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Monitoring Environmental Conditions in Airports with Wireless Sensor Networks †

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Abstract: In recent decades, the environment has suffered the negative consequences of industrial development and overexploitation, and the effect of growing population. There are many areas and sectors where actions can be taken to minimize negative environmental impacts. Despite the current technological advances in society, there is a pending debt to nature, environment and care of air quality. This paper presents a system based on Wireless Sensor Networks, whose objective is to monitor environmental conditions in airport environments. Since the proposed system allows managing notifications and alerts when dangerous conditions are detected, it can also be considered a procedure to protect critical infrastructures in general. Due to the importance of security requirements in these facilities, the system includes several cryptographic measures to provide robust authentication and encryption of information.

Keywords: environment; airports; WSN; security

1. Introduction

This paper proposes the use of a wireless sensor network to monitor environmental variables in real time that may affect human health. Air pollution poses a major environmental risk to human health. The focus problem is the presence of pollution in potentially harmful levels. The combination of different atmospheric conditions and the presence of polluting gases can deteriorate the air quality in the monitored area.

Airports are one of the greatest air pollution sources in any city in the world, mainly due to the combustion in vehicles and equipment engines. In addition, there is an accumulation of different types of transport vehicles, such as vehicles, taxis, trucks and passenger cars circulating around the airport terminals; and fuel-intensive internal airport vehicles, repair and maintenance workshops, forklifts, substations, workshops equipment, etc., which further increase air pollution and decrement the air quality at airports. Thus, emissions of transport air pollutants that damage our health must be reduced without delay in airports so that these sites are emission-free and its air quality is appropriate for airport users and people moving around airports.

In this work, an Arduino-based system is proposed to measure and control through a wireless sensor network with integrated sensors different environmental variables such as carbon dioxide (CO_2), carbon monoxide (CO), temperature, oxygen, and humidity. These data are processed to produce alerts whenever necessary and can be accessed using smartphones through a web service and an Android mobile application.

One of the main aspects regarding the implementation of the proposed solution that have been analyzed in this work is security. In the proposal, sensors are connected to the platform through commonly used networks, such as the Internet, Wi-Fi or Bluetooth, so there are many possible attacks such as interception, eavesdropping, injection, alteration, retransmission and illegal access/dissemination. Therefore, different security mechanisms have been implemented to prevent such threats.

This work is structured as follows. Section 2 describes some related works. The proposed system is defined in Section 3. Section 4 describes alerts management. Section 5 presents some details of the security protocols used in the proposal. Finally, some conclusions and open questions close this work.

2. Related Works

The review [1] summarizes the state-of-the-art research on aircraft and airport emissions in 2014. Specific analyses of airport pollution problems are presented in the works [2,3], where the conclusion of the latter is that in general there are no measured controls in airports, although airport pollution can contribute to 40% of permissible EU levels.

Different systems to monitor gases, such as Carbon Monoxide or Carbon Dioxide have been presented in several works [4–6]. In particular, the first one of those papers used an Arduino micro-controller system to monitor greenhouse gases and visualize the results in real time through a web-based application. Another research for habitat monitoring is [7], where a wireless sensor network system is described using a weather board.

Several authors have taken security into account in related researches. The work [8] outlines many security issues in sensor networks. For instance, other work proposes a system that collects some environmental information such as temperature, humidity, carbon monoxide and carbon dioxide from sensor nodes, and transmit them protecting confidentiality and integrity through IEEE802.15.4 [9]. The proposal for wireless sensor networks [10] related to this paper includes the use of both symmetric and asymmetric cryptosystems to protect confidentiality, data integrity, availability, authenticity and privacy. In particular, the system uses a combination of symmetric (AES 256-bit), asymmetric (RSA 1024-bit) and hash function (SHA 256-bit) cryptographic algorithms.

In several works, WSN (Wireless Sensor Network) implementations have been established for CO_2 monitoring in different urban areas [11,12]. In this last work, distributed clustering was implemented to improve the performance of the network during data mining.

The authors of the work [13] implemented a geo-sensor network that monitors air pollution and takes measures to prevent pollution, warning the building administrator to close the windows when there is a potential contamination hazard from outside.

Differently from all above papers, the proposal here presented includes an Arduino-based system to control airport emissions, which includes some cryptographic protocols to protect the security of information. Air quality monitoring is an important technical problem for which proposed sensor networks can provide a solution. The proposed system therefore generates a series of alerts for airport staff. This system will allow them to control air quality in different areas of the airport, take different solutions if there are changes in the levels of pollution both outside and inside (movement of people, ventilation, etc.) as well as generate graphs of the state in different periods of time and spaces.

3. Proposed System

The aim of this work is to monitor air quality and to establish environmental control inside and outside airport terminals by using Internet of Things (IoT) devices. In order to achieve such a goal, a sensor network distributed through airport terminals and outdoors has been deployed. On the one hand, the chosen sensors ensure a high calibration accuracy to measure the required information. On the other hand, the chosen IoT devices have a high technical quality that makes it possible to get real-time information from any of them.

The proposed system (see Figure 1) allows monitoring different environment variables (such as humidity, temperature, carbon dioxide, etc.). Taking into account this application prototype, airport staff will be able to know in real time whether the environmental conditions of the entire airport terminal are the most appropriate for the health of users. The system has been specially designed for airport staff as it provides information on variations in air quality measurements inside and outside airports to ensure the comfort and healthy level of the facilities, and the safety of airport passengers and workers.

