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A System for Individual Environmental Risk Assessment and Management with IoT Based on the Worker's Health History

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Abstract: This paper presents a monitoring system to measure dust, noise, ultraviolet radiation, illuminance, temperature, and humidity and to check the presence of flammable gases—liquefied petroleum gas (LPG), propane, hydrogen, butane, methane, and carbon monoxide. The system is composed of monitoring devices, a server to process data received from the devices and that runs a web application for employers, and a mobile application for workers to check their exposure data. During employee registration, the health history of the worker concerning common diseases and symptoms related to the monitored agents must be informed. This information is analyzed through a set of predefined rules to generate alerts that the company can consider for planning professional activities to minimize exposure to risk agents. The tests presented in this work are focused on verifying the functionalities of the web interface for employee registration, especially regarding the provision of health information, the updating of this information, and the generation of corresponding alerts. At this stage, fictitious employee information was used. The results showed that the system adequately performs the proposed functionalities, and it was concluded that the solution is viable for testing in a work environment in the future stages of development. The innovative features of this study concern the correlation between workers' health history and harmful agents to build suggestions and alerts to guide long-term OSH-related decisions.

Keywords: occupational safety and health (OSH); monitoring system; risk assessment; health history



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1. Introduction

About 2 million people die because of work-related causes worldwide every year. However, this amount might be greater because not all occurrences are reported and, in several countries, there are no adequate data collection systems [1]. This statistic indicates that efforts are needed to prevent diseases and accidents at work. This section introduces concepts related to occupational risks, diseases, accidents, and technologies to modernize workplaces concerning occupational health and safety (OSH). At the end of the section, the technological proposal developed within this research study is briefly described.

1.1. Occupational Diseases, Accidents, and Injuries

Occupational diseases are characterized by the existence of a causal link between a health condition and exposure to factors during work or in the work environment. Such

diseases often occur after several years of exposure and, in some cases, they can arise even after exposure has ceased [2].

According to ILO [1], occupational injury is a personal injury, disease, or death resulting from an occupational accident. An occupational accident, in turn, is an unexpected and unplanned occurrence, including acts of violence, arising out of or in connection with work and affecting one or more workers.

According to Jilcha and Kitaw [3], occupational diseases and accidents can cause the worker to leave their job temporarily or even permanently, causing negative impacts on the quality of life of workers and their families, and increasing government costs regarding health and social security. Moreover, occupational diseases and accidents can have a significant negative impact on the productivity, competitiveness, and reputation of companies. The economic burden of occupational diseases is discussed in [4,5].

1.2. Occupational Risks

Occupational risk factors can be defined as agents that can cause damage to a worker's health. The potential risk factor is called hazard. Occupational risk is the combination of the probability of damage to the worker's health and its severity, assuming that there is exposure in the workplace. Employers must protect their employees and others from damage. For this purpose, employers need to identify hazards and risks and act to eliminate the hazards or at least control the risks [6].

When we consider the physical risks to which workers are exposed during work, a compilation of responses to the European Survey of Working Conditions (EWCS) questionnaire for 2015 provided the following data [6]:

- 28% are exposed to high noise levels.
- 23% are exposed to high temperatures.
- 21% are exposed to low temperatures.
- 20% are exposed to vibrations from machines and tools.
- 17% are exposed to chemicals.
- 15% are exposed to fumes and/or dust.

The exposures mentioned in the answers occur in a part of the work shift corresponding to 25% or more. The data cover all sectors of activity in European Union countries plus Switzerland and Norway [6].

Eurofound [6] highlights that improving working conditions and job quality is a significant goal in European policies. This issue both influences and is influenced by other European policies, such as innovation and gender equality. Improving working conditions involves modernizing workplaces. In this aspect, one of the needs is the monitoring of the different risks present in workplaces. The relevance of physical risks is demonstrated by the responses to the EWCS.

1.3. Technologies for Modernizing Workplaces

A necessity for modernizing the work environment and to help in preventing diseases and accidents has been recognized. In recent decades, the terms Industry 4.0, Industry 5.0, and Internet of Things (IoT) have been introduced.

The term Industry 4.0 defines a new level of organization and control over the entire value chain, aiming for continuous improvement and avoiding waste [7,8]. Industry 4.0 has not been largely developed in all countries. However, as discussed in [9,10], business and technological innovators are already looking ahead to Industry 5.0. In Mourtzis et al. [9], Industry 5.0 is defined as the era of the socially intelligent factory which will involve autonomous manufacturing with human intelligence and AI as a backbone technology. In addition, the concept of Industry 5.0 is focused on environmental sustainability and more skilled jobs compared to Industry 4.0 [11]. Nevertheless, it is important to highlight that there is still little literature on this topic.

Concerning IoT, its main goal is to provide a network infrastructure with interoperable communication protocols and software to allow for the connection of a variety of objects to the Internet. IoT can be applied, for example, to monitor machines in factories and farms, as well as workers' movements to prevent and identify accidents [12].

In this context, various technologies have been added to work environments to enable, for example, the automatic verification of the use of personal protective equipment (PPE), the continuous monitoring of exposure to risks, and the automatic identification of emergencies. It must be highlighted that not only industry requires this kind of system, but also other sectors such as agriculture, mining, and services, among others. For example, smart PPE and monitoring systems were proposed by [13–20]. A review of technologies and trends of environmental risk assessment and management in the Industry 4.0 context is shown by Lemos et al. [21]. Fanti et al. [22] developed a systematic review of the literature to discuss useful sensors for occupational risk assessment.

The solutions mentioned above can help companies to reduce accidents and work-related diseases, and an analysis of the large amount of data collected by these smart devices has the potential to guide companies to improve OSH programs.

1.4. Proposed System

This paper presents a monitoring system to measure dust, noise, ultraviolet radiation, illuminance, temperature, and humidity and to check the presence of flammable gases—liquefied petroleum gas (LPG), propane, hydrogen, butane, methane, and carbon monoxide. The system is composed of the following parts:

1. Monitoring devices: they must be clipped to the employees' clothes to collect measures and send them via encryption through the Internet to the server.
2. Server: It runs applications to collect, process, and display data received from the monitoring devices. The server hosts a web application that allows companies to register employees and provide their health information.
3. Mobile application: it is intended for workers to check their exposure data.

These components are described in detail in Section 3.

The system presented in this article is aligned with the concepts of Industry 4.0 and 5.0 because IoT technologies are applied for continuous monitoring, storage, and display of workers' exposure to the risks specified above. Workers' health data are also used to help the company plan preventive actions.

