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Smart Health and Safety Equipment Monitoring System for Distributed Workplaces

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Received: 14 October 2019; Accepted: 5 November 2019; Published: 11 November 2019

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Abstract: This paper presents a design and prototype of an IoT-based health and safety monitoring system using MATLAB GUI. This system, which is called the Smart Health and Safety Monitoring System, is aimed at reducing the time, cost and manpower requirements of distributed workplaces. The proposed system is a real-time control and monitoring system that can access on-line the status of consumable devices in the workplace via the internet and prioritise the critically high location that need replenishing. The system dynamically updates the status of all location, such as first aid boxes, earplug dispensers and fire extinguishers. Simulation results of the proposed system gives shorter path, time and cost in comparison to manual maintenance systems.

Keywords: smart monitoring; cloud data storage; health and safety products; MATLAB

1. Introduction

Under rapid technological development, the world has entered a new era of interconnectedness through advancements such as the Internet of Things (IoT). The IoT comprises two concepts, namely, 'Internet' and 'Things'. 'Internet' is a technique for information exchange, and 'Things' refers to devices equipped with wireless sensors, software, electronics, actuators and connected networks. Through the IoT, objects and everyday items can collect and exchange information ubiquitously without much need for human intervention [1]. The IoT can be regarded as the interconnection of concrete devices through a network to establish a smart system. Hence, connected products may be made smart by changing their nature [2].

Through effective combination and coordination, physical and computational systems can send and receive data under IoT-based infrastructure. An existing network system can monitor, detect and remotely manage interconnected objects to facilitate the exchange of information according to user requirements. This process is different from that used by governments and those employed in industries and production [3].

At present, the continuous development of high-quality assistance within people's living environment has become an important requirement. Therefore, the benefits of IoT applications in the development of new networks of intercommunicating objects in consumers' everyday life have attracted the attention of many organisations and companies. To address the need for progress in people's living standards, all sectors are expected to keep up with industrial advancements [4]. The health industry is crucial in world safety because it is closely associated with human life. Global health systems thus face unprecedented financial, social and environmental challenges. The improvement of the healthcare industry may be possible through innovative IoT technologies [5]. IoT technologies, such as the cloud and sensors with mobile technologies, show great potential in addressing the issues related to data processing, storage, accessibility, security and distribution [6].

Although the IoT has been used widely in the healthcare industry, such as in the monitoring of patients' health and blood pressure (BP) and electrocardiogram equipment, it has yet to be adopted to monitor health and safety (H&S) products [7]. Numerous H&S products in the healthcare field should undergo regular inspections conducted by facility managers. Managers of H&S companies are tasked to consistently evaluate devices because they lack direct knowledge of the usage of such devices. Such evaluation needs time, effort, cost and manpower.

These deficiencies may be addressed by an innovative IoT-based monitoring system that could also ensure the compliance of equipment to regulatory requirements. A solution lies in healthcare IoT that can remotely construct, operate and control H&S products through a network that analyses and exchanges data using the cloud. In the healthcare industry, the application of the IoT is a simple, fast and low-cost solution [2,8]. Therefore, healthcare organisations have used the IoT to transform their existing tools into efficient, interoperable and coordinated systems. Data analytics in the realm of the IoT is increasingly being used by enterprises to limit maintenance costs, prevent equipment failure and guarantee compliance with regulatory requirements in H&S facilities. This approach is applicable to sectors overseeing a large volume of assets and coordinating complex and distributed processes.

In the current work, the importance of IoT-based services in proposing various changes is considered in order to make the IoT practical for the healthcare sector. Specifically, hardware and software are combined to explore novel IoT technologies and their functions in healthcare. A dynamic software system is also proposed. This system is designed to monitor and predict the status of equipment in the workplace. When any facility requires updating, the system automatically alerts building service managers. In monitoring the status of equipment, the proposed system measures the changes in weight, level and battery. It then determines whether the equipment is suitable for continuous daily use in accordance with regulatory requirements. The data collected by the system are stored in the cloud and analysed accordingly for decision making. Smart sensors collect data from the devices used to monitor the status of different facilities. Companies today are expected to observe the conditions of devices in the workplace for compliance with regulatory requirements. The early detection of devices with critically low state requires an effective maintenance system. As a potential solution, the proposed smart monitoring system can monitor equipment in different facilities simultaneously. Using this system is beneficial for building service managers and customers in hospitals. Information and communication technology should serve as the core platform for boosting the efficiency of H&S systems to fulfil update requests. Benefiting from the IoT structure, building service managers can secure contracts for different facilities to guarantee the availability of all equipment and limit confusion in daily tasks. With such enhancements, customers receive superior service without delay. By identifying H&S devices that are in critical state and do not meet regulatory requirements, hospitals reduce risks and ensure the safety and lives of their patients and personnel.

In this paper, Smart Health and Safety Monitoring System is presented, which is a novel maintenance system for the early detection of H&S devices that are in critical state. The proposed system uses smart sensors for data collection and status monitoring. The goal is to monitor the status of consumable items, such as plasters and sterile wipes, in first aid boxes by monitoring the total change in box weight, level of earplug dispenser or weight change of a fire extinguisher. The battery state (i.e., remaining charge) is also monitored because H&S monitoring systems are equipped with smart sensors which run on batteries. The proposed prototype achieves high efficiency by using a genetic algorithm (GA), ant colony optimisation (ACO) algorithm and travelling salesman problem (TSP). With these algorithms, the system can find the shortest path within a short time and then access the facilities whose devices are critically low and thus require maintenance or replenishment. Furthermore, artificial neural networks to predict the optimal performance of the system and the correlation between effective input factors and performance output.

Results prove that the proposed system is applicable to the simultaneous management of H&S products in different locations and workplaces in various health sectors. The system is designed with such capability on the basis of the IoT to identify consumable H&S devices that are in a critically low state and to enable sales personnel to replenish these devices to meet regulatory requirements. Overall, the results reflect the effectiveness of the system relative to manual maintenance techniques in terms of time, cost, effort and manpower resources.

2. Literature Review

On the basis of innovative IoT technology, Catarinucci et al. [9] developed a smart hospital system (SHS) that can automatically detect and control patients' biomedical devices in hospitals and nursing organisations. The SHS is based on radio frequency identification (RFID), wireless sensor network (WSN) and smart mobile technologies that are interoperated through a Constrained Application Protocol/IPv6 over a low-power wireless personal area network (6LoWPAN) to provide a representational state transfer (REST) network infrastructure. The SHS also uses an ultra-low-power hybrid sensing network that is composed of 6LoWPAN nodes integrating UHF RFID functionalities. Through this network, the SHS can detect and gather the real-time variations of critical patients' physiological data with their environmental conditions. Local and remote users can easily access these sensed parameters. The parameters are then delivered to a control centre via a modified REST web service. Hence, the proposed SHS can identify and track patients, staff and biomedical equipment within hospitals and nursing institutes whilst facilitating power-effective remote patient nursing and emergency management.

By applying IoT technologies to improve the healthcare industry IoT (Health IoT), Hossain and his group developed a real-time controlling and monitoring system that accesses and scrutinises patients' healthcare information to offer quality patient care and prevent avoidable deaths. At the centre of this Health IoT system are functional strategies, such as interconnected technologies, sensors, devices, apps and health specialists who can access, store and analyse patient data anywhere in real time to monitor and track their patients on a timely basis. The authors conducted an experimental assessment and simulation to validate the appropriateness of this approach. Health IoT data, such as electrocardiography (ECG) signals, are collected by mobile devices and sensors which securely send the data to the cloud for later access and monitoring by healthcare professionals. The authors utilised different analytical approaches such as signal enhancement and healthcare data watermarking to ensure that data are sent to the cloud for secure, safe and high-quality health monitoring and thereby avoid identity theft or clinical errors [10].

The increasing number of the elderly population and people suffering from chronic diseases motivated Ghanavati et al. [11] to advocate for the indispensability of the IoT in the healthcare context. To realise the remote monitoring of patients' health status in real time, the authors suggested an independent location framework that is based on the IoT, interconnected sensors and wireless body area network (WBAN). Nevertheless, the remote monitoring of patients in different hospital locations calls for enhancements in IoT capabilities and their integration with other applications. Connecting WBAN to a computing cloud by using smartphones for managing the health status of patients can be performed to process various applications though data distribution. The proposed framework was proved to be capable of assessing sensor lifetime, energy consumption and existing costs relative to the normal WBAN. However, it could not guarantee data privacy and security.

Islami et al. [12] presented a comprehensive survey of the different aspects of IoT-based healthcare technologies that are supposedly beneficial for health experts and professionals who work in the IoT and healthcare domains. The authors offered comprehensive insights into the recent advances in sensors, devices, Internet applications and other technologies to enhance medical devices and combine them with other IoT-based healthcare services. To enable medical data transmission and reception easily, they introduced innovative IoT-driven healthcare services, applications and network architecture/platforms, such as vast data, environmental intelligence and wearables. This broad study explained the application of IoT-based healthcare in handling paediatric and ageing care, chronic disease observation and special health and fitness supervision. Furthermore, the research highlighted the IoT and eHealth procedures and protocols adopted all over the world to determine their role in developing economies and societies. To present an intelligent design that can reduce the security risks of Health IoT, the team investigated a number of security and privacy features and requisites, such as security requirements, threat models and attack problems, in the healthcare sector.

