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# Impact of Multi-Sensor Technology for Enhancing Global Security in Closed Environments Using Cloud-Based Resources

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**Abstract:** By nature, some jobs are always in closed environments and employees may stay for long periods. This is the case for many professional activities such as military watch tours of borders, civilian buildings and facilities that need efficient control processes. The role assigned to personnel in such environments is usually sensitive and of high importance, especially in terms of security and protection. With this in mind, we proposed in our research a novel approach using multi-sensor technology to monitor many safety and security parameters including the health status of indoor workers, such as those in watchtowers and at guard posts. In addition, the data gathered for those employees (heart rate, temperature, eye movement, human motion, etc.) combined with the room's sensor data (temperature, oxygen ratio, toxic gases, air quality, etc.) were saved by appropriate cloud services, which ensured easy access to the data without ignoring the privacy protection aspect of such critical material. This information can be used later by specialists to monitor the evolution of the worker's health status as well as its cost-effectiveness, which gives the possibility to improve productivity in the workplace and general employee health.

**Keywords:** multi-sensor technology; security; closed environment; cloud-based resources

## 1. Introduction

Today, the work environment is challenged by various factors such as personal health, workplace security, employee safety and performance, and workflow efficiency. In particular, these parameters can have a tremendous impact on the closed work environment. Employees in these areas are also exposed to serious health issues and face many pressures, mainly relating to their long stay in the same environment. It is therefore important to keep their vital and health data in order to be able to follow closely their health to anticipate risk situations and be proactive by sending a warning to through the hierarchy.

Indeed, employees can spend more than eight hours daily in such environments which can deeply affect their psychological and physiological equilibrium. Moreover, closed rooms or areas may pose a particular risk because of the lack of ventilation, unpurified air or humidity problems that can eventually lead to serious illness. Many external factors could also interfere, such as sound with high decibel level, electromagnetic radiations, abnormal temperature, lighting not conducive to the conventional eye wavelength range, etc. [1].

Besides, in some cases, long and boring stays in closed environments may lead employees toward misbehaviors, like sleeping while on duty, or a deterioration of health conditions, like surprising cramps.

Therefore, an efficient solution for tackling these issues must be implemented to enhance the workflow performance, guarantee a higher level of security, preserve the healthy state of the employee, and prevent unsafe situations.

Technology can, in this context, play a fundamental role in these difficulties. Recently, sensor technology has confirmed its impact on individuals, society and our daily life in terms of monitoring, process control, awareness, security, and safety. A combination of data stemming from multiple sensors, as well as related information, and data fusion techniques led to the emersion of a hardly novel concept known as multi-sensor data fusion (MDF). This has offered the possibility to attain more specific interpretations and inferences than could be obtained with a single, independent sensor. MDF is the subject of diverse military and nonmilitary applications as a form of automated target recognition (e.g., for smart weapons), guidance for autonomous vehicles, remote sensing, monitoring of manufacturing processes, robotics, and so on [2–5].

Moreover, the Shared Sensor and Actuator Networks (SSANs), allow the sensing and communication infrastructure to be shared among multiple applications [6]. MDF can be considered the key to reducing the huge number of sharing applications by decreasing the amount of sensor-generated data diffused in wireless channels and, accordingly, saving energy. This is understandable since wireless sensors and actuators usually rely on batteries, as their energy source, whose replacement is either undesirable or unfeasible [4].

Additionally, various types of scientific research have discussed and resolved many life problems by introducing sensor technology. This technology has been introduced into industrial applications offering monitoring, surveillance and safety solutions [7]. Moreover, sensors are the core of the medical equipment involved in diagnostics, control processes, and personal health, as well as critical care [8–10]. In Reference [11], the authors proposed a promising solution based on four sensors to ensure the safety of soldiers working in critical zones.

Sensors can enhance many domains, such as fitness and sporting activities [12], smart cities [13], along with energy sources such as solar power, batteries and fuel cells [14]; it can also be used for environmental monitoring, exploring space [15], and in the security and safety of people and nations [16,17].

Scalable data processing platforms are needed to handle data collected from various sensors. The cloud is considered a perfect computational platform [18] for hosting data processing applications for smart devices due to its effectiveness and nimbleness.

In this paper, we propose a novel approach based on multi-sensor technologies, taking into account the multiple parameters described above, so as to enhance system security as well as workflow performance. This approach is far from adopting sensor networks [19,20]. Indeed, the sensors are characterized by the hybrid aspects of their categories, communication technology, and geographic location. Therefore, technologies and approaches developed in sensor networks do not fit in our present context.

This paper is organized as follows. Section 2 presents, on the one hand, the high levels of requirements of multi-sensor technology and, on the other hand, the different selected sensors and applications for increasing security in critical closed zones. We divided these sensors into three categories: environmental sensors, indirect contact sensors, and direct body contact sensors. The subsequent section (Section 3) maps the specified requirements with the adopted MDF approach, combines the results obtained from the sensors, analyzes the main security risks and the corresponding countermeasures that the closed environment may face and evaluates the performance and efficiency of this technology when deployed in the architecture of cloud storage. Finally, our conclusions and future work are the subjects of Section 4.