The proposed system provides continuous monitoring of workers' exposure to the agents mentioned above, addressing privacy issues and creating transparency for companies and workers when accessing that information as its main contributions. Regarding innovative aspects of the system, during employee registration, the health history of the worker in respect to common diseases and symptoms related to the monitored agents must be informed. The set of diseases and symptoms was defined in collaboration with two physicians. By observing alerts coming from the analysis of health data through a set of predefined rules, the company can plan professional activities aiming to minimize exposure to certain agents, decide to monitor health conditions more frequently, and guide internal health awareness campaigns.

The architecture of the monitoring device and the web interface for recording employees of an early-stage version of the proposed system is described in Lemos et al. [23]. At that stage, the monitoring device only had humidity, temperature, and illuminance sensors. The solution was tested to check the functioning of the web application concerning employee registration (still without health information), the full information path, data acquisition from the sensors, communication protocols, data storage in the server, and display graphs in Grafana. Tests regarding the suitability of the hardware resources available on the server (memory, disk, and CPU) were also conducted.

2. Literature Review

In this section, we describe both proposals for monitoring risks in workplaces and studies that discuss the use of workers' sensitive data by this type of solution.

Firstly, we present systems that use IoT-based technologies to prevent and/or identify accidents in workplaces, mitigate and/or eliminate risks, check working conditions, and check workers' physiological data. The studies were selected using similarity as a criterion with the proposal of this work regarding technologies and/or monitored quantities.

In the study by [13], a continuous monitoring device was proposed to measure the physiological variables of miners at high altitudes, where they must handle extreme climatic and physiological hazards without specialized medical supervision. The system includes the monitoring of physiological variables such as electrocardiogram and respiratory activity and environmental variables. The non-invasive sensors of the proposed system are embedded throughout each worker's T-shirt. The device calculates heart and respiration rates and exchanges data with a central monitoring station.

Sánchez et al. [14] proposed a smart PPE solution with a sensor network located on a helmet and a belt to monitor the state of the worker and the environment. The system implements continuous risk monitoring biometrics of the worker, detects the external impact, shock, luminosity, gases, and temperature, and provides real-time recommendations to workers. The data collected by the system can be visualized by the user on a tablet or a mobile phone. The device incorporates an LED strip on the sides of the helmet that activates automatically if the worker is in poorly lit areas.

The study conducted by Yang et al. [15] focused on monitoring the level of physical load during construction tasks to assess the ergonomic risk of an individual construction worker. By using a wearable inertial measurement sensor to monitor a worker's bodily movements, this study investigated the feasibility of identifying various physical loading conditions by analyzing a worker's lower body movements. To develop a method for physical load detection, this study first analyzed the effect of the physical loads on a worker's gait cycle and examined whether physical loads create any identifiable perturbations on the signals collected from an ankle-worn wearable inertial measurement unit. This study used machine learning to detect different physical load levels.

Campero-Jurado et al. [17] proposed a smart helmet prototype that monitored the conditions in the workers' environment and performed a near real-time evaluation of risks. The data collected by the sensors were sent to an AI platform for analysis. The equipment aims to protect the operator from impacts while monitoring light, humidity, temperature, atmospheric pressure, presence of gases, and air quality. Alerts can be transmitted to the operator by sound beeps. An LED strip deployed on the helmet can notify the worker of anomalies in the environment through color codes.

Costa and Souto [18] present an IoT-based low-power consumption device to help industries track air quality. The device measures temperature, humidity, levels of carbon dioxide, and PM2.5 and PM10 particles. The NodeMcu ESP8266 acts as a controller and a printed circuit board (PCB) is used to integrate all hardware components of the proposed architecture. The authors related that the proposed system showed the feasibility of creating a network of sensors to monitor air quality in all workstations in a factory environment, especially because of the use of common low-cost hardware.

Singh et al. [19] proposed a real-time surveillance helmet for mine workers based on IoT. The proposed prototype is a three-tier architecture. The first one measures the health and environment parameters through Arduino Uno and sensors for temperature and humidity, gas, dust, heartbeat, and fire. The second tier is the fuzzy classifier, which determines the environment types based on the first-tier parameters. The third tier generates the miner's health report and is also responsible for alerting the monitoring and rescue team in case of the worst situation. A built-in GPS tracker aids in tracking the worker's current location.

Rajakumar and Choi [20] proposed a real-time helmet-mounted system to monitor hazardous gases (methane, hydrogen sulfide, ammonia, and carbon monoxide), oxygen, temperature, and humidity. Workers outside and inside confined spaces receive alerts every second to immediately initiate the rescue operation in the event of a hazard. To develop the system, they used Arduino Mega and the HC-05 Bluetooth module which sent the recorded data and alerts to the workers outside of the confined place. A printed circuit board (PCB) was designed to combine gas sensors into a single unit. The designed helmet-mounted safety system was tested under normal, toxic, and confined atmospheric conditions.

Regarding privacy aspects, according to Maltseva [24], wearable devices have the potential to create multiple opportunities in measuring and tracking health data and occupational risks, helping companies to significantly improve organizational performance. However, attention is needed to extend the use of wearables from the professional to the private domain.

The study conducted by Fugate and Alzraiee [25] provided a quantitative analysis of wearable safety devices in the construction industry and analyzed the reasons why workers resist using this type of equipment. The authors highlighted that employees hesitate to adopt this type of technology because they fear that the devices might capture data that they consider to be personal and private. In addition, employees mentioned that they do not want to be continuously monitored while they work. Another concern raised was about the use of private health data in decisions regarding health insurance or employment.

Privacy aspects in the context of the use of IoT/Industry 4.0 technologies in OSH are also discussed in the study by Jiang et al. [26]. Other issues mentioned by the authors are that not all OSH criteria can be easily digitalized and that for some OSH risks, there is no clear prevention criterion, aside from the need for monitoring devices to be comfortable to use and not cause any inconvenience during working.

Waqar et al. [27] discussed the challenges of adopting IoT in small construction projects. Among the main points raised are the complexity of data architecture, the need for the implementation of a heterogeneous distributed IoT system, the occurrence of false alarms, data privacy concerns, energy and device management, a lack of standards, a lack of legal and regulatory requirements, inexistent or inadequate government policies and incentives, and the need for technical education for workers.