To ensure safe working environments and reduce the health risks in the construction industry, Wu et al. proposed the implementation of a hybrid wearable sensor network infrastructure that is based on IoT-connected industrial safety and health monitoring applications. Two networks were integrated in this system: a WBAN for short-range wireless communication, which collects user data via Bluetooth low energy, and a low-power wide-area network for long-distance data transmission, which connects the WBAN to the Internet by using LoRa. The WBAN comprises two sensor nodes, namely, health and safe nodes. The health node monitors physiological signals, such as the heart rate (HR), respiration rate, ECG, body temperature, body position and BP. By contrast, the safe node measures environmental conditions, such as temperature, humidity, UV and CO_2. Within the proposed network, a standalone local server (gateway) was designed to perform edge-computing functions, such as preprocessing sensor signals, displaying environmental and physiological data in real time and activating warnings in cases of emergencies. The cloud is implemented to connect the gateway to the Internet and to provide the IoT applications of the system, such as data storage, website monitoring and mobile applications. This IoT-enabled wearable sensor system was proven to be viable in safety monitoring applications for industries in which the health conditions of workers and their environmental circumstances are vital to their overall well-being [13].

The traditional techniques for maintaining medical devices in hospitals are neither efficient nor practical due to their growing number and declining quality. To identify and monitor the status of healthcare equipment in real time, Maktoubian et al. proposed an architecture on the basis of IoT technologies and big data analysis. This architecture supports real-time management, predicts data analysis and solves the storage and computational challenges of big medical data in healthcare. They presented an IoT-enabled autonomous integrity monitoring construction for the real-time investigation and maintenance of medical devices that generate large-scale and real-time data in healthcare organisations. The proposed system combines precautionary maintenance and self-integrity monitoring with big data analytics to timely predict possible equipment failure. The architecture can also estimate the remaining life of equipment components and tackle the practical elements of deducing data. This approach ensures access to medical device status and provides real-time device monitoring capabilities which can reduce operating costs through the improved efficiency of the supply chain. Therefore, this system was proven to be significant in advancing the reliability of health devices and their maintenance by decreasing the accidentally lost time. Nevertheless, the above research did not discuss local integrity monitoring techniques for individual medical devices [14].

Taking advantage of the progress of IoT and mobile-based healthcare applications, Banka et al. proposed a remote health monitoring system that ensures the continuous monitoring of numerous vital body parameters, such as HR, BP and body temperature, to predict any abnormality or disease. This system eliminates the need for patients to frequently visit hospitals by connecting their medical data and health status to healthcare personnel via wearable devices that are equipped in equipment running on an affordable Raspberry Pi microcontroller. The implementation of this structure in hospitals allows voluminous data to be obtained and stored on a cloud server database and then displayed on websites and mobile applications accessible to authorised personnel. The system can be further improved with AI components to facilitate the exchange of medical information between doctors and patients in cases of medical emergencies. Data mining techniques have been used to analyse the data on patients' medical history, including the parameters and corresponding results; in addition, these techniques are used to search for constant patterns and systematic relationships in diseases to predict disorders in their preliminary stages for effective decision making [15].

RFID systems have been increasingly used in several domains, including the healthcare sector, because of properties such as the ability to trace, identify and communicate data in real time across users and devices. In this way, RFID systems aid organisations in saving time and cost. Healthcare device manufacturers utilise RFID systems to enhance the tracking and tracing of patients and equipment, reduce errors in patient care, effectively manage health resources and conduct assessment and prediction in advance. However, using RFID systems entails serious challenges, such as financial, practical, organisational and privacy and security issues. To achieve scalability, synchronisation and trust between parties, scholars have utilised attribute-based access control (ABAC) schemes that are built on centralised models as the supply chain. Figueroa et al. proposed and implemented a prevention system based on an ABAC in an RFID system by using a blockchain decentralised model. The proposed system aims at solving security and safety risks and conducting a trustworthy tracking and tracing of medical authorities by preventing access to incorrect areas, which could lead to human errors or external threats. These controlled-access strategies are accomplished by using the decentralised application (DApp), which interfaces with smart contract and blockchain technology. Apart from their use to solve issues in current centralised systems, smart contract and blockchain technology can flexibly secure RFID systems by offering the trust and support relationship of the ABAC model. To demonstrate the viability of the implementation, the authors deployed four recommended tools in a local and test net environment: ETH Network Status, Etherscan Ropsten Testnet Network, Infura dashboard and truffle test. Hence, the system can permit or deny access to assets such as surgical devices which contain a coding scheme (connected RFID tag) that restricts their access to certain areas. Although the suitability of the proposed system was validated for healthcare systems, it requires an underlying business model [16].

Given the advancement of technology, using telemedicine and health sensors is indispensable for physicians as they remotely track patients, book patient appointments and enhance the self-management of diseases. Bayo-Monton et al. proposed and later assessed a new measurable portable system for the remote management of chronic conditions. This system is an integration of five biosignals from wearable sensor devices with two affordable computing components (i.e., Arduino and Raspberry Pi), which are used to evaluate the extent to which portable devices can be compared with fixed systems. The authors used a process choreography machine to implement such integration for the transmission of data from sensors to a display unit via network services and a simple communication procedure involving two modes of data deployment scenarios (i.e., desktop computer with Windows 10 operating system and Raspberry Pi with Windows 10 Core IoT Operating System). The key performance indicators of the two systems were compared on the basis of the latency (the duration of delay between acquiring and displaying data) in the wearable devices' data transmission of biosignals and data loss. Although Raspberry Pi produces considerable delay regardless of the computer setting, the delay does not affect real-time remote monitoring. Therefore, an advantage of the implementation of health sensor nodes aided by Raspberry Pi is the possibility to build new portable systems for the remote management of chronic conditions using desktop computers. This study proved to be dependable because it confirmed the following: portable devices can support the transmission and analysis of biometric signals into scalable telemedicine systems; although these portable components cause increased latency in communication, the latency is insignificant [17].

The concept of sustainability has sparked an increasing interest amongst researchers. Closed-loop supply chain (CLSC) is a sustainable design that attracts considerable attention due to the increase in environmental concerns and important economic impact of customer returns. CLSC is an effective means to collect customer returns and recycle used items. Secondary markets are important channels to sell these products.

Guo et al. [18] aimed to design sustainable supply chain systems in the current business environment. They proposed a CLSC to solve a location–inventory problem (LIP) by considering the used products in the secondary market and the sales of new ones in the primary market. LIPs are NP-hard. Thus, the aforementioned authors developed a new heuristic approach by introducing an effective self-adaptive mechanism into differential evolution to solve the above-mentioned problem efficiently. A mixed-integer nonlinear programming model was developed to optimise facility location and inventory management decisions jointly, and the logistics flows between the two markets were modelled precisely. Sustainability numerical experiments were conducted to validate the solution approach and provide valuable managerial insights. Results show that the algorithm is robust and effective and has better finance performance of the closed-loop system than Lingo. This work fills the gap in the existing literature on CLSC by incorporating the secondary market into the study of CLSC. This work is also beneficial in improving the sustainability and efficiency of modern supply chains [18].

Sustainable supply chain networks (SSCNs) are attracting considerable attention as a means of dealing with various environmental and social issues. Environmental and social issues are important aspects of the design of SSCNs because they involve complex decisions that are related to strategic design and tactical operation within a dynamic and uncertain environment.

Tsao et al. [19] studied SSCN planning under uncertain atmosphere to consider economic costs, environmental impacts and workplace hazard parameters. They used an interactive multi-objective fuzzy programming approach that combines the two-phase stochastic and fuzzy multi-objective programming in the design of an SSCN for measuring social objectives. The numerical analyses indicate that the proposed approach is a promising multi-objective problem under uncertainty decision environment. This approach can provide un-balanced and balanced efficient solutions for decision makers with compromise of the conflicting objectives. The proposed model aims to maximise social benefits whilst minimising economic costs and environmental impacts by helping in decision making in the following aspects: selecting production technology materials and determining the number of locations of production, distribution centres and quantity of products to be transported between facilities. Two-phase stochastic variables were used to deal with the uncertainty related to customer demand, whilst fuzzy number programming was utilised to handle the overall costs, carbon emissions, job opportunities and detrimental effects of the resulting solutions. However, this approach strongly relies on the preferences of the decision maker for parameters (e.g., the compensation coefficient of objectives) and their confidence level to deal with flexible constraints (e.g., the a-cut level in selecting the final preferred compromise solution). Numerical analysis demonstrates the efficacy and efficiency of the proposed model in solving large-scale problems due to its computational advantages. However, the model is suitable only for designing SSCNs with a single product and environmental and social impacts. The performance of the model also highly depends on the capacity of facilities opened on the network [19].