## 2. Multi-Sensor Technology and Effects on Closed Workplaces

This section scrutinizes the issue of the security and safety of workers in mainly closed environments through multi-sensor technology. Undoubtedly, many employees show indicators like mental and physical deficiencies produced by lack of sleep, excessive physical, mental and/or emotional stress, sickness, medications, or a combination of these conditions. This can stem from workplace loneliness, the restlessness or anxiety typically arising from an imminent event or daily life problems that may reduce, at astounding rates, the effectiveness and productivity of the worker and can give rise to safety issues in critical areas [11,16,17]. In this context, multi-sensor technology can be an efficient solution to overcome these difficulties and to improve the performance of workers, apart from the classical strategies and techniques for increasing the outcomes of employees [21].

To investigate multi-sensor technology in a specific context, it is highly recommended to identify the requirements which can play a crucial role in its successful implementation [22]. For that reason, the specification of the high level requirements associated with multi-sensor technologies can blaze a trail towards efficient solutions for closed workplace security. In the following subsection we investigate these requirements.

### *2.1. High Level Requirements for Multi-Sensor Technologies*

In order to combine several sensors in a specific closed environment, high level requirements have to be met. This guarantees a minimum quality so that the collected information has more pertinent value and prompt timing. The most important requirements can be summarized as follows:

- Sensitivity: The concept of sensitivity refers to the minimum input of physical parameters that produce a detectable output change. More precisely, it can be defined as either the input parameter variation needed to generate a standardized output variation or an output voltage variation for a given variation in an input parameter.
- Resolution: This defines the lowest detectable incremental variation of an input parameter that can be found in the output signal.
- Precision: The precision aspect of sensor technology is related to the degree of reproducibility of a measurement. Ideally, the sensor should produce, for a given scenario, the same value every time. Small variations can be detected in the majority of sensors relative to the correct value.
- Accuracy: This focuses on the difference between the concrete value of the physical quantity and the measured quantity. Accuracy can be defined by a percentage or in absolute terms.
- Range: This indicator specifies the maximum and minimum values that could be captured by the sensor. This range should encompass the minimum and maximum bounds encountered.
- Response time: This can be defined as the time in which the output reaches a certain percentage (e.g., 95%) of its final value in response to a step variation of the input. It depends on the sensor nature and should be short enough, compared to the physical aspect, to capture.
- Sampling frequency: Some sensors have continuous output during certain time intervals. Technically speaking, a periodic measurement is performed according to the sensor sampling rate. This sampling frequency has to be greater than double the maximum frequency (Shannon theorem) that may be captured. This ensures that the coincidence between the sensor output curve and the actual physical parameters are measured.
- Tolerated physical environment quantities: Some sensors may face extreme weather conditions and it is important that the sensor work properly. These physical conditions can be related to temperature, sunlight, wind, smoke, audio noise, electromagnetic rays, humidity, dust, and so on.
- Lifetime and maintainability: It is important to estimate the lifetime of the sensor before its adoption in order to adequately plan all the logistics related to installation and maintenance.
- Communication medium: In the cases where sensors are integrated in an all-encompassing system, it is necessary to be precise in regards to the communication medium adopted by the sensor. This is particularly useful for multi-sensor fusion as well as multi-sensor fusion.
- Interoperability: In a multi-sensor context, interoperability is highly recommended. This allows the integration of sensors with hybrid communication protocols.

Once the high level requirements are specified, we will plan a full-study of the multi-sensor technology. Overall, sensors can be classified into three different packages. The first includes the environmental sensors including air and temperature sensors, $CO_2$ sensors, humidity sensors, radiation sensors, sound/noise level sensors, and so on. The second category, indirect-contact sensors, includes eye motion sensors, heartbeat sensors, body temperature sensors, camera sensors, etc. The last represents the direct-contact sensors containing motion and temperature sensors, smart-health sensors, and fingerprint sensors.

In what follows, we shed light on the most important sensors to be implemented in the closed workplaces and the enhanced safety levels and degree of security of work and workers

### 2.2. Environmental Sensors

Environment sensors are ordinarily attached to environment monitors. They offer global perceptions of the environmental parameters needed to construct an accurate library monitored by dedicated data and computation centers. These sensors are available as heat and/or humidity, air flow, and liquid. The computational center triggers a specific action when any sensitive limit is reached.

#### 2.2.1. Air Sensors

It is very valuable to collect information from the workplace atmosphere as in References [15,23,24]. Air sensors permit obtaining, in real time, all information regarding carbon dioxide, temperature and humidity levels (Figure 1). This may be very useful for handling, without pause, the physical conditions with which the workers may be confronted.


