidents on construction sites. The widespread adoption of IoT is mainly attributable to its well-recognized capabilities. IoT can enhance work efficiency, boost productivity, improve Occupational Health and Safety (OHS) standards, mitigate adverse environmental impacts, and generate additional societal value.

Initially, IoT technology was evolving, but it has since advanced significantly, incorporating virtual reality (VR) and augmented reality (AR) technologies. These advancements have facilitated various applications within the construction sector, including vocational training, OHS for construction workers [15], site monitoring [16], and quality and progress management [17]. For instance, wearable detection technologies are employed to collect and analyze worker safety and health data, thereby supporting real-time proactive security management. These devices include motion and physiological sensors, such as heart rate sensors, which detect electrode activity, skin temperature sensors, eye trackers, and brain wave measuring machines. The primary objective of these devices is to identify potential safety hazards and continuously monitor workers' health at construction sites [18].

5. Key Data for Telecom Tower Climber Safety Support System

5.1 Heat index

Telecommunication tower construction involves outdoor work, exposing workers to intense heat from the sun. This can lead to serious health issues, including illness and death. The cardiovascular system struggles with sudden temperature increases, making it hard for the body to adapt. Those most at risk include individuals with heart disease, diabetes, obesity, fever, dehydration, mental illness, alcohol consumption, and other chronic conditions. Heat stress can cause dehydration, fatigue, heat stroke, fainting, heat cramps, and heat tetany, characterized by expanded blood vessels in the skin, insufficient central blood flow, rapid shallow breathing, and muscle tightness.

The World Health Organization (WHO) and the Department of Health, Ministry of Public Health, Thailand, have indicated that a heat index of 38 degrees Celsius or higher begins to affect health adversely. The body may become weakened by the heat, leading to symptoms such as dizziness and cramps. At a heat index of 40 degrees Celsius or higher, there is an increased risk of heatstroke. Moreover, consistent exposure to a heat index of 43 degrees Celsius for several consecutive days can lead to potentially fatal system failures in the body due to excessively high temperatures [19].

Table 1. Measure value for Heat index

Sensor	Normal level	Alert level	Risk level	Reference
DHT 22AM2302	< 38	38.1-43C	> 43.1 C	WHO (2566)

5.2 Particulate matter less than 2.5 μg/m³ (PM2.5)

Solid particles or liquid droplets in the atmosphere, known as PM2.5, are tiny (2.5 microns or smaller). Outdoor workers in high PM2.5 areas face higher stroke risks, skin and eye irritation, coughing, sneezing, mucus, sinus inflammation, sore throat, breathing issues, and lung or circulatory system irritation. Blood clots can lead to arrhythmia and high blood pressure. Studies show a strong link between PM2.5 and cardiovascular-related deaths [20].

Table 2. Measure value for PM. 2.5

Sensor	Normal level	Alert level	Risk level	Reference
SHARP GP2Y10	< 37.5 μg/m³	< 37.6-75.0 μg/m³	> 75.1 μg/m³	Pollution Control Department (2023)

5.3 Wind

Wind is caused by air moving from high to low-pressure areas. The wind's direction shows its origin, like a southwest wind blowing northeast [21]. Radio communication towers are often exposed to strong winds due to their height and open locations. While airflow cools and refreshes operators and clears dust, high wind speeds can be dangerous for those working on towers. Safety personnel must assess and monitor wind speed before and during tower activities, as speeds above 23 mph or 7.0 km/h can affect balance. [22]

Strong winds complicate equipment control, tangle ropes with poles, and cause pillar structures to sway. Radio communication becomes ineffective, increasing accident risks. Assisting during accidents in strong winds is also problematic [22].

Table 3. Measure value for wind speed

Sensor	Normal level	Alert level	Risk level	Reference
RS-FS-N 01RS485	< 30 Km/Hr.	29-38 Km/Hr.	> 38 Km/Hr.	(Silo, tips, 2016)

5.4 Body temperature sensor

A body temperature above the normal range indicates a fever. When measured orally, the average human body temperature is approximately 37°C. The body needs to maintain its temperature within an appropriate range, which has mostly remained stable, allowing it to function correctly despite external temperature variations. A temperature indicating a fever is 37.2 °C or higher in the early morning or 37.8 °C or higher.