Open-shop scheduling problem (OSSP) is a popular topic with vast industrial applications and is an important issue in the field of engineering. OSSP is NP-hard and has a wider solution space than other basic scheduling problems, namely, job-shop and flow-shop scheduling. Thus, OSSP has attracted considerable attention from many researchers over the past decades. Numerous algorithms have also been proposed for OSSP.

Hosseinabadi et al. [20] investigated the effects of the selected crossover and mutation operators on the performance of genetic algorithms (GAs) in solving OSSP. They found that the operators greatly influence the efficiency of the GA. In other words, the performance of the proposed GA (EGA_OS) in solving the OSSP is largely dependent on the type of crossover and mutation operators used. The use of suitable crossover and mutation operators in EGA_OS results in a goal-oriented dispersion of the chromosomes in the problem space and leads to better solutions. The proposed algorithm (EGA_OS) was evaluated by comparing it with other existing algorithms. The results show that hybrid selection of genetic operation type greatly influences the quality of solutions for OSSP. The use of the one-point crossover operator along with the displacement mutation operator also finds better solutions at a short time. The proposed algorithm can find highly optimal solutions for all kinds of problems at a shorter computational time with higher objective values than the other developed algorithms. However, applying different operators increases the time complexity of the pro-posed solution method compared with those of state-of-the-art methods [20].

Zhang et al. [21] proposed a hybrid metaheuristics algorithm to solve a job-shop scheduling problem (JSSP). This algorithm integrates three metaheuristic algorithms, namely, shuffled frog leaping (SFLA), intelligent water drop and path relinking (PR) algorithms. They proposed a random multi-neighbourhood-based SFLA with PR (RMN-SFLA-PR) by developing a simulation model. The authors firstly tested on the test data of traveller salesman problem (TSP) and then on real-world production lines to solve the problem of minimum needed workers at the production line.

The proposed RMN-SFLA-PR includes two different neighbourhood structures with random size block operation, namely, a random structure size and applied order of the multi-neighbourhood-based local search strategy and a PR-based local search guiding strategy. The proposed RMN-SFLA-PR was tested on a set of four benchmark instances (dj38) of the TSP to solve the JSSP using two software environments, namely, MATLAB and Simio. The obtained results are reliable, robust and tangible. The computational results show that the new proposed RMN-SFLA-PR algorithm converges to the optimum at nearly 10 times faster than individual algorithms. The algorithm is also highly effective in solving combinatorial optimisation problems, especially in the cases of low dimensions. Theoretically, one worker is sufficient to complete all the machine checks in one shift for case C. However, the Simio simulation shows that the efficiency of the machine is only 85% in consideration of unexpected situations that may occur during the operation of the production lines. Therefore, case C should employ two workers instead of one to check the machines in one shift for solving the aforementioned problem [21].

3. First Aid Legislation

H&S consciousness has become prevalent, especially in the workplace. Hence, governments have passed legislation related to H&S to protect human life. Through such legislation, employers today could face litigation in cases of negligence. In the UK, H&S (First Aid) regulations established in 1981 require all job sites and workplaces to meet the standards established for first aid performance, kits and management.

Depending on workplace conditions, employers must provide suitable equipment, services and staff to guarantee appropriate assistance for workers who may suffer from a sudden illness or injury. With such provision, life can be preserved, health deterioration can be prevented, and recovery can be supported. The human brain can shut down within only 6 min due to lack of oxygen. Hence, first aid is critical to minimise fatalities and provide urgent medical action to injured or sick personnel. Employers are also required to provide not only first aid equipment for the treatment of cuts, scrapes and injuries such as sprains and burns but also supplies for addressing various health conditions.

A first aid box should contain bandages, plasters, antiseptic wipes and any supplies or equipment that are used to give medical treatment during an emergency. On the basis of the hazards and risks in the workplace, their size and other relevant factors, employers should evaluate their first aid requirements regularly to determine which first aid equipment should be provided. The Work Health and Safety Act and Regulations makes first aiders responsible for providing immediate lifesaving medical care before the arrival of regular medical help. First aiders must be trained in administering the suitable methods for providing medical assistance. They must also be prepared and capable of managing effective first aid in cases of life-threatening injuries or sudden illnesses in the workplace. However, the regulations do not make employers legally obligated to assign trained first aiders when the organisation is small (less than five employees) or is exposed to small risks, as in clerical jobs. Moreover, these regulations do not make first aid provision for nonemployees, such as the public. Appointed (trained) staff is strongly recommended to look for first aid kits and facilities and dial emergency services whenever necessary.

3.1. First Aid Box Design

Companies, factories, hospitals and the like have identifying addresses, hubs and H&S devices, such as first aid boxes, fire extinguishers and earplug dispensers. Each H&S device contains identifying address and sensors. The electronic sensor is powered by a rechargeable lithium-ion battery whose charge state is regularly monitored (Figure 1). In the proposed system, a special approach is utilised to monitor each equipment in the workplace depending on the measurement of weight, level and battery state. For the first aid box, two strategies are utilised: (1) monitoring the first aid box without shelves and (2) monitoring the first aid box with shelves.

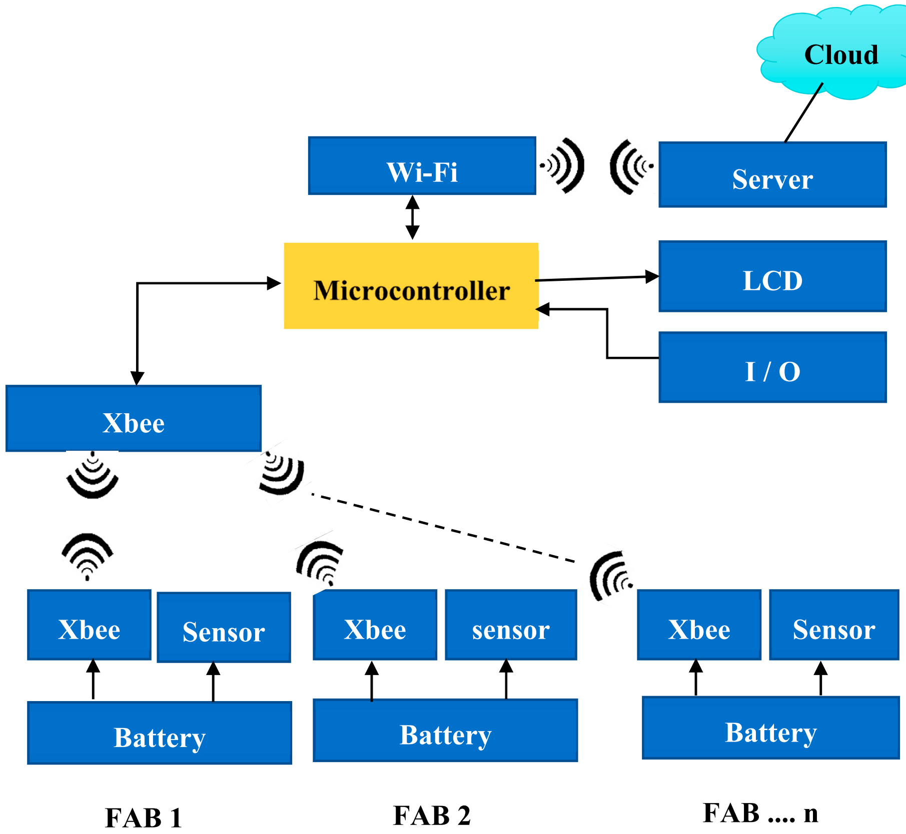


Figure 1. Networked first aid box.

The first strategy depends on the measurement of weight changes in monitoring boxes in different locations. Each box is assigned a special ID address and specific weight. A flexible sensor is fixed inside the first aid box. The sensor reads and sends data whenever the first aid box is opened or closed. The measurement of the total weight of consumables in a first aid box aids building service managers in observing whether the box is open (consumables are unused) without having to check them manually. The sensor records that a box is open but that it does not show any weight change. The total weight of the first aid box is taken by measuring the total weight of all the items inside the first aid box. The sensor conducts a reading when any weight change occurs and then sends a signal to the hub.

The second strategy applies to a first aid box with shelves. The weight cannot be directly measured because the box is screwed to the wall. Nevertheless, the total weight of the box can be obtained on the basis of the total weight of the consumables on each shelf. For example, conforming bandage (75 mm $\times$ 4 m) weighs 120 g, a pair of scissors weighs 200 g, gloves (pair) weigh 150 g, safety pins weigh 100 g, sterile wipes weigh 100 g, and a foil blanket weighs 130 g. The sensor reports the remaining weight to the hub to determine which any missing item. Specifically, the changes in weight are compared, and the network architecture of the first aid boxes in each location is considered. The hub holds the collected usage data and state of battery charge and is equipped with a clock. The data from H&S devices are forwarded by the sensor to the hub and include the identification numbers of the devices (i.e., device1, device2 and device3). The clock marks the time when the data are sent (i.e., hours, days, weeks or months). The hub records the time period and the frequency of device usage. It also records the maintenance threshold which denotes how frequently a device is used before it is replenished. The data of the battery status should be monitored to ensure that it is sufficient to operate the hub.