**Figure 1.** $CO_2$/oxygen/temperature and humidity monitor (source: http://www.airovita.com/).

Certainly, the lopsided oxygen and carbon dioxide levels can have a negative impact on personal health, ability to concentrate and make right decision, and overall safety [25,26]. $CO_2$ and oxygen levels should always be examined in all closed environments in which many people stay for a longer period of time; otherwise, it becomes a life threatening condition. The sensor outputs deal with diverse values for $CO_2$, oxygen, air temperature and air humidity levels. When the thresholds are triggered, an alarm sounds and/or other connected safety systems are alerted.

#### 2.2.2. Ionizing Radiation Sensor

This is considered the most important sensor and can be very beneficial in closed environments. Essentially, everybody is conscious of the high degree of risk related to atomic radiation. Ionizing radiation—like Gamma rays and both Alpha and Beta particles transmitted from radioactive material and nuclear reactions—may generate chemical or physical problems when it transmits energy to the human skin [27,28]. Therefore, an ionizing radiation sensor (IRS) can be a good solution to prevent this danger in the work environment. This sensor, depicted in Figure 2, offers the possibility to detect the diverse rays and particles with silicon PIN photodiodes either through straightforward immersion in the crystal lattice or through the quantification of luminescence radiation of a scintillation crystal.

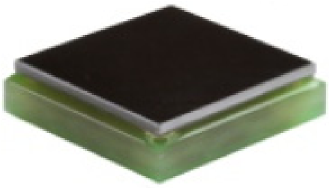


**Figure 2.** Ionizing radiation sensor (source: www.first-sensor.com).

In the IRS sensor, dark current signals and capacitance levels are very low and the fully depleted space-charge regions have minimal series resistance, which guarantees maximum absorption of radiation.

#### 2.2.3. Sound/Noise Level Sensors

Many workplaces need to measure and investigate sound and noise levels [29,30] in order to prevent any unexpected risk in the environment that can affect the natural workflow. This can be achieved by using an easily operated sensor called a Sound Level Sensor (SLS) (see Figure 3), which easily measures sound level, in decibels (dB), in a variety of given settings. No constraints are imposed on the use of SLS sensors; they react to sound loudness as the human ear reacts. They measure sound level to within 3 dB along a specific band from 55 to 110 dB; the frequency ranges from 30 Hz to 10 KHz. This sensor can be a beneficial tool for high schools or colleges to monitor classroom sound levels, detect resonation time, analyze sound insulation, and, thus, provide a good environment for education.


**Figure 3.** Sound/noise level sensor (source: www.vernier.com).

### 2.3. Indirect-Contact Sensors

The following category examines the sensors that target humans without any direct contact. This class of sensor has confirmed its role in the ubiquitous sensing domain and can play a vital role in the protection and well-being of people.

#### 2.3.1. Eye Motion Sensor

The sleepiness of the employees working in critical workplaces can cause grave risks. Infrared (IR) sensors can be an efficient tool to resolve this problem and increase the performance and security of workers in closed spaces. Recently, this technology has been investigated in References [31–34] to avoid unexpected vehicles accidents stemmed from lethargy, drugs, or any narcotic substances. The algorithm in Reference [31] describes the eye movement detection in detail.

In space, the position and orientation parameters identifying the user's eye must be computed. This data can only be extracted from the camera's image using a precise eye model that takes into account the complex eye form and motion features. In Reference [32], the authors studied the possibility of developing an eye model and integrating with eye-tracking systems. Its consistency depends on the precision of object recognition throughout the image processing, as shown in Figure 4. To obtain a consistent calculation of the model parameters, efficient algorithms were developed in References [35,36].

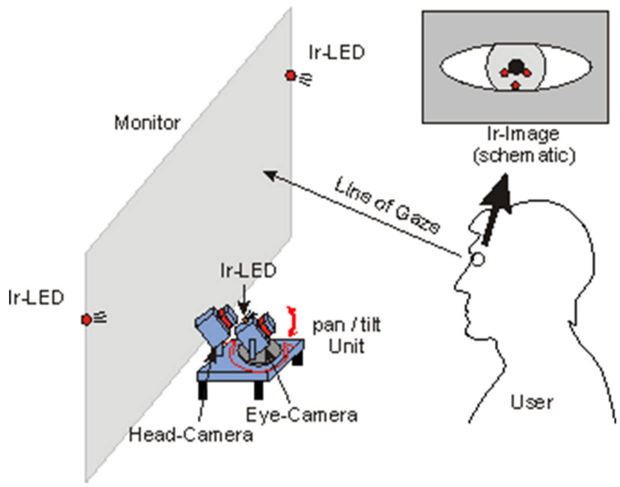



**Figure 4.** Eye-tracking system. (Source: http://www.kt.e-technik.tu-dortmund.de/cms/en/research/finished_projects/eye_tracking/).