Kraipiboon [23] noted that body temperature varies throughout the day, especially between 11:00 a.m. and 5:00 p.m. It declines with higher outside temperatures, reaching its lowest at 11:00 p.m. before rising again. Factors such as muscle movement, hormone levels, clothing, and surroundings influence these changes. Temperature ranges indicate fever severity: 37.6°C to 38.4°C for low fever, 38.5°C to 39.4°C for moderate fever, 39.5°C to 40.4°C for high fever, and above 40.5°C for very high fever.

Table 4. Measure value for body temperatures

Sensor	Normal level	Alert level	Risk level	Reference
DS18B20	- 35.4°C37.4 °C	- 37.5°C 38.4°C	> 38.5°C	Kraipiboon, P. 2016

5.5 Heart rate

Working at heights demands more physical effort, increasing muscle oxygen needs and heart workload [1]. The heart's workload rises significantly. Consuming stimulants like canned coffee, energy drinks, kratom, or amphetamines can cause rapid and irregular heartbeats [1].

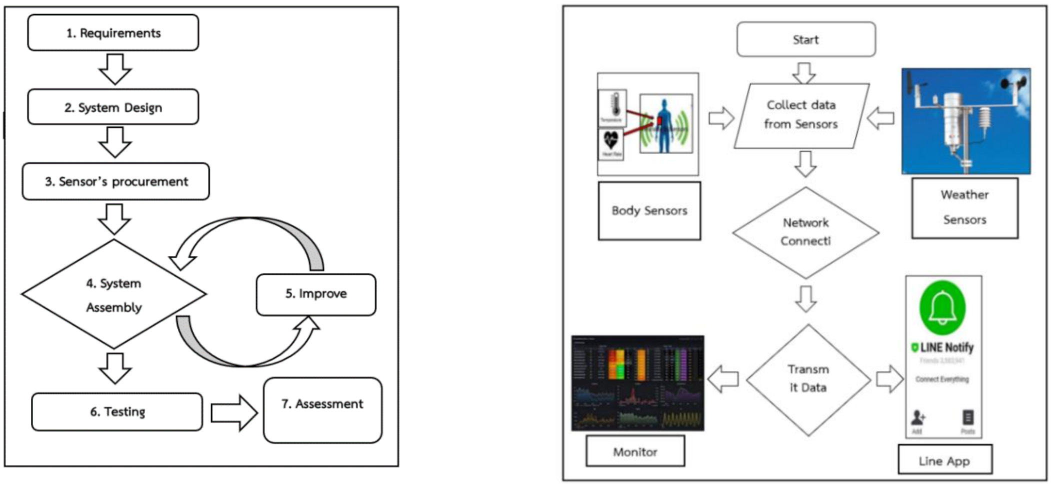
Additionally, working in the sun for extended periods can result in dehydration. Dehydration may be caused by significant blood loss, insufficient rest, inadequate sleep, infection, high fever, hyperthyroidism, diarrhea, certain medications, and factors related to the heart and blood vessels, such as acute myocardial infarction. The heart's muscle wall may thicken abnormally due to conditions including congenital heart disease, heart valve disease, and high blood pressure. These conditions can lead to a faster-than-normal heart rate, potentially causing dizziness. Workers may faint or lose consciousness, which could result in other serious accidents. Therefore, monitoring and checking the heart rates of individuals working at heights is essential to prevent accidents and harm. The average heart rate ranges from 60 to 100 beats per minute (BPM), and when it exceeds 100 BPM, it is essential to identify any underlying factors that may be causing this increase.

Table 5. Measure value for Heart Rate

Sensor	Normal level	Alert level	Risk level	Reference
MAX30102	78 – 36 BPM	79-114 BPM	> 114 BPM	Bangkok Heart Hospital (2023)

Methods research

The Occupational Safety and Health Support System for Telecommunication Tower Climbers was developed using the Internet of Things. The researcher followed the System Development Life Cycle (SDLC) theory, involving six steps: (1) Analyzing system needs and feasibility, (2) Designing measurement tools, (3) Developing the system, (4) Testing to prevent errors, and (5) Deploying the system. The operation diagram was designed as shown in Figure 4 & 5.