Nnaji et al. [28] presented a research work conducted in the U.S.A. with 330 workers with experience in the use of wearable sensing devices. The authors investigated the types of devices preferred by field workers and managers and the types of functions that they consider to be essential. Smartphones are the most accepted option by all respondents. According to the authors, the preference for smartphones could be due to the reported resistance workers have against putting on additional PPE or carrying additional equipment. Other options that are among the most accepted by workers are smart safety vests, smart hats, and safety glasses. Managers also mentioned smart hats, smart glasses, and attachable devices among the preferred options. The authors comment that the use of smartphones as wearable sensing devices comes with some safety risks because they could cause distractions that lead to accidents. Functions that were considered more useful were the detection of smoke and fire, proximity to energized cables, toxic gases or chemicals, and proximity to potential falling objects.

3. Materials and Methods

The monitoring system is composed of three parts:

- **Monitoring devices:** They must be used by each worker during the work shift. They are responsible for collecting the exposure data of the workers and sending those data to the server through Wi-Fi. Monitoring devices also check whether the measures are within the limits determined by the current regulations or not. If the exposure values exceed the preset values, the equipment will trigger alarms by turning on different LEDs.
- **Server:** It runs in the cloud and collects and processes the data received from the monitoring devices. A web application allows companies to register employees

providing health information, view employee data, report retirement or dismissal, and check alerts generated based on health information. A second web application shows graphs with exposure information and allows data to be downloaded in CSV files. In the future stages of development, the server will also host software based on machine learning to improve alerts and suggestions considering historical exposure data.

- Mobile application: with this application, the workers can check their exposure data, either presented as a summary and as detailed historical data.

The architectures of the components are detailed in the next sections.

3.1. Monitoring Device Architecture: Hardware

The monitoring device is composed of ESP32, a battery, light emitting diodes (LEDs), and the following commonly used low-cost sensors:

- GUVVA-S12SD ultraviolet radiation sensor [29];
- KY-038 noise sensor [30];
- Light-dependent resistor (LDR) [31];
- DHT11 temperature and humidity sensor [32];
- MQ-2 flammable gases sensor [33];
- Shinyei PPD42NS dust sensor [32,34].

The choice of sensors considered low-cost options are commonly used in similar solutions, such as in [13–20]. ESP32 is a series of low-cost and low-power microcontrollers and is also a system-on-a-chip (SoC) with an integrated microcontroller, Wi-Fi, and Bluetooth. ESP32 is a dual-core system commonly used for academic and industrial purposes, such as automation, wearables, and cloud-based IoT applications. The modules have a wide operating temperature range from $-40\text{ }^{\circ}\text{C}$ to $105\text{ }^{\circ}\text{C}$, being capable of functioning reliably in industrial environments [35]. In the proposed system, ESP32 runs an embedded application that reads the sensors mentioned above, connects to the Wi-Fi network, and sends the measures to the server, as detailed in the next sections. A simplified diagram of the monitoring device is shown in Figure 1.

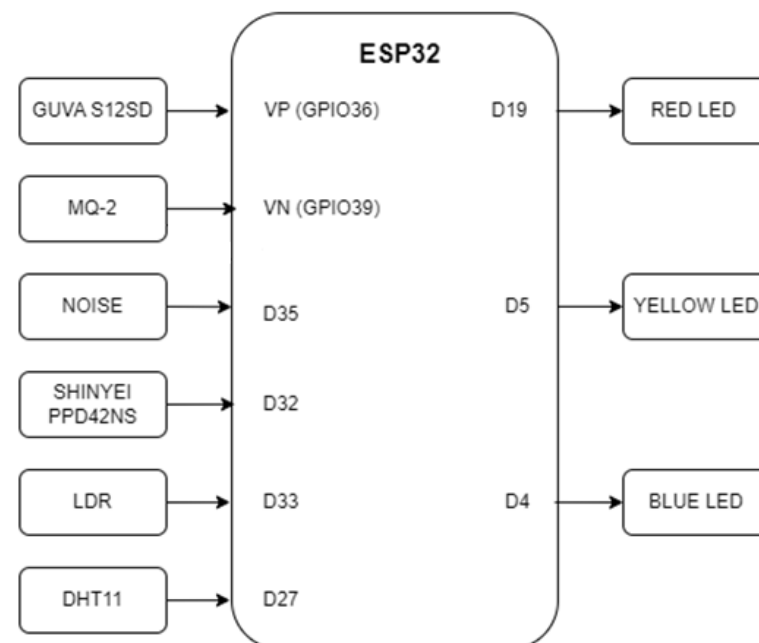


Figure 1. Monitoring device diagram.

Firstly, the monitoring device was mounted on a breadboard to verify correct operation in terms of sensor readings, Wi-Fi network connectivity, and communication with the cloud server. The ESP32 sensors and the device assembled on a PCB are shown in Figure 2.

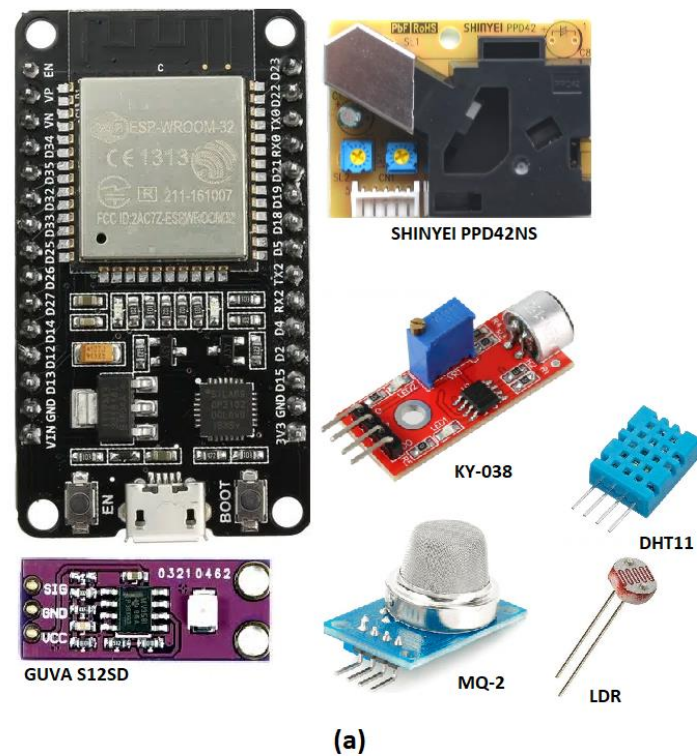


Figure 2. ESP32 and sensors (a) and device assembled (b).

The embedded application that runs in the monitoring devices is explained in the next section.