Generally, an infrared sensor—a device composed of IR LEDs and IR photodiode—detects infrared radiation shed. It has a positive response in terms of relative sensibility [37] that sets it apart from other detectors such as UV sensitive, standard camera and human eye responsive (Figure 5). IR light is emitted into our eyes using the IR emitter and reflected rays are received from the eye through an infrared receiver [38], depicted in Figure 6. The receiver signal remains high for unmoving or unwinking eyes and diminishes in other scenarios. This is a straightforward way to determine the eye status so that the alarm may be activated if the signal becomes low.

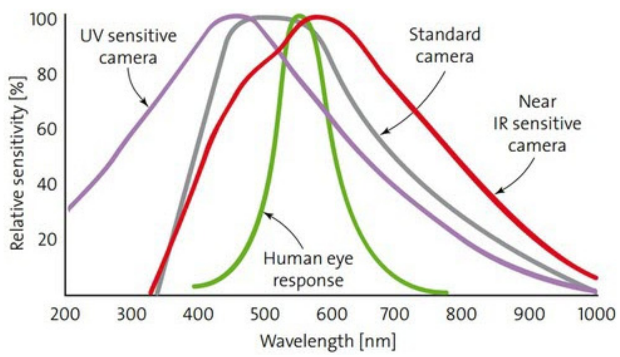



**Figure 5.** Comparison between a UV sensitive, standard camera, human eye responsive and near IR sensitive camera in terms of relative sensibility. (Source: https://www.stemmer-imaging.com/en/knowledge-base/spectral-response/).

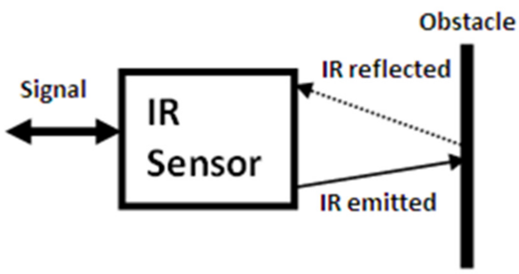



**Figure 6.** IR sensor working principle (adapted from Reference [38], with permission from the 2016 Research Trend).

To detect the number of eye blinking, the IR sensor must be positioned near the eye in the transmitter region. The microcontroller digitizes the received analog data from this sensor and decides whether the alert must be activated. This system can be configured and set up in closed workplaces requiring high levels of vigilance to protect employees from sleepiness.

### 2.3.2. Heartbeat Sensor

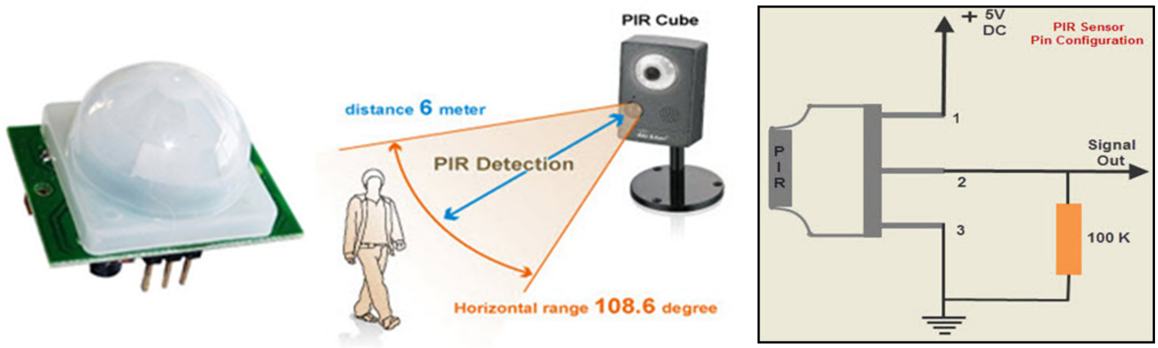
The proposed technology, a heartbeat sensor, is used to detect the pulses or heart beats of a person's heart. It is considered a powerful tool to monitor employee health. It can improve at astonishing rates the security of workers. The Kinect sensor, depicted in Figure 7, offers the possibility to distantly sense and monitor a human heart rate from approximately one meter away [39]. By identifying the blood speed, the camera, recognizing how fast the blood is pumping, can compute the beat rate of the heart.

**Figure 7.** Kinect Sensor (source: https://en.wikipedia.org/wiki/Kinect).

### 2.3.3. Body Temperature Sensor

Many infections and diseases can originate from severe variations in body temperature. Similarly, the pathway of some diseases can be controlled through the measuring of a person's temperature and by evaluating the efficacy of the treatment prescribed by the doctor. Measuring body temperature is considered a key feature of clinical research and medical studies. Recently, due to technological advancements, many studies have used various measurement approaches [40,41]. The signals received can characterize the process of continuous physiological control can anticipate and treat many cardiovascular, neurological and pulmonary problems in their infancy.

Therefore, measuring body temperature is considered of paramount medical importance and can be achieved by the IR temperature sensor shown in Figure 8a.