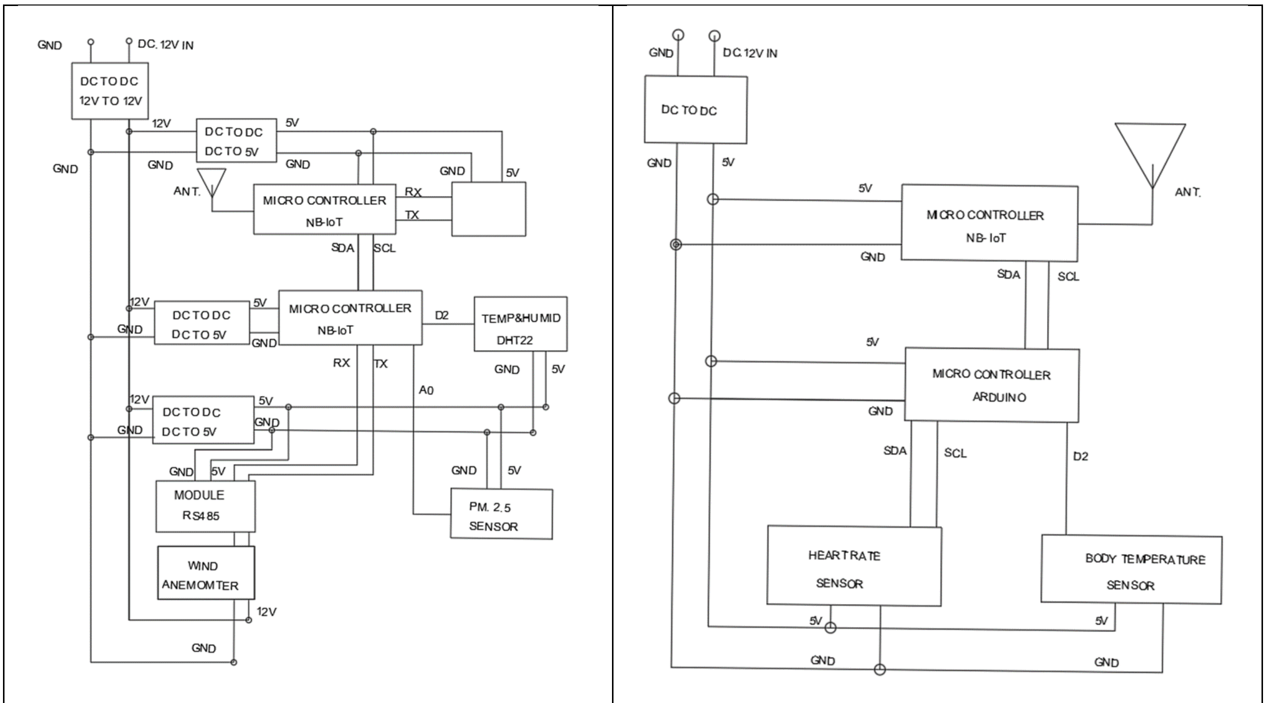


Operation steps | Conceptual design

Figure 4. System design

(1) Designing electronic circuits

The researcher has devised the electronic circuit according to its planned purpose, commencing with the initial stage of conceptualizing the design by (1) establishing specific criteria and conditions to ensure the comprehensive visibility of all components and structures. (2) Provide precise details to specify the characteristics and functionalities of different measuring instruments, including those used for electrical measurements. (3) Creating circuit diagrams and assessing their feasibility through calculations. (4) Examination and evaluation after constructing the gadget by the circuit design. The researcher has assessed the efficacy of utilization. (5) Develop a prototype that will be manufactured for practical implementation.



Circuit diagram of a climate measurement system	Circuit diagram of body measuring system

Figure 5. Circuit diagram

(2) Instruments and implements used for measurement

To link various sensors to Arduino, create a Sensor Library for the Arduino platform. Without this library, you cannot upload code that makes Arduino UNO function as intended.