3.2. Monitoring Device Architecture: Embedded Application

The embedded application runs in ESP32. Concerning the monitored parameters, as previously mentioned, the device uses a light-dependent resistor (LDR) to determine illuminance changes. The resistance of the LDR decreases as the illuminance increases. The ESP32 analog input pin converts the voltage (between 0 and 3.3 V) into an integer value between 0 and 4095. The embedded application classifies values as follows: less than 40—“dark” (level 1); 40 to 799—“dim” (level 2); 799 to 1999—“light” (level 3); 2000 to 3199—“bright” (level 4); greater than 3200—“very bright” (level 5) [31,36,37].

This approach is useful because in various activities, such as those related to civil construction, building maintenance, and agriculture, minimum illuminance is required, but at the same time, workers are often exposed to abrupt variations in illuminance that can lead to accidents, such as because of “temporary blindness”, for example. There is little literature exploring these variations in illuminance that occur when workers move between indoor and outdoor environments several times during the work shift due to the characteristics of professional activities [38]. The illuminance level is not considered to generate alarms. Instead, it will be used by the machine learning model to be developed and will run in the server to identify abrupt changes in illuminance and generate alerts and suggestions to employers. This information may be considered, for example, for reorganizing the flow of workers’ activities. Regarding temperature, in heat stress assessments, it is recommended to estimate the metabolic rate with or without exposure to solar radiation and according to the intensity of the activity performed [39]. This is an important factor both in outdoor activities (e.g., agriculture or construction) and indoor activities (e.g., industry sectors using furnaces or freezing chambers). To perform measurements with this standard requires expensive hardware. Because of this limitation, it was decided to consider temperatures lower than 10 °C and greater than 30 °C as limits to trigger the alarm [40]. This alarm does not indicate non-compliance with standards but recommends attention be paid by workers to drink water and dress appropriately, for example. If the air’s relative humidity is under 50% or above 70%, the same alarm is triggered. The limits for dust, noise, UV radiation, and flammable gases were set by [41–44].

Measurements are carried out every ten minutes, except for the concentration of flammable gases, which is checked every minute. If the total concentration exceeds the limit, the blue LED turns on to indicate that the worker must leave the location. As with most gas sensors, MQ-2 detects multiple gases but cannot identify them. The description of the monitored parameters, their limits, and alarms are presented in Table 1.

Table 1. Monitored parameters and limits.

Quantity	Description	Limits for Trigger Alarms	LED
Illuminance level	Classified as 1—dark, 2—dim, 3—light, 4—bright, and 5—very bright.	-	-
Dust	Total dust (particles/m ³).	>1,415,000	Red
Noise	Noise (dBA)	>85	Red
UV	UV radiation in standard erythema dose (SED)—total amount per day. SED is checked every ten minutes, and its sum is registered in a file.	>1.3	Red
Temperature	Temperature (°C).	<10 or >30	Yellow
Humidity	Relative humidity (%).	<50 or >70	Yellow
Flammable gases	The total gas concentration is measured every minute.	>1000	Blue

Monitoring devices communicate with the server through the Internet. For this purpose, it uses message queuing telemetry transport (MQTT) through Wi-Fi. The MQTT protocol was chosen because it is widely used, with very good documentation. Furthermore, there are several free implementations of this protocol ready to use. MQTT is a messaging

protocol commonly used by smart sensors and other IoT devices to transmit data. MQTT supports device-to-cloud and cloud-to-device messaging. The MQTT protocol follows the publish/subscribe model. In traditional network communication, clients and servers communicate directly with each other. MQTT uses a publish/subscribe pattern to decouple the message sender (publisher) from the message receiver (subscriber). A third component called a message broker filters messages received from publishers and distributes them to subscribers [45].

To address privacy issues, MQTT communication is secured by transport layer security with a pre-shared key (TLS-PSK). Messages sent by a device are encrypted and signed using a secret key shared between the equipment and the server (broker in MQTT). The same key is used for the decryption and authentication of messages by the destination. The pre-shared keys (PSKs) are 256-bits long, and they are configured between each device and the MQTT broker, as recommended by [46]. The keys were automatically generated by using the OpenSSL [47]. On the monitoring device side, the keys are fixed in the code. In the MQTT broker, the keys are configured in a broker configuration file specific for this purpose. MQTT topics are composed of the device ID (a four-digit number) together with the name of the monitored quantity, such as “6068/dust”, “6070/humidity”, etc. IDs are unique to allow for association with the employees in the applications running on the server.

3.3. Server Architecture

The server-side applications run on a virtual private server (VPS) provided by a web hosting company. The VPS runs the Ubuntu Server 20.04 operating system [48] and has 8 GB RAM, 2 virtual CPUs, 100 GB disk space, and 2 TB of bandwidth.

An overview of the monitoring system, including server-side applications, is shown in Figure 3.

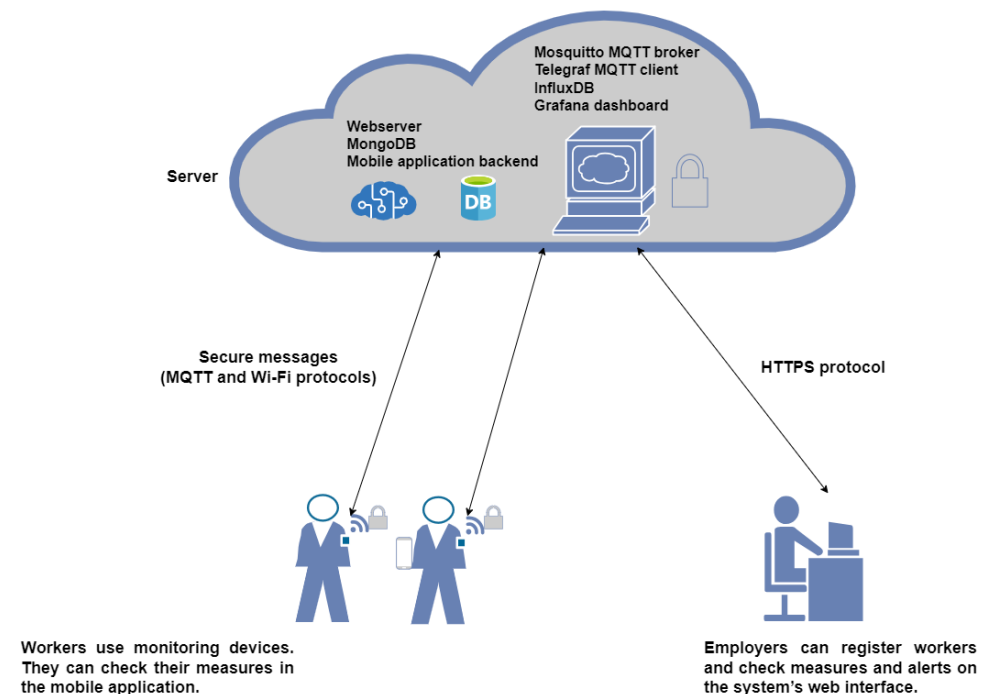


Figure 3. Monitoring system overview.