(**a**) (**b**) (**c**)

**Figure 8.** (**a**) PIR sensor; (**b**) working of PIR sensor; (**c**) PIR sensor circuit. (source: www.elprocus.com/pir-sensor-circuit-with-working/).

Indeed, it measures the average temperature of the area in the field of view (FOV), which changes according to the distance from the sensor to the target person. This sensor can be used over longer distances but the influence of atmospheric conditions like dust, humidity and noise can be important.

Evidently, IR waves are too small to be seen by the human eye. They are situated between visible light and microwaves, in terms of wavelength (λ), and characterized by the following:

Electromagnetic spectrum = [0.75 μm, 1000 μm]
Near IR if λ [0.75 μm, 3 μm]
Mid-IR if λ [3 μm, 6 μm]
Far-IR if λ > 6 μm

This sensor does not emit the mentioned IR signals itself. Rather, it passively detects the IR radiations hailing from the human bodies in the surrounding space (see Figure 8b). For that reason, it can be called a passive IR (PIR) sensor.

The PIR sensor band is up to 10 m at an angle of +15° or −15°. The detected radiation is transformed into electrical charges, which are proportional to the detected radiation level. These charges are enhanced using a field-effect transistor (FET) design and loaded to the output pin of the device, as depicted in Figure 8c. This is then applied to an external circuit for further triggering and amplification of the alarm stages.

The proposed sensor technology is characterized by a fast response, broad band, and large dynamic range, taking into account the atmospheric conditions. It offers the possibility to protect employees working in closed environments from any unexpected disease.

### *2.4. Direct-Contact Sensors*

Direct-Contact sensors work through direct contact with the human-body. These sensors are able to detect physical variables such as heat, strain, and pressure. We concentrate in this section on the direct-contact sensors that can be used in closed workplaces and which play a significant role in employee safety.

#### 2.4.1. Human-Motion Sensors

The human-motion sensor was introduced to detect the human movement and can play a crucial role in both safety and security purposes, mainly in closed workplaces. Recently, many scientific types of research have been presented based on this technology its applications [42,43]. Indeed, a novel approach identifying the daily motions of humans using wearable motion sensor systems is presented in Reference [43].

In Reference [42], the authors present a sensor-based architecture called SensX, permitting the monitoring and investigation of the multi-dimensional action steps. The working of this technology is described in Figure 9. IR can evidently be detected by this sensor although it cannot be seen by individuals due to the fact that infrared wavelengths are greater than those of visible light.

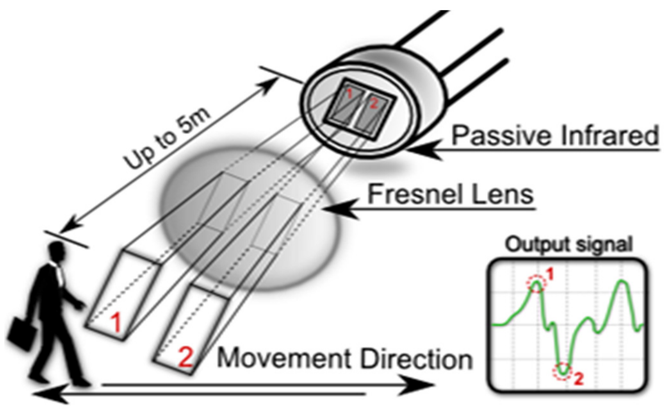



**Figure 9.** Motion detector operation. (source: http://www.blog.kslemb.com/).

In its field of detection, the motion sensor captures the variations in IR radiation coming from human temperature. Novel flexible and stretchable physical sensors (see Figure 10) offer the possibility to monitor human-activity and identify personal healthcare by detecting pressure, strain, and heat parameters [44,45]. This technology can be mixed with motion sensors to regularly collect all convenient data of the human body and subsequently enhance the quality of the obtained results.

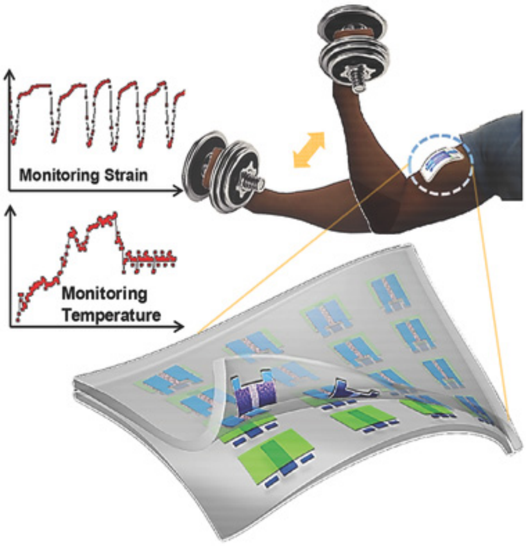



**Figure 10.** A transparent stretchable (TS) gated sensor array with high optical transparency (adapted from Reference [44] with permission from Wiley).