The usage data and battery state held by the hub are regularly sent and stored in the database in the cloud. Such data help building service managers determine which device or H&S product needs to be replenished. The two strategies help reduce time and cost requirements. For instance, the hub taps into the Wi-Fi system of the facility, which is less costly than setting up cellular or RFID communication. As the monitored equipment are installed inside facilities, the need for a cellular communication system is eliminated.

3.2. Earplug Dispenser Measurement

A suitable way to measure the numbers of earplugs available in light and dark environments is to utilise an image sensor in a micro digital camera in addition to a laser light that is affixed at a certain level of the other side of the earplug dispenser (see Figure 2). The image sensor of the micro digital camera activates when it senses the laser light and the device's storage reaches the sensor level. The camera records the image of the storage once the laser light is transmitted through the empty level to the camera. This image is recorded and analysed accordingly. Moreover, the hub records the state of the earplug dispenser in the database in the cloud, along with the time and date of the recording. The analysis software periodically checks the state of earplug dispensers. For example, the software marks the dispenser as 25%, 50% or 100% empty and then notifies the building service managers via SMS, email or website alert. In this way, the building service managers can decide whether or not to replenish the earplug dispenser for future use.

Figure 2. Earplug dispenser (http://www.seton.co.uk).

4. AI Techniques

4.1. Shortest Path Routing

The database holds the latitude and longitude information of all locations. The distance between each location and the corresponding travel time are obtained from Google maps. The distances to the location from the starting point are arranged in ascending order. The location with the shortest distance is visited first. The travel time is calculated using the distance and average speed of the sales personnel.

4.2. Clustering into Regions

The total time needed to visit all equipment in critically low state is calculated as:

$$T_{total} = \sum_{i=1}^{N} t_i,$$

where T_{total} is the total time taken, N is the number of critically low equipment and t_i is the time spent to reach the next location from the starting point 5 days a week; 7 h a day is considered as the working hours of each salesman. The time exceeding 7 h is considered 1 day of work. A new cluster is created and serviced every day, and the number of clusters is proportional to the number of days. The number of clusters is set to 2 when the time needed to visit all critically low equipment is 2 days. The number of clusters is equal to the number of days. The total number of clusters is calculated as:

$$n = \frac{T_{total}}{7}.$$

where K-means clustering is used to divide critically low equipment into regions.

4.3. Running the Simulation

The simulation proceeds as follows. As soon as the timer starts, the database is accessed to obtain the previous states of all shelves and battery. Energy consumption is calculated, and the state of each node is classified into active, low and critical states. The simulation time and threshold are set in the GUI. The opening and closing times of the nodes are calculated at the beginning of the simulation using the class event node. An event node is a class used on the event list in the simulator. It essentially keeps track of all events, and it is represented as a DLL of nodes. Objects with multiple DLL nodes can be linked together to create linked lists. Each node contains a piece of data related to an event and provides access to the next and previous nodes. The time needed to close the shelf when the node is opened is calculated, and the next node is subsequently inserted. The battery state is read, and the open shelf is identified. When the battery charge status is higher than the limit, the node remains active. The weight of the toolbox is defined, and any change in the weight of the shelves indicates the removal of the toolbox. The changes in total weight determine which medical component is removed as the shelf weight and the weight of the medical components inside the toolbox are known. A reduction in weight is sensed by the sensor, and the information is updated in the database (Figure 3).

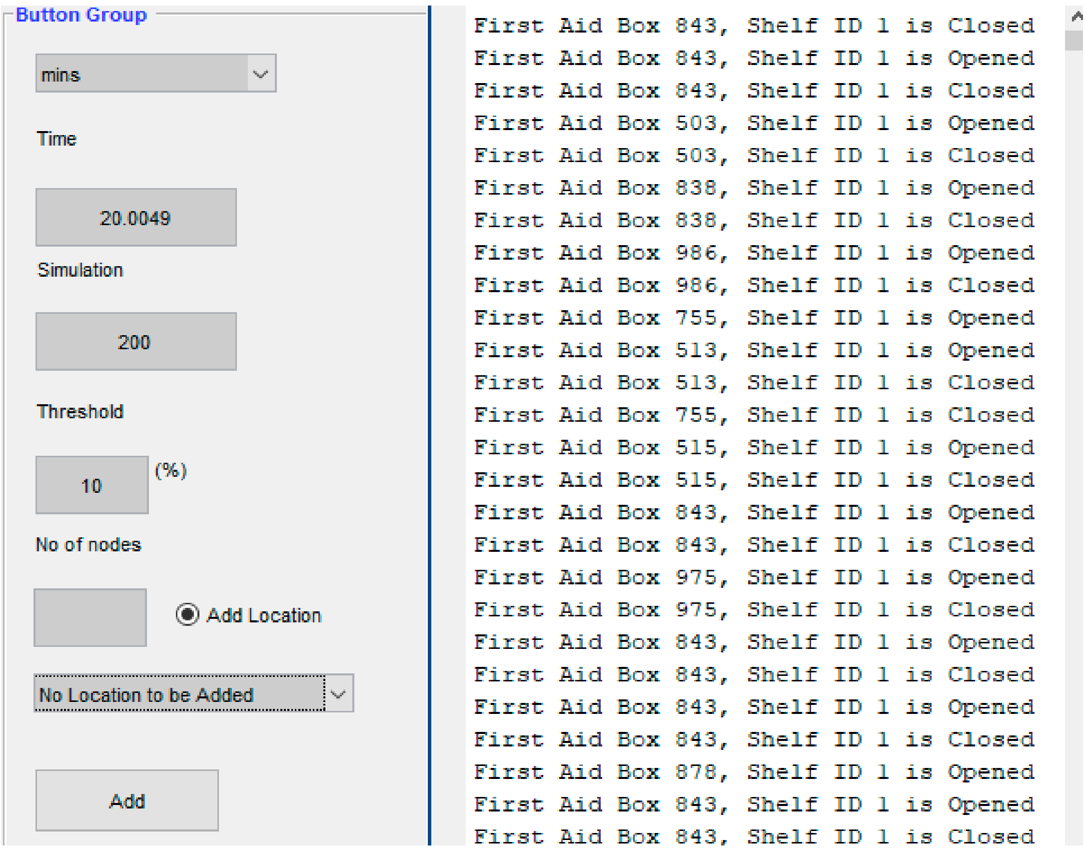


Figure 3. Number of times first aid boxes are opened/closed.

5. Simulation Scenario Definitions

The simulation involved 100 hospitals within the South East of UK. Their names and locations in terms of latitude and longitude are tabulated. Their location and names are then plotted on a map. Each hospital utilises 10 first aid boxes, and each box contains 4 shelves. Each shelf is assigned with an ID (i.e., 1–4) (Table 1).

Table 1. First aid box parameters.

Parameters	Values
Number of locations	Input from file
Number of nodes in each location	10
Sensing duration	5 s
Coordinates	Latitude and longitude (Read from the file)
Equipment	First aid boxes, fire extinguishers, ear plug dispensers, life jackets
First aid box	Bandage, scissor, thermometer, glue, tape
Fire extinguisher	Fire fighter
Ear plug dispenser	Earplugs
Life jacket	Jackets
Shelf weight	1000 gm
Scissor weight	20 gm
Glue tape weight	10 gm
Thermometer weight	5 gm
Energy Consumption/bit	185.9 NJ/bit
Initial battery charge	2 J
Extinguisher weight	5 kg
Ear plug dispenser level	100
Life jacket weight	1.5 kg
Total no. of life jackets	20
Threshold	20% of total energy
Simulation duration	200

The materials from the first aid boxes are randomly used on the basis of a negative exponential distribution, which is defined by its mean parameter. Then, the corresponding weight is detected by the weight sensor whenever a material is removed. The information about the removed material is automatically updated in the database. A usage flag that equals true indicates that the toolbox is opened, whereas a usage flag that equals false indicates that the toolbox is opened but the materials are unused. Hence, the total weight of the shelf is automatically updated depending upon the insertion and removal of materials from the shelves in the toolbox. The door sensors run on batteries, and energy is consumed during the transmission and reception of information. The remaining energy level in the battery is recorded. The packet size transferred to the base station is set to 175 bytes. When energy is consumed, the remaining battery energy is calculated. The battery energy is identified as active, low or critically low. A battery status greater than the threshold (the threshold is set to 20% of total energy) and less than (threshold +20) the node is considered to be low. A battery status less than the threshold and the node is considered to be critically low. Otherwise, the node is active.