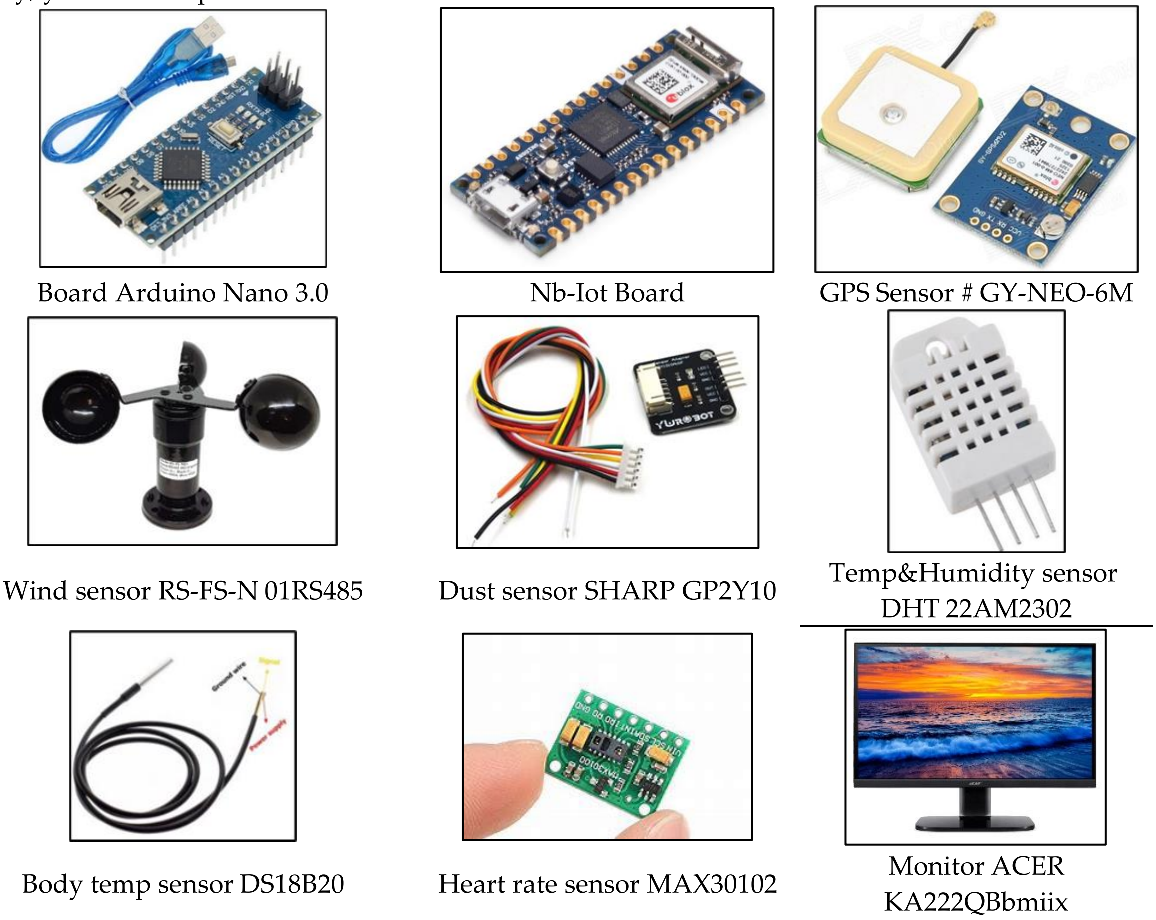


Figure 6. Measuring equipment

After the development, instruments were sent for calibration to SP Metrology System (Thailand) Co., Ltd., accredited by ANAB, USA, following ISO/IEC 17025:2017, before conducting trials with the sample groups. Users must handle the device carefully during transport to ensure accurate measurements and recalibrate it annually.

3. Results and Discussion

Data from the device on the operator's wrist and the weather station is sent to the cloud, dashboard, and line every 10 minutes, with alarms triggered at monitored and risk levels. The dashboard can be accessed at this link using User: v89tech@v89tech.com and Pass: xxxxxx. On-site, a light tower displays sound and light alarms corresponding to each data level received. It shows green for everyday situations, yellow for alert situations, and red with a siren for critical levels.

Figure 7. System development

System Assessment

A safety and occupational health support system was created for telecommunication tower operators. To test its efficacy, 15 specialists trialed it and distributed it to 60 experienced individuals in Bangkok and nearby regions. The researcher obtained human research ethics approval. The system's performance satisfaction was assessed using a five-point Likert scale questionnaire.

Assessment of Expert's Satisfaction

We evaluate the system's performance in each domain by calculating the mean ($\bar{x}$) of the standard deviation (S.D). The performance evaluation of a panel of 15 experts is summarized in Table 6.