A flowchart containing the step-by-step implementation is shown in Figure 4.

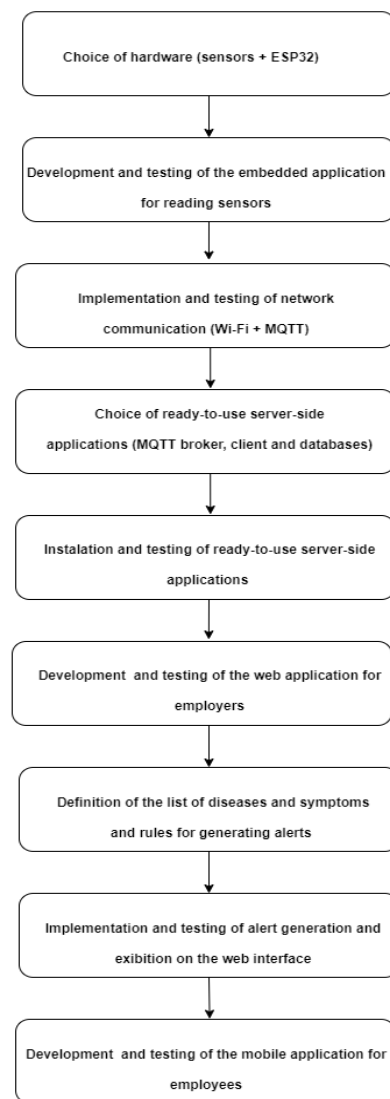


Figure 4. Flowchart with the implementation step-by-step.

The applications that are executed on the server are explained below.

- Mosquitto: It is an MQTT broker [49]. Mosquitto receives the measures sent by the monitoring devices.
- Telegraf: It is an MQTT client [50]. It subscribes to the topics that contain the exposure information of the employees and records them in the database.
- InfluxDB: It is a time-series database [51]. InfluxDB stores the exposure information of the workers.
- Grafana: Grafana is a platform for visualizing and analyzing metrics through graphs [52]. The server reads data from InfluxDB to generate graphics that show the exposure information of each worker. The data can be downloaded in CSV files.
- MongoDB: It is a document-oriented database [53]. MongoDB stores employees' information.
- Web application: It was built using HTML5 [54–58] and is accessible through HTTPS (hypertext transfer protocol secure), using digital certificates [59]. It is intended to allow managers, the OSH team, etc., to register employees and associate them with monitoring device IDs, display the list of monitoring devices and the IDs of the employees who use them, display the current activity and the history of activities (if any) performed by a person in the company, update employee details, and register when an employee retires or leaves the company. This information is stored in MongoDB. This web application provides a web page where the alerts and suggestions may be

verified for each employee. This information is generated considering the diseases and symptoms stored during employee registration and can be updated anytime by the company. On the same web page, there is a link to Grafana, where the employers can view the graphics with information about the workers' exposure. The use of the web application, mainly for employee registration, is better explained in the next section.

- **Machine learning module:** This module is under development and aims to help employers make long-term decisions about occupational safety and health by suggesting points that deserve attention. The machine learning module will be part of a recommendation system that will analyze the exposure data provided by each monitoring device and classify the data as risky or not. Alerts and suggestions will be generated based on the responses in this module.
- **Mobile application for workers and backend server:** The mobile application is intended for workers to check their daily exposures using a very simple interface that is composed of a homepage, showing buttons to access the summary of the last 24 h for all of the monitored quantities. By clicking on one of these buttons, it is possible to check the minimum, maximum, and average values, and alarms (yes or no). For all of these quantities, at the bottom of the web page, the summary shows the following buttons: "View history of the last 24 h", "View history of the last 7 days", and "View history of the last 30 days". When clicking on one of these buttons, the application will show the device ID and a list with the date, time, and value of the monitored quantity for each 10 min for the selected period. These data are read from the InfluxDB database. A web page with help content presents relevant information about the study and its objectives, a summary of the monitored quantities and their limits, and information regarding data privacy. This application was built using the same technologies as the web application for employers and can be downloaded on Android smartphones and can also be accessed through the Internet. Access is achieved using HTTPS. The mobile application will be evaluated by a group of workers in the next stage of the work.

The next section provides details about the registration of employees in the web application. The information provided during registration is especially important because it is considered in the preparation of suggestions and alerts by the applications running on the server.

3.3.1. Web Application: Employee Registration

Monitoring devices were designed to receive arbitrarily generated four-digit unique identification codes when they were produced. To register an employee who will use a device, the employer must choose a device from the list shown on the web page and create a unique four-digit code to identify the employee. An employee ID with more digits is not suitable to avoid direct association with document numbers. The uniqueness of this ID is verified and, if the record already exists, an error is shown and it will be necessary to choose another ID. Similarly, it is not possible to register more than one employee with the same device. The employee ID must be stored by the company in a safe place so that the employee's personal data can be retrieved later.

Once the ID is validated, the following information must be provided to proceed with the registration: gender, date of birth, disease history and symptoms, subsidiary, sector, job, job start date, other positions the employee may have at the company (if any), and total time worked in other companies in similar positions. This information is important to consider the total time that the worker has been exposed to the monitored agents. The job must be chosen from a predefined list that was prepared considering professional activities related to civil construction and building maintenance. Fourteen jobs were included: air conditioning technician; bricklayer; carpenter; construction cleaning worker; construction general worker; ditcher; drain man; electrician; gardener; gutter installer; painter; plasterer; plumber; and roofer. The worker's data are stored in MongoDB.

Concerning disease and symptom history, three lists were prepared considering the quantities measured by the monitoring device (temperature, humidity, dust, noise, and UV radiation). The illuminance level was not considered because its data will be used only by

the machine learning module to alert the company about abrupt changes in illuminance, as explained earlier. Flammable gases were also not considered because they are monitored to avoid accidents by indicating immediately that the worker must leave the place when the volume is dangerous.

The first list presents the more common diseases that can be worsened by exposure to the monitored agents. The second one presents the more common occupational diseases that can be caused by exposure to the monitored agents. The third list, in turn, presents the more common symptoms that may result from those exposures. When registering a worker, all of the applicable options must be marked. In respect to pre-diagnosed diseases, only those that have been diagnosed by a physician should be marked. The symptoms must be recorded by the worker if they are persistent and/or occur often.