Therefore, it is very useful to install an efficient system based on motion sensors in closed environments so as to control the psychological and/or physiological status of employees throughout the human actions analysis.

2.4.2. Smart-Health Sensors

Generally speaking, this class of sensor is flexible and attached directly to the human body without any loss of movement freedom. The smart health sensor focuses on the sweat secreted by the skin to measure metabolite and electrolyte levels in the sweat [9,46,47]. More precisely, these measures mainly concern skin temperature, in addition to the glucose, lactate, sodium, and potassium in sweat. The resulting measures are analyzed and sent wirelessly to a phone or other type of device (see Figure 11). These data can be monitored by a supervisor. An alert can be triggered if the gathered data indicate health issues like high temperature, dehydration and general fatigue.


**Figure 11.** The smart wristband sensor (source: https://www.yanliudesign.com/readmood). This sensor is particularly distinguished by its accurate output, which could be helpful in calibrating similar outputs from different sensor technologies.

### 2.4.3. Fingerprint Sensors

Fingerprint sensors were popularized and adopted for smartphones as well as companies [48–51]. This sensor, depicted in Figure 12, recognizes the fingerprint of an employee and sends information to the supervisor, such as the action time. In order to ensure the security of a specific closed area, such as guards control rooms, it is possible to frequently request a fingerprint validation to make sure that the employees are in a suitable state to fulfill their task and are neither sleepy nor outside their offices.

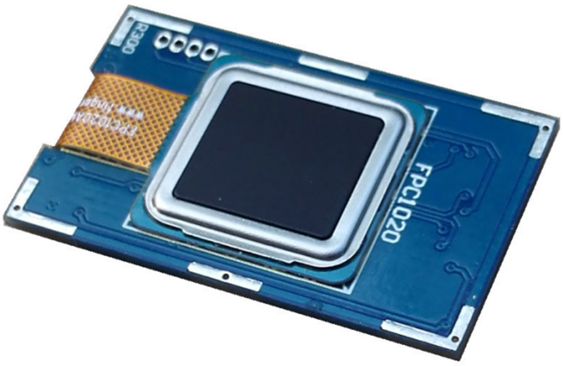



**Figure 12.** Fingerprint sensor (source: https://www.fingerprints.com).

## 3. Efficient Solution in Cloud-Based Resources

### *3.1. Mapping Requirements with Adopted Multi-Sensor Approach*

In this section, we try to match the requirements identified in Section 2.1, the adopted multi-sensor solution. Seeking to take advantage of the adoption of multi-sensor technology, it is important that sensors align with the requirements mentioned earlier.

Table 1 summarizes the high levels of requirements relating to environmental sensors. These sensors should be placed in a fixed location throughout their lifetime. Generally speaking, environmental sensors are concerned with checking if the working environment is safe for the employees. It is possible to use the output of these sensors in more general studies aiming to correlate environment values with employee performance and health.

**Table 1.** High level requirements for environmental sensors.

| Sensors Requirements | Environmental Sensors | | | | | |
|---|---|---|---|---|---|---|
| | Air Sensor | | | | Ionizing Radiation Sensor | Sound/Noise Level Sensor |
| | $CO_2$ | Oxygen | Temperature | Air Humidity | | |
| Sensitivity | 2% | 2% | 1 °C | 2.5% | 0.8–20 CPS/nv | 48–66 dB |
| Precision | 2% | 2% | 1 °C | 2.5% | 1% | 10 dB |
| Resolution | 1% | 1% | 0.5 °C | 2.5% | 1% | 10 dB |
| Accuracy | 1% | 1% | 0.5 °C | ±2.5% from 10–90% RH | 1% | 10 dB |
| Range | 0–10,000 ppm | 0–10,000 ppm | −20 °C–60 °C | 0–100% RH −40°–70 °C | 0–2 msv/h | 50 Hz–20 KHz |
| Response time | 20 s | 20 s | 10 s | 5 min | 1 s | 1 s |
| Sampling frequency | 5 $10^{-2}$ Hz | 5 $10^{-2}$ Hz | 0.1 Hz | 3 $10^{-3}$ Hz | 1 Hz | 1 Hz |
| Tolerated physical environment quantities | 0–10,000 ppm | 0–10,000 ppm | −40 °C–90 °C | 0–100% RH −40°–70 °C | 0–200 msv/h | Impedance: 50 Hz–20 KHz operating temperature 40 °C–85 °C |
| Lifetime and maintainability | 1 year | 1 year | 1 year | 1 year | 1 year | 1 year |
| Communication medium | Visual; Ethernet; Wi-Fi | Visual; Ethernet; Wi-Fi | Visual; Ethernet; Wi-Fi | Visual; Ethernet; Wi-Fi | Visual; Ethernet; Wi-Fi | Visual; Ethernet; Wi-Fi |
| Interoperability | important | important | important | important | important | important |

Thus, there is no need for high accuracy and precision as long as general information is provided. For example, it is suitable that the temperature indicator (as part of the air sensor) be around precisely 1 °C, whereas interoperability is highly recommended as long as the air sensor is part of a more global system.