All information is regularly stored in the database. Only the critically low equipment that requires replenishment by sales personnel is extracted from the database. The critically low equipment is marked by a red marker, and the TSP algorithm is employed to visit all the critically low nodes and replace their medical components and batteries for reactivation.

6. Hospitals' H&S Infrastructure Network Modelling

Companies face cases of nonfatal injuries amongst their employees on a daily basis. As indicated in Table 2, UK companies deal with 340 accidents per day [22]. Hence, first aid boxes should be accessible and immediately available as they might be used over 340 times a day. A roulette algorithm can be used to find the probability of the possible location of an accident within a company facility in London in proportion to the population size of the company.

Table 2. Probability of number of accidents in the UK per day.

Number of Employees per Company	Average No. of People	No. of Companies	Average Total Number of People	Probability of a Person Working for a Size of Company	The Number of Accidents per Day in the UK
1–4	2	1,638,155	3,276,310	0.168545519	57.44682
5–9	7	74,295	520,065	0.02675407	9.11882
10–19	15	136,375	2,045,625	0.105234525	35.86799
20–49	35	73,335	2,566,725	0.132041839	45.00496
50–99	75	23,165	1,737,375	0.089377004	30.46313
100–249	175	13,340	2,334,500	0.120095325	40.93312
250–499	375	4305	1,614,375	0.083049428	28.30645
500–999	750	2095	1,571,250	0.080830919	27.5503
1000+	1500	2515	3,772,500	0.19407137	66.14702
	Total No.		19,438,725	**Total No.**	340.8386

7. Search Algorithms

7.1. TSP Algorithm

TSP is a combinational optimisation problem. It is a classic but difficult mathematical optimisation algorithm that can quickly converge to a solution by using computational networks to solve difficult optimisation problems. TSP focuses on reaching optimised solutions [23]. TSP is widely use in various fields, such as engineering, science and other computational processes. It can be easily represented by a graph to define the places of a group of nodes [24]. In the current study, the TSP is employed to identify the best route by starting from one city, travelling to all other listed cities individually and returning to the home city where the salesmen begins in a short (or minimum) total path length. The best solution is that in which the salesman travels in the least time, distance and cost. TSP is categorised into two groups: symmetric TSP and asymmetric TSP. Symmetric TSP is when the travelling distance between two locations, such as A to Z, is the same as the distance between Z and A. The TSP is asymmetric when the distances are not the same. Generally, asymmetric TSP is more common than symmetric TSP. Hence, asymmetric TSP can be converted into symmetric TSP by applying a certain algorithm to find solutions [25]. Although TSP, being an NP-complete problem, is difficult to solve, numerous questions can be modelled and solved as a type of TSP. TSP has become popular because of its wide applicability, theoretical appeal and high representativeness.

Figure 4 presents four different cases involving the TSP algorithm. The cases comprise (a) 10, (b) 21, (c) 44 and (d) 49. Three performance parameters are used in the algorithm simulation: distance in kilometres, iteration number and execution time in seconds. Each case is run 50 times to obtain the outcome. The best total distance, which is 1.45 km, is obtained in Case (b). The minimum number of iterations (i.e., 7 iterations) is obtained in Case (a). The minimum execution time, which is 0.58815 s, is obtained in Case (a).

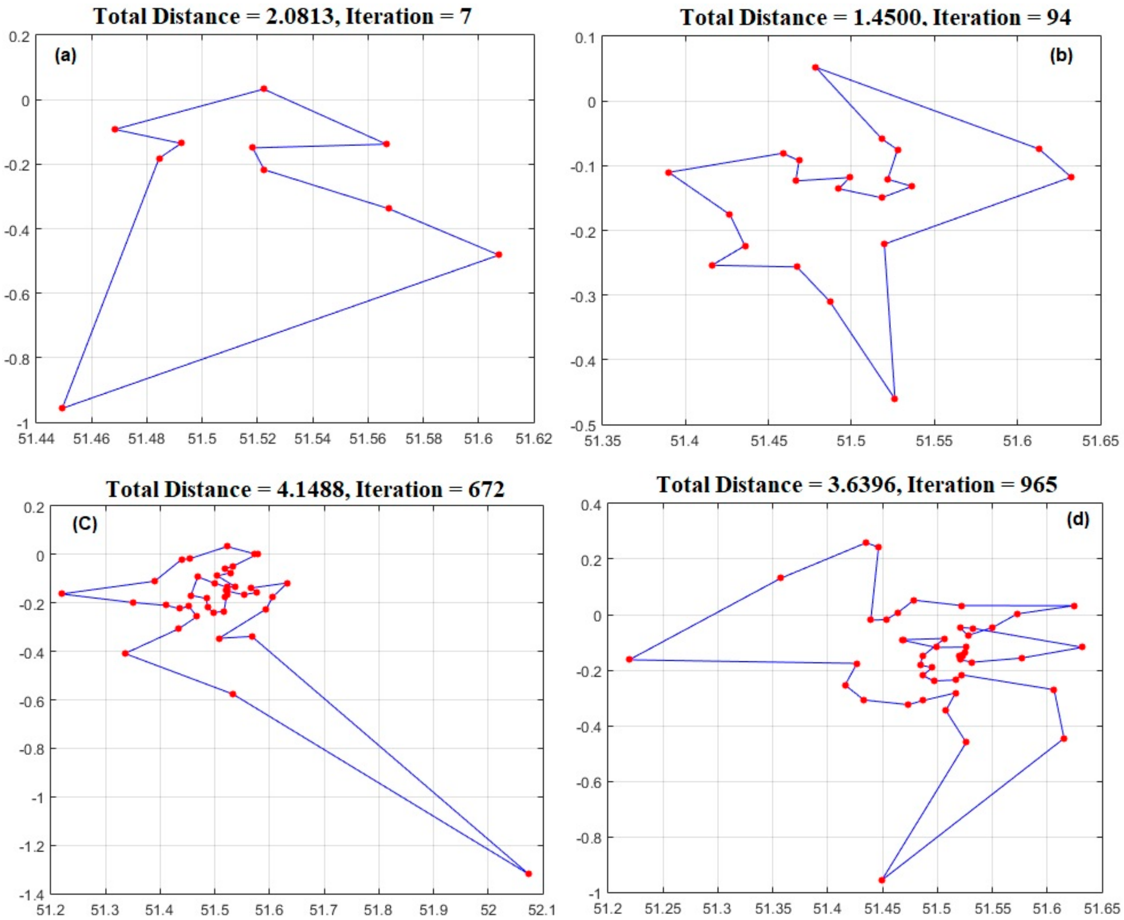


Figure 4. TSP algorithm best distance results.

7.2. ACO Algorithm

In the IoT, heterogeneous devices have unlimited connections and interconnections with one another through the Internet. Consequently, intelligent web applications should be used to manage IoT systems. These applications collect and send sensed data to a main manager for additional processes. A trusted routing procedure is implemented during data transmission. ACO is a tracking algorithm used to improve the best route selection for the transmitted data within an IoT system [26]. It is a metaheuristic search method for global optimisation to find the optimal path in a graph. ACO is an imitation of the performance of real ant colonies.

Ants generally follow the shortest path from their food source to their colonies. Ants can trace a trail using pheromones to help other ants follow the same route [27]. The algorithm benefits from the use of the ant colony idea in the IoT system to obtain the best route. This optimisation technique has been successfully used in structural engineering problems and others [28]. TSP is a classical combinatorial optimisation problem that is successfully solved by utilising ACO. ACO is illustrated in Figure 5. Similarly, four cases with (a) 10, (b) 21, (c) 44 and (d) 49 nodes are utilised to illustrate ACO. Distance in kilometres, iteration number and execution time in seconds are also used for measurement in the simulation. Different outcomes are obtained after running each case for 50 times. The best total distance, which is 1.45 km, is obtained in Case (b). The minimum iteration number of 1 iteration is obtained in Case (a). For the execution time, the least time, which is 1.419915 s, is achieved in Case (a).