To choose the diseases and symptoms mentioned in this work, appropriate studies were consulted, together with the collaboration of two physicians. The presence of physicians in the system development was useful in selecting the data most relevant to the worker's health care. This assistance was also necessary to validate the relationship between the collected variables and the most relevant diseases to each one of them. The monitoring system should not only be of interest to the worker's self-monitoring but can be a useful tool for health care. In this regard, the interaction between developers and the specialists that potentially will use the application is fundamental.

The diseases and symptoms, as well as their correlations with the monitored agents, are shown in Table 2.

Details concerning the use of these correlations to generate alerts and suggestions are presented in the next section.

3.3.2. Web Application: Exposure Data and Alerts

Based on the health information supplied when registering a worker, the web application will automatically define attention points (exposures with which greater care should be taken). The rules for this purpose consider the columns "Agents", "Pre-diagnosed diseases", and "Symptoms". The agents correlating with all of the pre-diagnosed diseases and symptoms are considered to generate alerts along with the total time worked in other companies in similar positions. The health data provided during employee registration can be updated by the employer at any time. The alerts are shown on the web page "Exposure data and alerts" and the general format of an alert is as follows:

"In respect to diseases and symptoms, this person has: disease 1, disease 2, disease n. Due to reported diseases and symptoms, it is advised to avoid or reduce exposure to the following agents: agent 1, agent 2, agent n. Including other companies, the worker has performed activities of the same type and has been exposed to the same agents for n years. Attention to health is recommended."

Examples are given below:

- (a) When registering a worker who has been diagnosed with a single disease, e.g., asthma, all of the agents related to asthma in Table 2 (cold, dust, and high and low humidity) are considered to generate an alert.
- (b) When registering a worker who has been diagnosed with two diseases, each correlating with a different agent, e.g., dust and noise, an alert considering both agents is presented.
- (c) When registering a worker who reports that he or she was not diagnosed with any of the diseases listed but mentions at least one symptom that may be caused or worsened by the exposure to one agent, e.g., cold, an alert related to cold is shown.
- (d) When updating the records of a worker who was diagnosed with a disease correlating with a single agent but currently mentions a symptom correlating with another agent, an alert considering both agents is shown.
- (e) If a worker does not present symptoms or diseases, the system does not generate alerts.

Table 2. Agents, diseases, symptoms, and their correlations.

Agents	Pre-Diagnosed Diseases	Related Occupational Diseases	Symptoms
Cold [60–63]	Asthma Hypertension Rheumatic diseases Spinal disorders Respiratory diseases Previous allergic diseases and reactions	Worsening of respiratory diseases Increase in musculoskeletal disorders	Chest pain Cough Dyspnea (shortness of breath) Headache Hemoptysis (blood cough) Skin lesions Skin rash Weight loss Neck, lower back pain, and joint pain
Dust [61,64,65]	Asthma Lung cancer Lung diseases Previous tuberculosis Smoker	Pulmonary fibrosis (asbestosis) Lung cancer (due to inhalation of asbestos dust)	Chest pain Cough Dyspnea (shortness of breath) Fever Hemoptysis (blood cough) Weight loss
Heat [66,67]	Diabetes Heart disease Hypertension Hypotension Kidney disease	Dehydration (favors the occurrence of kidney problems) Heart attack Stroke Dryness of the nasal mucosa (favors the emergence of respiratory infections)	Chest pain Dyspnea (shortness of breath) Fainting (syncope) Headache Increased thirst Increased urinary volume Weight loss
High humidity [61,68,69]	Asthma Diabetes Respiratory diseases Previous allergic diseases and reactions	Worsening of respiratory diseases	Chest pain Cough Dyspnea (shortness of breath) Hemoptysis (blood cough) Increased thirst Increased urinary volume Weight loss
Low humidity [69–71]	Asthma Respiratory diseases Previous allergic diseases and reactions	Worsening of respiratory diseases	Chest pain Cough Dyspnea (shortness of breath) Hemoptysis (blood cough) Skin lesions Skin rash

Table 2. Cont.

Agents	Pre-Diagnosed Diseases	Related Occupational Diseases	Symptoms
Noise [62,72,73]	Diabetes type 2 Hearing disorders Hypertension Smoker	Hearing loss Hypertension	Difficulty understanding conversation in situations with background noise Feeling that the ears are plugged up Speech or other sounds muffled after exposure to loud noise Transient tinnitus
UV radiation [74–76]	Eye disease Heart disease Skin cancer Skin diseases	Dehydration Skin lesions Heat stroke Burns Skin cancer Photosensitization Erythema Acute inflammatory eye reactions Increased risk of cataracts Suppression of the immune system (favors the occurrence of infections and cancer)	Chest pain Dyspnea (shortness of breath) History of resection of skin lesions Skin lesions Skin rash

It is important to highlight that regarding pre-diagnosed diseases, the proposed approach is based on the following: a certain previously diagnosed disease might be caused by various factors, such as genetics or agents related to professional activities or others. If a worker who has that disease is often exposed to agents that are known to aggravate such conditions, his or her health status tends to worsen. In addition, it cannot be concluded that a disease was caused by exposure to certain agents unless the occupational physician has supporting documentation/tests available. This aspect was considered in the present study. For example, according to [77], family history, air pollution, smoking, and occupational exposures are among the factors that play an important role in the development of asthma. For such reasons, the proposed web application considers all of the agents related to asthma (cold, dust, and high and low humidity) for a worker who has this condition and generates an alert to reduce or avoid exposure to these agents.

Concerning the symptoms that may be reported by workers during registration or information updating, they may be motivated by diseases that cannot be related to their professional activities and that have no severity. On the other hand, a reported symptom may be one of the first signs of a serious disease related to the activities carried out by the worker in the company. It is essential to highlight that this type of assessment can only be carried out by a physician, as well as requests for additional tests that can confirm or rule out suspicions.

In other words, the objective of the proposed system is that alerts issued preventively can assist OSH professionals/physicians in decision making to define, for example, when it is necessary to carry out further investigation. Aside, OSH professionals may use the information provided by the system as input to guide personalized health-care routines and create or improve internal health awareness campaigns. For example, OSH professionals may advise managers and supervisors to plan workers' activities aiming to minimize exposure to certain agents.

The recommendation system to be implemented is composed of two parts: the machine learning module that will analyze the exposure data provided by each monitoring device and classify the data as risky or not, and the already implemented module that performs the verification of the health conditions as described above. This approach is expected to improve the alerts.