Table 6. Experts' Satisfaction

Items	$\bar{x}$	S.D.	Meanings
1. Perceived of Usefulness	4.120	0.497	High
2. System performance	4.333	0.474	High
3. Data quality	4.156	0.474	High
Total	**4.203**	**0.482**	**High**

Table 6 shows expert evaluations of satisfaction with the Occupational Safety and Health Support System for Telecommunication Tower Climbers. The system is seen as valuable. For system quality, it meets high criteria ($\bar{x}$ = 4.120, S.D. = 0.45). Efficiency in terms of data quality is also high ($\bar{x}$ = 4.333, S.D. = 0.474). Experts' overall satisfaction is high across usefulness, system performance, and data quality ($\bar{x}$ = 4.203, S.D. = 0.482).

Users' satisfaction

The study aimed to evaluate the effectiveness of a heart rate and body temperature monitoring and notification system for workers at heights using the Internet of Things. Using the arithmetic mean ($\bar{x}$), standard deviation (S.D.), and efficiency level values, which were evaluated by 60 people who had tried using it, with details as shown in Table 7

Table 7. Users's satisfaction

Items	$\bar{x}$	S.D.	Meanings
1. Perceived of Usefulness	4.040	0.543	High
2. System performance	4.167	0.560	High
3. Data quality	4.167	0.565	High
Total	**4.125**	**0.546**	**High**

Table 7 shows user satisfaction with the Occupational Safety and Health Support System for Telecommunication Tower Climbers. Perceived Usefulness: Satisfaction is high ($\bar{x}$ = 4.040, S.D = 0.543). System Performance: High satisfaction ($\bar{x}$ = 4.167, S.D = 0.560). Data Quality: Rated high ($\bar{x}$ = 4.16, S.D = 0.565). Overall System Satisfaction: High among users ($\bar{x}$ = 4.1, S.D = 0.546), as shown in Figure 8.

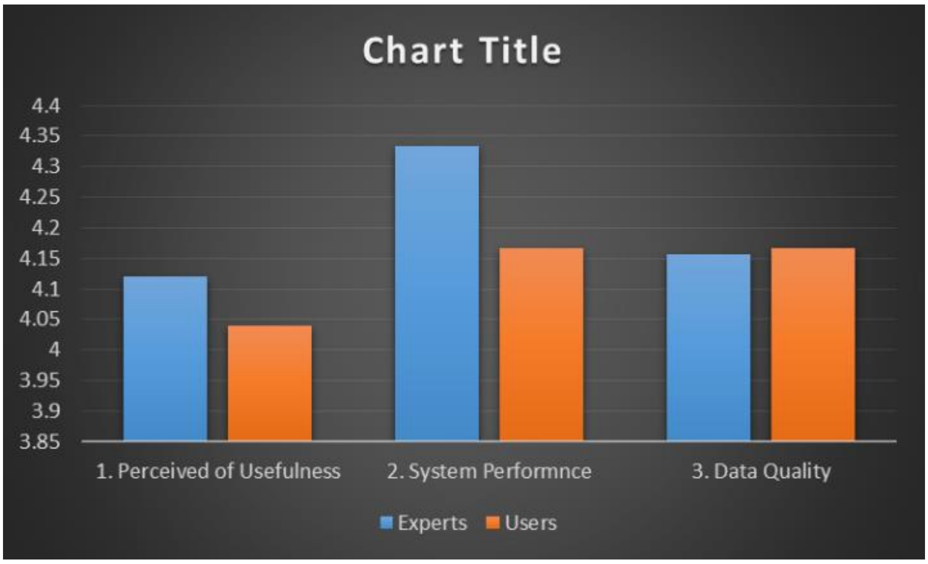


Figure 8. Compares expert and user satisfaction levels.

4. Conclusions

This research aims to develop a safety and occupational health support system for telecommunication tower operators, which currently does not exist in Thailand. To address potential hazards from changes in physical conditions and the environment, safety officials should implement procedures to minimize risks for tower workers. Future research should quantify and notify variables like blood pressure and oxygen levels to enhance safety decision-making and accident prevention. A potential issue with extended use is that the tool's workload may become overwhelming for a device intended to be used by a limited number of individuals working in groups of one or two people.

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