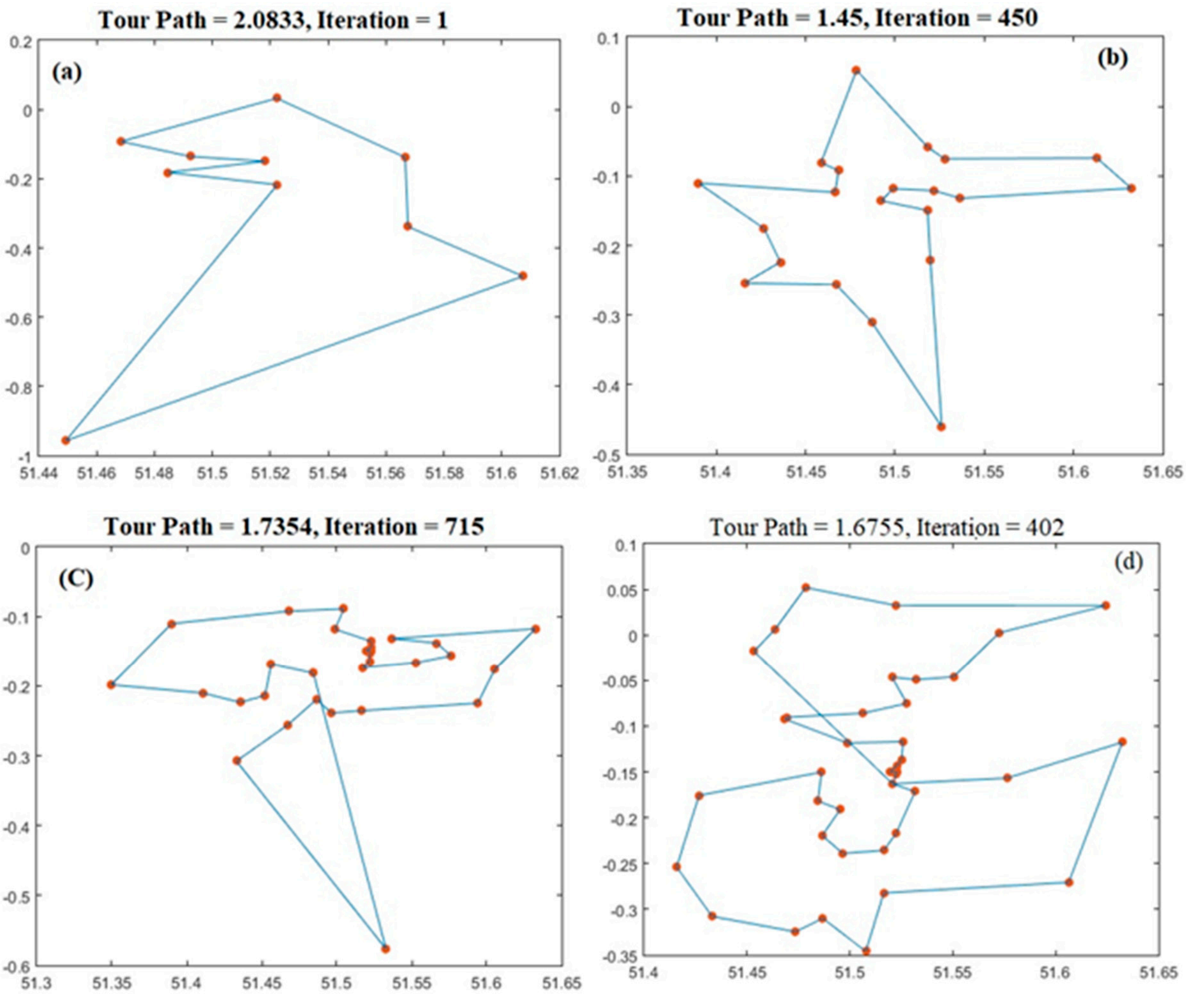


Figure 5. ACO algorithm results.

7.3. GA Algorithm

Darwinian evolutionary principles have become the primary concept in various research fields. Influenced by evolution theory, GA uses biological techniques, such as selection, mutation, inheritance and recombination, to find reasonable solutions for complex problems. GA is actively utilised in search and optimisation methods in numerous areas, such as science, commercial trade, optimised telecommunication routing and engineering design. Such popularity is attributed to its comprehensive applicability, ease of use and global perspective. GA is used in AI and computing to find optimised solutions for search problems following the concepts of biological selection and evolution. Therefore, GA is an excellent heuristic search method for searching through large and complex datasets [29]. In the implementation stage in the current work, GA is applied to find the optimal results for the shortest path within the shortest time for salesmen to replenish critically low devices and ensure their compliance. The four cases shown in Figure 6 with (a) 10, (b) 21, (c) 44 and (d) 49 nodes obtain different results. In the simulation, measurements are conducted in distance in kilometres, iteration number and execution time in seconds.

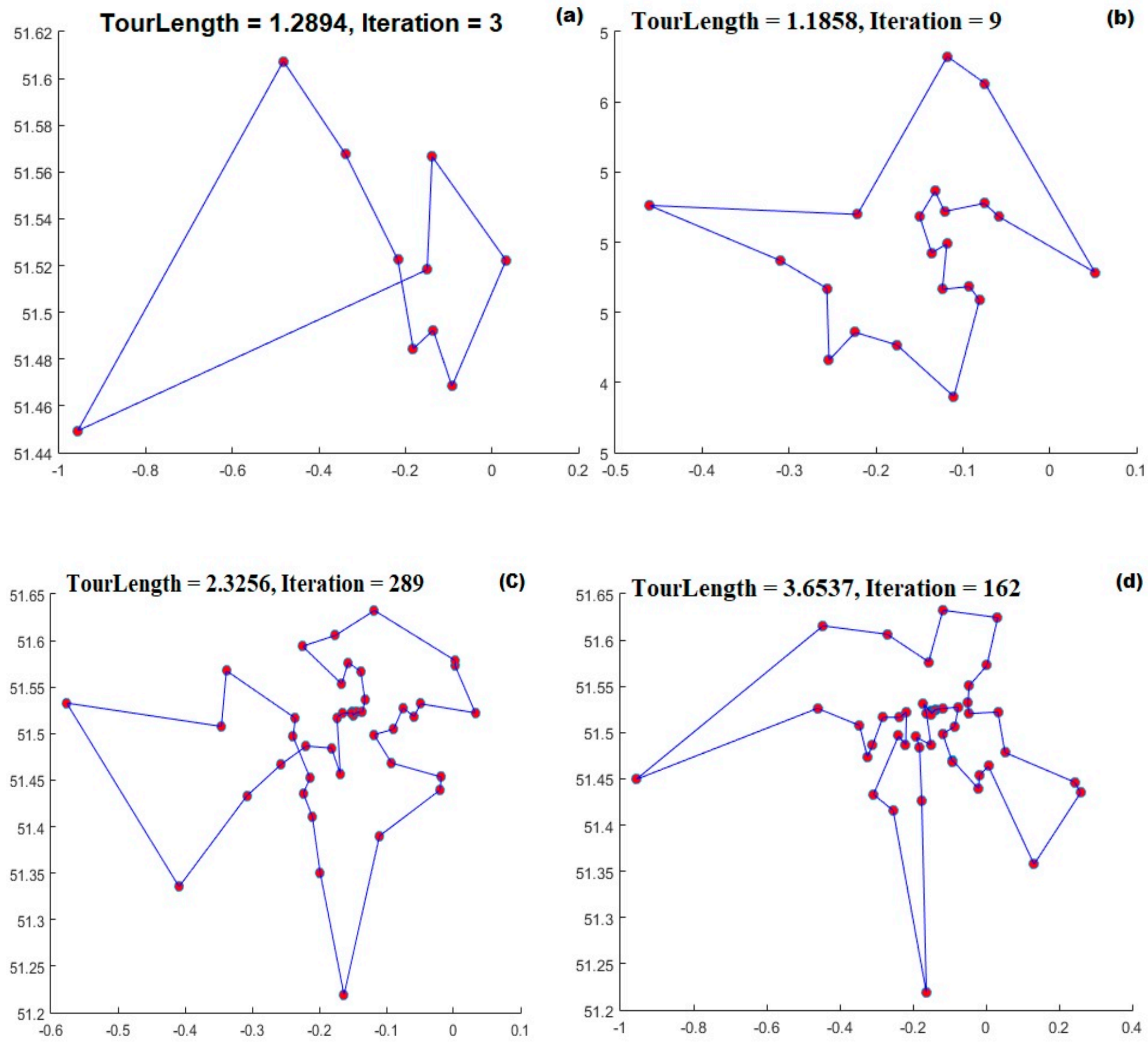
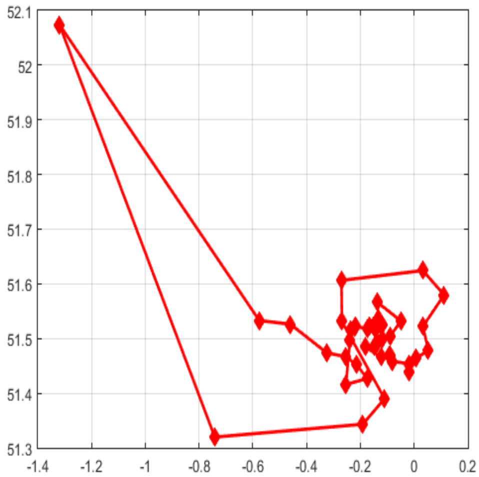


Figure 6. GA search results.