Similarly, the indirect-contact sensors mentioned in Table 2 are investigated with the same philosophy. However, the body temperature sensor tackles body temperature and informs if the employee's physical condition does not remain safe. Thus, higher precision and resolution is required compared to that of the temperature air sensor.

**Table 2.** High level requirements for indirect-contact sensors.

| Sensors Requirements | Indirect-Contact Sensors | | |
|---|---|---|---|
| | **Eye Motion Sensor** | **Heartbeat Sensor** | **Body Temperature Sensor** |
| Sensitivity | 71% and 88% for detecting ≥3 lapses (PVT) in a minute and 100% and 86% for ≥5 lapses | 3 BPM | 0.2 °C |
| Precision | | 3 BPM | 0.2 °C |
| Resolution | | 3 BPM | 0.2 °C |
| Accuracy | | 3 BPM | 0.2 °C |
| Range | 360 degree detection, covering up to 7 m from unit | 0–200 BPM | 20 °C–50 °C |
| Response time | 0.5 s | 5 s | 2 s |
| Sampling frequency | 2 Hz | 0.2 Hz | 0.5 Hz |
| Tolerated physical environment quantities | Work in low lightening | 0–200 BPM | 10 °C–60 °C |
| Lifetime and maintainability | 1 year | 1 year | 1 week |
| Communication medium | Ethernet, Wi-Fi | Visual, Wi-Fi, Bluetooth | Wi-Fi, Bluetooth |
| Interoperability | Important | Important | Important |

Speaking of direct-contact sensors (Table 3), it is important that these sensors be in line with daily human use. The sensitivity and precision of the fingerprint sensor should distinguish fingerprints with no ambiguity. The response time is not a principle issue in this case, and we can tolerate slow equipment as long as interoperability is guaranteed.

**Table 3.** High level requirements for direct-contact sensors.

| Sensors Requirements | Direct-Contact Sensors | | |
|---|---|---|---|
| | **Human-Motion Sensor** | **Smart-Health Sensor** | **Fingerprint Sensor** |
| Sensitivity | High | High | 508 ppi |
| Precision | | | 508 ppi |
| Resolution | | | 508 ppi |
| Accuracy | | | 508 ppi |
| Range | Up to 7 m away | N.A | N.A |
| Response time | 1 s | 10 s | 1 s |
| Sampling frequency | 1 Hz | 0.1 Hz | 1 Hz |
| Tolerated physical environment quantities | Tolerance to sweat, muscle contact ... | N.A | N.A |
| Lifetime and maintainability | 1 weak | 1 year | 1 year |
| Communication medium | Wi-Fi, Bluetooth | Wi-Fi, Bluetooth | Ethernet, Wi-Fi |
| Interoperability | Highly recommended | Highly recommended | Highly recommended |

Meeting the aforementioned requirements is important for proposing a comprehensive solution so that these sensor data collaborate as a team. This is the object of the following section.

### 3.2. Analysis and Combined Results in Cloud-Based Resources

The use of each piece of technology mentioned above can be very beneficial separately but combining these technologies can strengthen and enhance the security and safety of individuals as well as workflow. The collected information may improve employee performance. This can be achieved by analyzing the biometric data, captured in the different contexts, which will then be combined with the environmental sensor output to create an efficient library for further investigation.

The sensors can be partitioned into two categories, basically, analogue and digital. As depicted in Figure 13, analogue sensors communicate with an amplifier that captures the received signal data and sends them back to an analogue/digital converter (ADC). This ADC forwards the data to a microcontroller unifying the monitoring to one single interface. It is possible to calibrate and set these sensors by a direct control interface (a Level 0 control). A more advanced software control version can be deployed within the microcontroller (a Level 1 control). The microcontroller communicates the information to a PC which is responsible for gathering all sensor (digital as well as analogue) feedback. A Level 2 control can also be implemented in this machine. In order to guarantee the safety and portability of all collected data, it is important to use cloud data storage as a repository for all necessary information. Communication with the cloud data center can be ensured throughout the multi-class of light clients over different and heterogeneous platforms, including the Level 3 control.