4. Results

As mentioned earlier in this study, concerning tests, in [23], it is described how this technological solution was tested to check the functioning of the web application concerning employee registration, the full information path, which includes data acquisition from temperature/humidity and light sensors by ESP32, the sending of encrypted data over the Internet through the MQTT protocol, the processing of the data on the server, storage in InfluxDB, and display graphs in Grafana. The tests regarding the suitability of the hardware resources available on the server (memory, disk, and CPU) are described. In the present work, the tests are focused on verifying the functionalities of the web interface for employee registration, especially regarding the provision of health information, the updating of this information, and the generation of corresponding alerts. All of the tests consider fictitious employees and health information, aiming to ensure that the system works according to what was planned. Usability tests with workers and employers will be carried out in a future stage of development of this system. The results are shown below.

Figures 5–8 show the web pages for employee registration. The first step of employee registration is shown in Figure 5. This stage occurs after the choice of employee ID and monitoring device ID.

Figure 6 shows the questions related to other professional activities that may be performed by the worker. This information is optional. On the other hand, it is mandatory to record for how long the worker has held similar positions in other companies.

Employee registration - Job and health information

Employee: 8465

Device: 6068

Please provide the following information:

1) Personal information

Gender:

Date of birth:

2) Job information

a) Basic job information

Subsidiary / Location:

Sector:

Job:

Job start date:

Figure 5. Personal and basic job information.

b) Considering the employee's qualifications, does he/she have other job possibilities in this company?

☐ 01 - Air conditioning technician
☐ 02 - Bricklayer
☐ 03 - Carpenter
☐ 04 - Construction cleaning worker
☐ 05 - Construction general worker
☐ 06 - Ditcher
☐ 07 - Drain man
☐ 08 - Electrician
☐ 09 - Gardener
☐ 10 - Gutter installer
☐ 11 - Painter
☐ 12 - Plasterer
☐ 13 - Plumber
☐ 14 - Roofer

c) In this step, the employee must answer about the following question: Have you held these positions in other companies before? If yes, for how long in total?

☐ No
☐ Yes, for less than one year
☐ Yes, for one to two years
☐ Yes, for two to five years
☒ Yes, for five to ten years
☐ Yes, for ten to fifteen years
☐ Yes, for fifteen to twenty years
☐ Yes, for more than twenty years

Figure 6. Additional job information.

The questions about previously diagnosed diseases and symptoms currently or recently observed are shown in Figures 7 and 8. In this case, the authors chose hypertension as a disease and skin lesions as a symptom.

3) Employee health conditions and diseases

a) In this step, the employee must answer about the following question: Do you have or had any of these conditions? Which ones?

☐ 01 - Asthma
☐ 02 - Diabetes
☐ 03 - Diabetes type 2
☐ 04 - Eye disease
☐ 05 - Hearing disorders
☐ 06 - Heart disease
☒ 07 - Hypertension
☐ 08 - Hypotension
☐ 09 - Kidney disease
☐ 10 - Lung cancer
☐ 11 - Rheumatic diseases (such as lupus, arthritis, arthrosis)
☐ 12 - Spinal disorders (such as neck pain, low back pain)
☐ 13 - Respiratory diseases
☐ 14 - Previous allergic diseases and reactions
☐ 15 - Previous tuberculosis infection
☐ 16 - Skin cancer
☐ 17 - Skin diseases
☐ 18 - Smoker

Figure 7. Health information—previously diagnosed diseases.

b) In this step, the employee must answer about the following question: Currently or in the last months, have you felt any of these symptoms?

- ☐ 01 - Chest pain
- ☐ 02 - Cough
- ☐ 03 - Difficulty understanding conversation in situations with background noise
- ☐ 04 - Dyspnea (shortness of breath)
- ☐ 05 - Fainting (syncope)
- ☐ 06 - Feeling that the ears are plugged up
- ☐ 07 - Fever
- ☐ 08 - Headache
- ☐ 09 - Hemoptysis (blood cough)
- ☐ 10 - History of resection of skin lesions
- ☐ 11 - Increased thirst
- ☐ 12 - Increased urinary volume
- ☐ 13 - Speech or other sounds muffled after exposure to loud noise
- ☒ 14 - Skin lesions
- ☐ 15 - Skin rash
- ☐ 16 - Transient tinnitus
- ☐ 17 - Weight loss
- ☐ 18 - Neck, low back pain, joint pain

Figure 8. Health information—symptoms.

The web page “Exposure data and alerts” is presented in Figure 9. A list of the previously registered workers is shown.

Home	Exposure data and alerts	Company and employee info	Settings	Employee registration	Employee update	About	Logout
Exposure data and alerts							
The graphics with details on exposure to all the monitored quantities for each employee are shown in Grafana application.							
View dashboards in Grafana							
To check alerts for an employee, please click on one of the IDs below.							
Device	Employee ID						
6066	1234						
6065	1000						
6067	8888						
6068	8465						

Figure 9. Exposure data and alerts web page.

Clicking on the ID 8465, it is possible to view the alert generated for the employee who was registered with hypertension and skin lesions. All of the agents related to the disease and symptoms are considered according to Table 2. The alert presented in Figure 10 also highlights the total time worked in similar positions including the current job.

Employee personal data and alerts	
Employee ID	8465
Device	6068
Gender	Male
Birthdate	8/9/1984
Job	14 - Roofer
Alerts	<p>In respect to diseases and symptoms, this person has: 07 - Hypertension, 14 - Skin lesions. Due to reported diseases and symptoms, it is advised to avoid or reduce exposure to the following agents: Cold, Heat, Noise, Low humidity, High exposure to UV radiation. Including other companies, the worker has performed activities of the same type and has been exposed to the same agents for 5 to 10 years. Attention to health is recommended.</p>

Figure 10. Alert considering hypertension and skin lesions.

Figure 11 shows the web page for updating employee information. In this case, “Update employee’s health conditions” was selected, and skin diseases and cough (as symptoms) were chosen as the conditions previously recorded.

Employee update
Please check the following employee information before proceeding:

Employee ID	8465
Device	6068
Gender	Male
Birthdate	8/9/1984
Subsidiary	01 - BR - São Leopoldo
Sector	01 - Construction and maintenance
Job	14 - Roofer
Job start date	3/2/2023
Possible jobs	
Diseases	07 - Hypertension
Symptoms	14 - Skin lesions

To update the health conditions of the employee specified above, change his/her job position or report his/her contract termination or retirement, please fill in the fields below:

Job information
Please, what do you need to inform?

Date of the event:

Figure 11. Health information update.