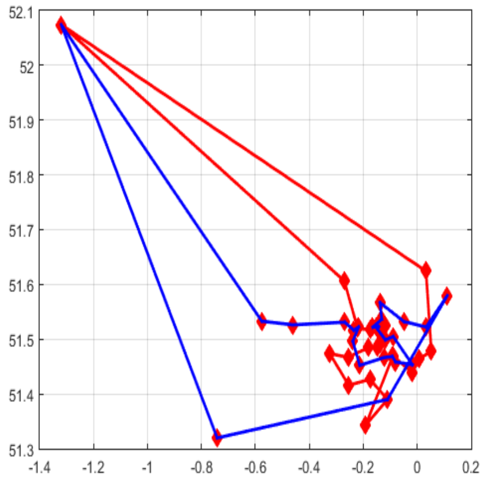
Similar to the procedure in the previous algorithms (e.g., ACO and TSP), each case is run for 50 times to obtain the outcomes for GA. Case (b) achieves the best total distance of 1.1858 km. The minimum iteration number of 3 iterations is achieved in Case (a). The minimum execution time of 1.0029 s is obtained in Case (a).

8. Salesmen Routing Path

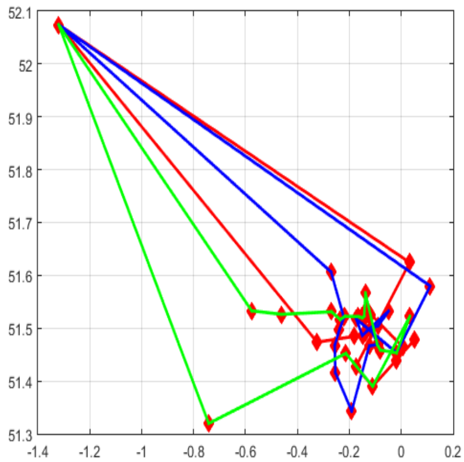
The k-means algorithm is utilised to divide the critically low devices into two clusters. Each cluster is run separately by one or more salesmen. The time spent for each cluster is recorded for each salesman. The total spent time is recorded on the basis of the maximum time spent by the salesman rather than the number of salesmen. Take for example three salesmen engaged in a parallel run: the first salesman takes 2 h, the second salesman takes 3 h, and the third salesman takes 4 h. The total time is measured on the basis of the maximum time spent by any salesman. The total time taken to run the cluster is 4 h; that is, total time = max ($TS1$, $TS2$, $TS3$), where $TS1$ is the time taken by Salesman 1, $TS2$ is the total time taken by Salesman 2 and $TS3$ is the total time taken by Salesman 3 (Figure 7).



a. One salesman



b. Two salesmen



c. Three salesmen

Figure 7. Multi salesmen routing path.

9. Results Analysis

Figures 8–10 respectively show the simulation results of TSP, ACO and GA with different numbers of nodes after running 50 simulations. The numbers of nodes are 10, 21, 44 and 49. Three performance metrics are used to measure the simulation: distance in kilometres, iteration number and execution time in seconds. GA outperforms TSP and ACO in terms of the minimum path under a low number of nodes (i.e., 1.2 km and 1.47 km). For a high number of nodes, such as 44 and 49, ACO obtains the lowest distances of 1.95 km and 1.87 km, respectively. For the minimum number of iterations, TSP obtains the lowest values of approximately 86 times for 10 nodes, 861 times for 44 nodes and 906 times for 49 nodes. TSP obtains the best result of 86 times for 10 nodes. The number of iterations of TSP increases from 275 iterations to 906 iterations as the number of nodes increases.

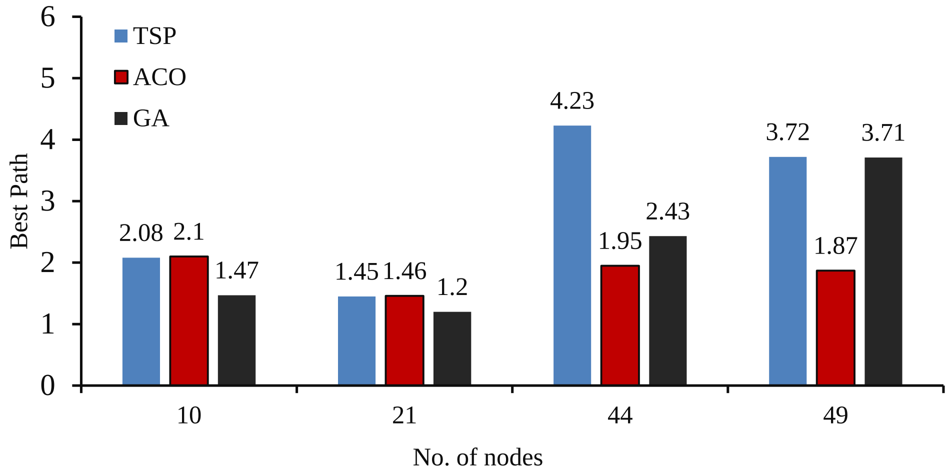


Figure 8. The best path selected by the search algorithms.

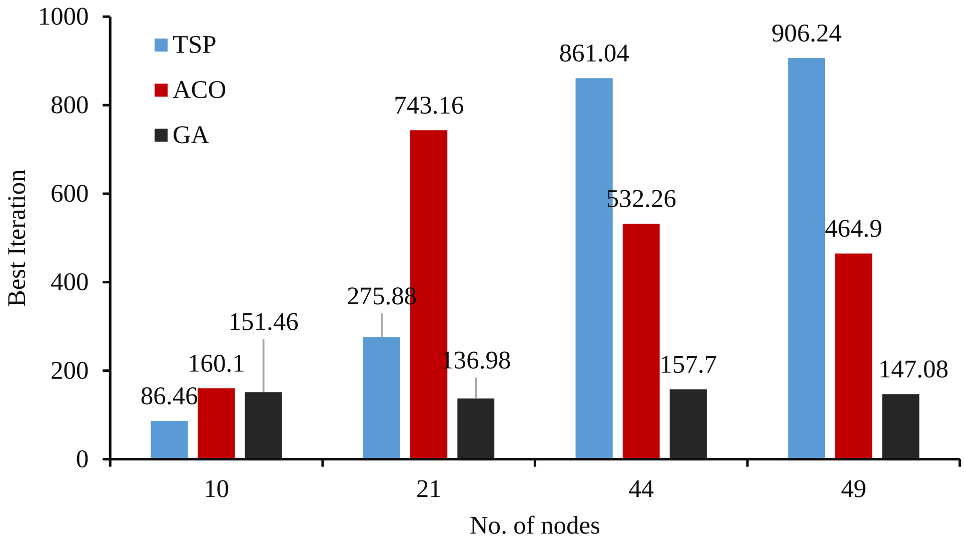


Figure 9. The best iteration number of the search algorithms.

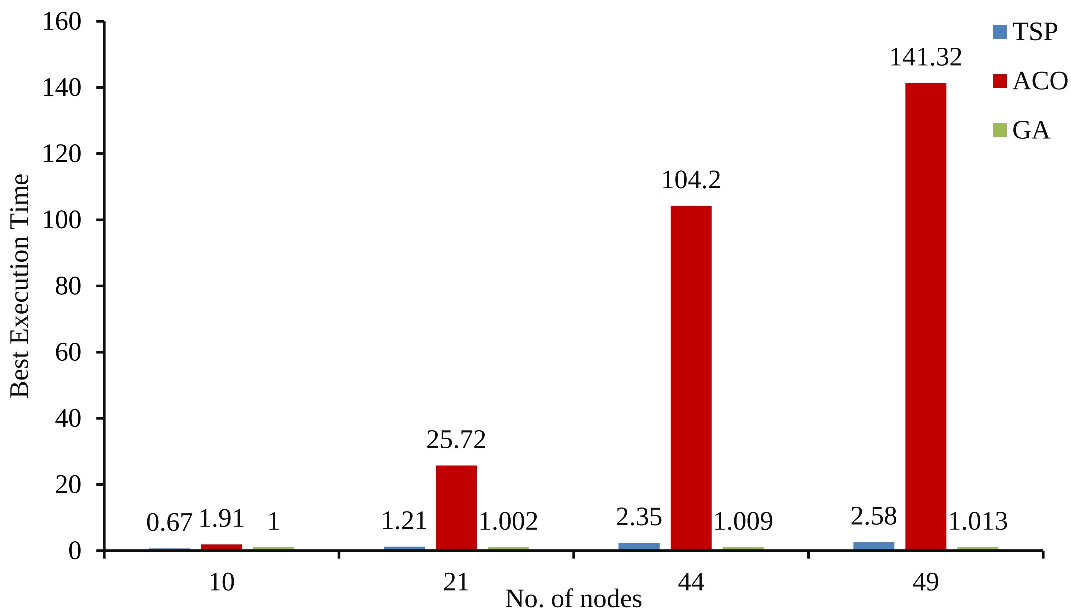


Figure 10. The best execution time of the search algorithms.