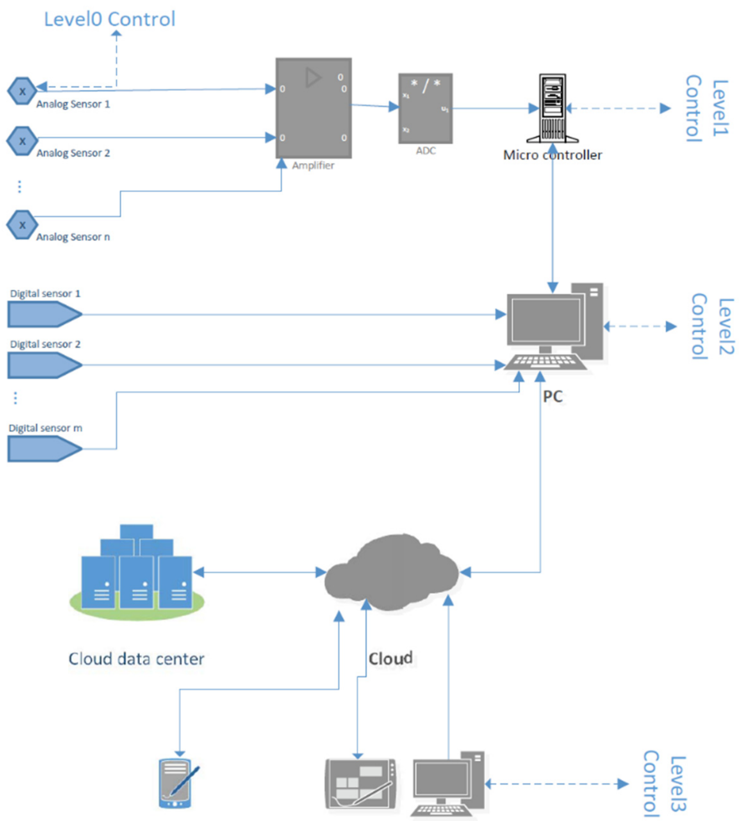



**Figure 13.** Proposed architecture system based on multi-sensor technology.

Using the cloud data center as a repository is beneficial in many ways. Firstly, it guarantees both the safety and reliability of the data. Secondly, it makes it possible to perform intensive computation that aims to generate statistics based on multi-sensory results since our solutions are deployed in highly performant infrastructure (IaaS). Furthermore, the sensor results may be coupled with many geographically distant closed areas belonging to the same company. This helps to benchmark comparison studies and improve any detected deficiency or weakness in terms of time response, public health care, workflow performance, and control processes. To this end, the adoption of multi-sensor technologies with cloud-based storage is a flexible solution that can be convenient to any specific context without becoming generic.

This approach is beneficial in many ways:

- The proposed system based on multi-sensor technology offers the possibility to calibrate inaccurate sensors. This can ensure good correlation between various groups of sensors. For instance, a sweat sensor detecting human temperature by direct contact can be more accurate than an IR temperature sensor and, then, the obtained data can be precisely calibrated in a suitable manner.
- Obviously, it is highly recommended to take into consideration the health status of workers in closed areas. Such environments can disturb, at astounding rate, the health of individuals. Combining both environmental and human-body sensors reduces this issue by informing the supervisor of all pertinent data, which could prevent many catastrophic scenarios.
- The performance of workers can be improved when their physiological data in different circumstances are known. Many further studies can be performed on the correlation between physiological and environmental data associated with the productivity of employees.
- The results obtained from the combined sensors present a positive effect on global security. Once all workers know they are tracked by a multitude of sensors, it will influence their behaviors and performance to fit with their job requirements. Besides, any misbehavior will be captured by supervisors and will trigger an adequate reaction. Additionally, any abnormal results captured by the multiple sensors will be discovered immediately by supervisors who are then able to react appropriately.
- The described approach is considered flexible, interoperable, and able to tolerate many configuration points. This means that this solution could be applied to a variety of systems having their own specifications and details. The adoption of cloud-based resources makes the data availability independent of any specific platform or architecture.
- To realize a failsafe connection with minimum effort, transportation of the semantic context of the collated data to the cloud, such as data type, identifier, and the location in the object model, is guaranteed by the actual communication architecture.
- This approach is presented as a high level framework. However, the concept of the solution is open to various types of communication medium, database structures, etc. For instance, communication could be implemented with, but not limited to, soap web services. The data format could be a hierarchical data format (HDF), network common data format (netCDF), or any other proprietary format [52].
- Many statistical studies can be performed based on the raw sensor data. It is possible to use the cloud data center to deploy statistic modules.

## 4. Conclusions

The importance of sensor technology in different application domains as well as its impacts on individuals and society was presented in this work. The identified sensors pertaining to environmental, direct and non-direct contact such as smart health sensors, air sensors and heartbeat sensors were successfully presented and investigated in the context of employee safety and security in closed workplaces. An efficient approach based on a combination of proposed multi-sensor and cloud-based services was presented to give a higher degree of security to employees and workflow. This system can also be very useful in criminal investigations. Sensors related to more specific environments can be integrated into our system to enhance the security level, such as radioactivity sensors, light spectrum sensors, vibration sensors, pollution sensors, etc. The sensor calibration introduced in our system can open a good workspace for investigating solutions using deep learning techniques. The introduction of recent algorithms implemented with MDF such as standard fusion algorithms [53], wavelet-based methods [54], and artificial neural networks [55] can strength our developed approach in terms of accuracy and the potential to resolve many challenging problems.

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