The new alert is presented in Figure 12. This alert was built considering all of the conditions registered (hypertension, skin diseases, skin lesions, and cough).

Employee personal data and alerts

Employee ID	8465
Device	6068
Gender	Male
Birthdate	8/9/1984
Job	14 - Roofer
Alerts	In respect to diseases and symptoms, this person has: 07 - Hypertension, 17 - Skin diseases, 02 - Cough, 14 - Skin lesions. Due to reported diseases and symptoms, it is advised to avoid or reduce exposure to the following agents: Cold, Heat, Noise, High exposure to UV radiation, Dust, High humidity, Low humidity. Including other companies, the worker has performed activities of the same type and has been exposed to the same agents for 5 to 10 years. Attention to health is recommended.

Figure 12. New alert considering the health status update.

As explained, the web interface for registering employees and generating alerts worked properly. The complete system will be evaluated in at least one company. For this purpose, it will be necessary to assemble a few devices. They will be used by a group of workers who will be asked to access the mobile application once a day. The web application will be used by a manager and/or OSH professional. It is planned for participants to answer questionnaires about the usability of the solution.

5. Discussion

The system presented in this work benefits from the use of IoT technologies. Importantly, the establishment of correlations between previously existing diseases, whether because of occupational exposure or not, symptoms presented by the employee, and harmful agents to which they are exposed in the work environment provides opportunities for carrying out personalized analyses that can contribute to planning preventive actions in OSH. This monitoring solution aims to help companies identify conditions that could damage workers' health in the longer term. This type of functionality was not found in the studies described in Section 2. In addition, addressing privacy in OSH monitoring systems is still not common.

To achieve these goals, this system's proposal includes both the handling of environmental data and health history information. In this context, recent research has explored workers' concerns about incorporating IoT/Industry 4.0 and Industry 5.0 technologies in

OSH. The fact that workers do not know exactly how the data can be used has often been reported as a justification for resistance to the continued use of monitoring equipment. Workers are afraid of being harmed by the analysis of sensitive data, such as health data. On the companies' side, concerns are generally related to the costs or complexity of managing new technological solutions.

A very interesting aspect of the research presented in Section 2 is the suggestion to incorporate functions into monitoring systems that provide personal feedback on sensitive information, predominantly physiological metrics, to the workers and non-sensitive information (such as environmental metrics) to safety managers. This approach may help to reduce workers' resistance to the incorporation of new technologies.

Regarding the handling of sensitive data, workers' concerns are legitimate and should always be considered by companies. Employers must be aware of and up-to-date with data privacy legislation. In addition, it is essential to carry out appropriate training to make workers aware of the benefits arising from the adoption of new OSH solutions. The gradual use of equipment, for example, with small groups of workers, primarily for short periods, can be a viable alternative to help familiarize managers and workers with new technologies and, at the same time, demonstrate to workers the safety of the devices.

Countries might differ slightly on legislation for processing personal data. However, workers must always know exactly what data will be collected, how each piece of information will be processed, and for what purposes it will be used, such as what improvements can be implemented in the company by using data. In addition, procedures to ensure the confidentiality of data sent over the network and adequate storage by the employer or third-party technology companies are also essential items.

It is worth noting that although there are advanced regulations regarding data privacy in several countries, the limits of the use of artificial intelligence have not yet been well established, given the rapid evolution of algorithms and the large computational processing capabilities currently available. It is important to highlight that depending on the type of data collected and the analysis carried out, even if it is with the expressed authorization of the worker, solutions using machine learning may have a harmful bias toward certain groups of people.

For the reasons stated above, the creation of regulations for the use of such technologies in OSH is necessary and urgent. The lack of regulations is one of the reasons why companies resist adopting IoT-based solutions. Without the protection provided by adequate regulations and given the still high cost of implementing technological solutions, small and medium-sized companies tend to postpone the adoption of modernizations to monitor risks in work environments. In addition to the above, it is important to highlight that possible labor lawsuits for the use of sensitive data also have a high impact on smaller companies.

In any case, the design of solutions must be conducted responsibly and must consider the concerns of workers and employers. It is important to note that given the rapid technological evolution, it is expected that regulations will not always be able to keep up with all of the new developments and possibilities that arise. Therefore, responsibility and common sense are indispensable like never before.

In this system's proposal, data privacy is addressed, as explained in Sections 3.2 and 3.3. The mobile application provides help with where workers can find information about the data collected and its use.

In any case, companies that want to implement solutions such as the one proposed in this work must be aware that workers may disagree about the use of the equipment and that productivity may initially be impacted by workers' disbelief regarding the benefits of this type of equipment/system and distrust regarding the company's real intentions when carrying out monitoring.

To minimize negative impacts, it is expected that dialogues with managers and adequate training about the use of equipment and its benefits can bring positive results. In the next stages of the system development, it is planned that we will carry out a study with

a group of field workers and their manager, supervisor, or OSH personnel. This person will support the choice of employees who will wear the monitoring device during the work shift.

During the period of testing, the supervisor will be asked to use the web application and, in the end, he or she needs to answer a questionnaire to provide his/her impressions of the system. The questions will cover usability, privacy concerns, and suggestions to improve the system.

Employees must use the monitoring device throughout the work shift, use the mobile application to check their exposures once a day, and answer the questionnaires at the end of the test period. The questions will cover usability, privacy concerns, discomfort and problems with the monitoring devices, and suggestions to improve the solution.

Responses from employees and supervisors or managers are expected to provide information that will contribute to improving the system. Even though the proposed solution has already been designed in compliance with applicable privacy regulations to make communication and data storage secure, employees are expected to raise concerns about the potential uses of their health data. The answers provided may serve as a reference in the design of new solutions with a similar purpose.

6. Conclusions

By simplifying the visualization of data by organizations, the proposed system is expected to contribute in the long run to reduce the incidence of occupational diseases resulting from exposure to harmful agents and the worsening of other diseases, assisting companies in the development of and improvement in OSH management programs. The presented solution addresses privacy issues, and concerning innovation, monitoring working conditions and issuing alarms immediately are features that can be found in several solutions, as mentioned earlier. On the other hand, correlating a worker's health history with harmful agents and using it all to build suggestions and alerts to guide long-term decisions are innovative features.

Sensors for measuring other parameters can be added to the monitoring devices. In this case, on the server side, changes would be necessary in the backend of the web application intended for companies to (a) add diseases and symptoms corresponding to new monitored agents and (b) generate alerts considering the new agents, diseases, and symptoms. In the mobile application intended for employees, adjustments would need to be made to show the new measurements.

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