With regard to execution time, GA and TSP present the same trend. Figure 9 shows that the execution times for GA do not vary with the number of nodes. For all these cases, GA only requires 1 s to finish the simulation. This approach is stable with the increasing number of nodes. TSP obtains the lowest execution time of approximately 0.67 s when a network with 10 nodes is deployed; the time then increases to 2.58 s. The execution time of ACO increases. This approach obtains the worst value when the number of nodes increases, that is, the execution time increases from 1.91 s for 10 nodes to 141.32 s for 49 nodes. As previously mentioned, GA can be used to help salesmen identify the shortest path and the least time when equipment in different locations are critically low and require maintenance or replenishment. In the comparison of the three search algorithms, the case with 44 nodes demonstrates a result of 1.85 s, which accounts for approximately 49.73%. The results also show that the system provides and saves approximately 50% of the time spent for the salesmen to replenish the equipment. The contribution of the proposed system is to enable salesmen to visit only the locations where the equipment status is critically low.

10. Conclusions

Currently, H&S systems need to be revolutionised to maintain the safety of workplaces. The implementation of IoT technology in the workplace is crucial in the development of monitoring systems for first aid boxes, fire extinguishers, earplugs and batteries to ensure their readiness for daily use in accordance with regulatory requirements. Smart sensors are used to collect data from devices for the monitoring of the status of different facilities simultaneously. The data can be stored and analysed in the cloud.

The TSP algorithm, ACO algorithm and GA are implemented to find the shortest path or the shortest time to visit locations for the maintenance of H&S equipment. Measurements are carried out to identify the equipment which is likely to be in a critical state in the near future. In this manner, equipment can be replenished in the most opportune time. The proposed prototype is proven to be valid because it enables many companies and workplaces to monitor and control their H&S devices with the least time, money and manpower.

Data Availability Statement: All data produced for this study are available through Brunel University BURA data access system.

Author Contributions: Data curation, J.A.-D.; Investigation, J.A.-D.; Supervision, J.C. and M.A.; Writing—original draft, J.A.-D.

Funding: This research received no external funding.

Acknowledgments: This research is supported by Brunel University London, Electronic & Computer Engineering Department.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Niewolny, D. How the Internet of Things Is Revolutionizing Healthcare. White Pap. 2013, pp. 3–5. Available online: https://www.nxp.com/docs/en/white-paper/IOTREVHEALCARWP.pdf (accessed on 6 November 2019).
2. Metcalf, D.; Milliard, S.T.J.; Gomez, M.; Schwartz, M. Wearables and the internet of things for health: Wearable, interconnected devices promise more efficient and comprehensive health care. *IEEE Pulse* **2016**, *7*, 35–39. [CrossRef] [PubMed]
3. Fraga-Lamas, P.; Fernández-Caramés, T.M.; Suárez-Albela, M.; Castedo, L.; González-López, M. A Review on Internet of Things for Defense and Public Safety. *Sensors* **2016**, *16*, 1644. [CrossRef] [PubMed]
4. Kang, H.S.; Lee, J.Y.; Choi, S.; Kim, H.; Park, J.H.; Son, J.Y.; Kim, B.H.; Do Noh, S. Smart manufacturing: Past research, present findings, and future directions. *Int. J. Precis. Eng. Manuf. Green Technol.* **2016**, *3*, 111–128. [CrossRef]

5. Alex, G.; Varghese, B.; Jose, J.G.; Abraham, A. A Modern Health Care System Using IoT and Android. *Int. J. Comput. Sci. Eng.* **2016**, *8*, 117–121.
6. Muhammad, G.; Rahman, S.M.M.; Alelaiwi, A.; Alamri, A. Smart Health Solution Integrating IoT and Cloud: A Case Study of Voice Pathology Monitoring. *IEEE Commun. Mag.* **2017**, *55*, 69–73. [CrossRef]
7. Mahmud, M.S.; Wang, H.; Esfar-E-Alam, A.M.; Fang, H. A Wireless Health Monitoring System Using Mobile Phone Accessories. *IEEE Internet Things J.* **2017**, *4662*, 2009–2018. [CrossRef]
8. Mahdi, O.A.; Abdul Wahab, A.W.; Idna Idris, M.Y.; Abu znaid, A.M.; Khan, S.; Al-Mayouf, Y.R.B.; Guizani, N. A comparison study on node clustering techniques used in target tracking WSNs for efficient data aggregation. *Wirel. Commun. Mob. Comput.* **2016**, *16*, 2663–2676. [CrossRef]
9. Catarinucci, L.; De Donno, D.; Mainetti, L.; Palano, L.; Patrono, L.; Stefanizzi, M.L.; Tarricone, L. An IoT—A ware Architecture for Smart Healthcare Systems. *IEEE* **2015**, *2*, 1–12.
10. Hossain, M.S.; Muhammad, G. Cloud-assisted Industrial Internet of Things (IIoT)—Enabled framework for health monitoring. *Comput. Netw.* **2015**, *101*, 192–202. [CrossRef]
11. Ghanavati, S.; Abawajy, J.H.; Izadi, D.; Alelaiwi, A.A. Cloud-assisted IoT-based health status monitoring framework. *Cluster Comput.* **2017**, *20*, 1843–1853. [CrossRef]
12. Islam, S.M.R.; Kwak, D.; Kabir, H.; Hossain, M.; Kwak, K.-S. The Internet of Things for Health Care: A Comprehensive Survey. *Access IEEE* **2015**, *3*, 678–708. [CrossRef]
13. Wu, F.; Wu, T.; Yuce, M. An Internet-of-Things (IoT) Network System for Connected Safety and Health Monitoring Applications. *Sensors* **2019**, *19*, 21. [CrossRef] [PubMed]
14. Maktoubian, J.; Ansari, K. An IoT architecture for preventive maintenance of medical devices in healthcare organizations. *Health Technol.* **2019**, *9*, 233–243. [CrossRef]
15. Banka, S.; Madan, I.; Saranya, S.S. Smart Healthcare Monitoring using IoT. *Int. J. Appl. Eng. Res.* **2018**, *13*, 11984–11989.
16. Figueroa, S.; Añorga, J.; Arrizabalaga, S. An Attribute-Based Access Control Model in RFID Systems Based on Blockchain Decentralized Applications for Healthcare Environments. *Computers* **2019**, *8*, 57. [CrossRef]
17. Bayo-Monton, J.L.; Martinez-Millana, A.; Han, W.; Fernandez-Llatas, C.; Sun, Y.; Traver, V. Wearable Sensors Integrated with Internet of Things for Advancing eHealth Care. *Sensors* **2018**, *18*, 1851. [CrossRef] [PubMed]
18. Guo, H.; Li, C.; Zhang, Y.; Zhang, C.; Lu, M. A Location-Inventory Problem in a Closed-Loop Supply Chain with Secondary Market Consideration. *Sustainability* **2018**, *10*, 1891. [CrossRef]
19. Tsao, Y.; Thanh, V.; Lu, J.; Yu, V. Designing sustainable supply chain networks under uncertain environments: Fuzzy multi-objective programming. *J. Clean. Prod.* **2018**, *174*, 1550–1565. [CrossRef]
20. Asghar, A.; Hosseinabadi, R.; Vahidi, J.; Saemi, B.; Kumar, A.; Elhoseny, M. Extended Genetic Algorithm for solving open-shop scheduling problem. *Soft Comput.* **2019**, *23*, 5099–5116.
21. Zhang, H.; Liu, S.; Moraca, S.; Ojstersek, R. An effective use of hybrid metaheuristics algorithm for job shop scheduling problem. *Int. J. Simul. Model.* **2017**, *16*, 644–657.
22. Office for National Statistics. UK Business; Activity, Size and Location Statistical Bulletins. 2018. Available online: https://www.ons.gov.uk/businessindustryandtrade/business/activitysizeandlocation/bulletins/ukbusinessactivitysizeandlocation/previousReleases (accessed on 18 May 2019).
23. Hopfield, J.J.; Tank, D.W. Neural Computation of Decisions in Optimization Problems. *Biol. Cybern.* **1985**, *52*, 141–152. [PubMed]
24. Pan, G.; Li, K.; Ouyang, A.; Li, K. Hybrid immune algorithm based on greedy algorithm and delete-cross operator for solving TSP. *Soft Comput.* **2016**, *20*, 555–566. [CrossRef]
25. Weeks, J.P. Plink: An R package for linking mixed-format tests using IRT-based methods. *J. Stat. Softw.* **2010**, *35*, 1–15. [CrossRef]
26. Said, O. Analysis, design and simulation of Internet of Things routing algorithm based on ant colony optimization. *Int. J. Commun. Syst.* **2017**, *30*, 1–20. [CrossRef]
27. Yoo, K.-S.; Han, S.-Y. A modified ant colony optimization algorithm for dynamic topology optimization. *Comput. Struct.* **2013**, *123*, 68–78. [CrossRef]

28. Mavrovouniotis, M.; Yang, S. Ant algorithms with immigrants schemes for the dynamic vehicle routing problem. *Inf. Sci.* **2015**, *294*, 456–477. [CrossRef]
29. Ding, Y.; Fu, X. Kernel-based fuzzy c-means clustering algorithm based on genetic algorithm. *Neurocomputing* **2016**, *188*, 233–238. [CrossRef]