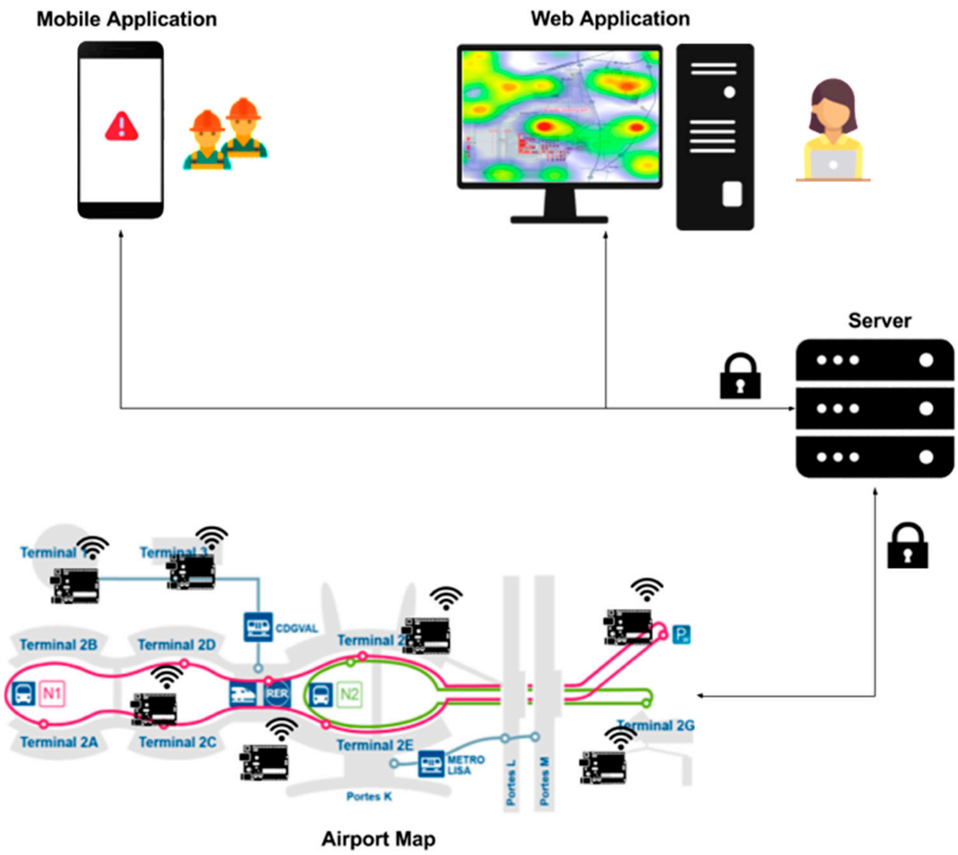

Figure 1. Proposal.

Ambient information is shown in real time on the platform, which is a software tool that integrates through a web service and a mobile application the visualization of data obtained from sensors and IoT devices. The use of the different sensors included in the system, the functionalities of the web service and the developed mobile application are explained in more detail below.

3.1. Sensors

IoT devices are distributed throughout the environment, both inside and outside airport terminals. Each device has several integrated sensors that measure the values of temperature, oxygen, humidity, carbon monoxide and dioxide. Specific measurement variables depend on the monitored zone and other factors. The IoT devices are based on an Arduino-based system platform, which is used to integrate the information obtained from the sensors, with an interface to show the environmental variables. The system also encrypts the information before transmitting it to the server through a Wi-Fi module connected to the airport computer systems, and the access to such information is protected thanks to a strong authentication protocol.

First of all, all the components of the IoT device are assembled before switching on process: four main sensors (one of them for measuring the temperature and humidity, other for oxygen concentration, other for carbon dioxide and the last sensor for carbon monoxide), Wi-Fi module and the motherboard, finally. It also includes a GPS service allows of accessing the location of IoT device. On the other hand, the Wi-Fi module allows Wi-Fi-Direct communications among IoT nodes. Taking into account the first sensor, temperature measurements can be registered operational ranges between −40° until 85 Celsius degrees (°C) and humidity values from 0% to 100% with an accuracy around 3%. Regarding oxygen (O_2) sensor, the measurement range is situated from 0 to 30%. With regard to polluting gases such as carbon dioxide (CO_2) and carbon monoxide (CO), the sensors are able to register measurements until 10,000 ppm and 1000 ppm, respectively.

Every time IoT devices and sensors interact with the ambient a measurement of temperature, air humidity, oxygen, carbon dioxide and monoxide are registered. Once all ambient data is available, before the cloud transmission process through Wi-Fi module, the information is encrypted in order to ensure its confidentiality and integrity. After this step, the device waits for a response message that is sent from the web service after the new ambient measurements reach to it correctly. Finally, the IoT device starts measurement cycle over again.

3.2. Web Service

Once the IoT devices have collected the required data, the information is sent to the web service that is responsible for the data analysis and the administration of the database of the entire information system. The main objective of the web service is to display the current state of air gases conditions and other parameters and to manage the alert to prevent possible health risks. This system is mainly composed of a web application and a server.

The web application (see Figure 2) included in the system is in charge of showing the collected ambient information and activating alerts in order to notify mobile application users (airport staff). The system shows a map of the airport terminal, including location of IoT devices, hazardous areas where sensitive material is stored, number of people in common user areas, heat map showing the level of air quality around the airport terminals and indication of the most polluted areas. All this ambient information is displayed in real time in the web application through different interactive elements, updated every time new measurements are taken and sent from IoT devices and sensors.

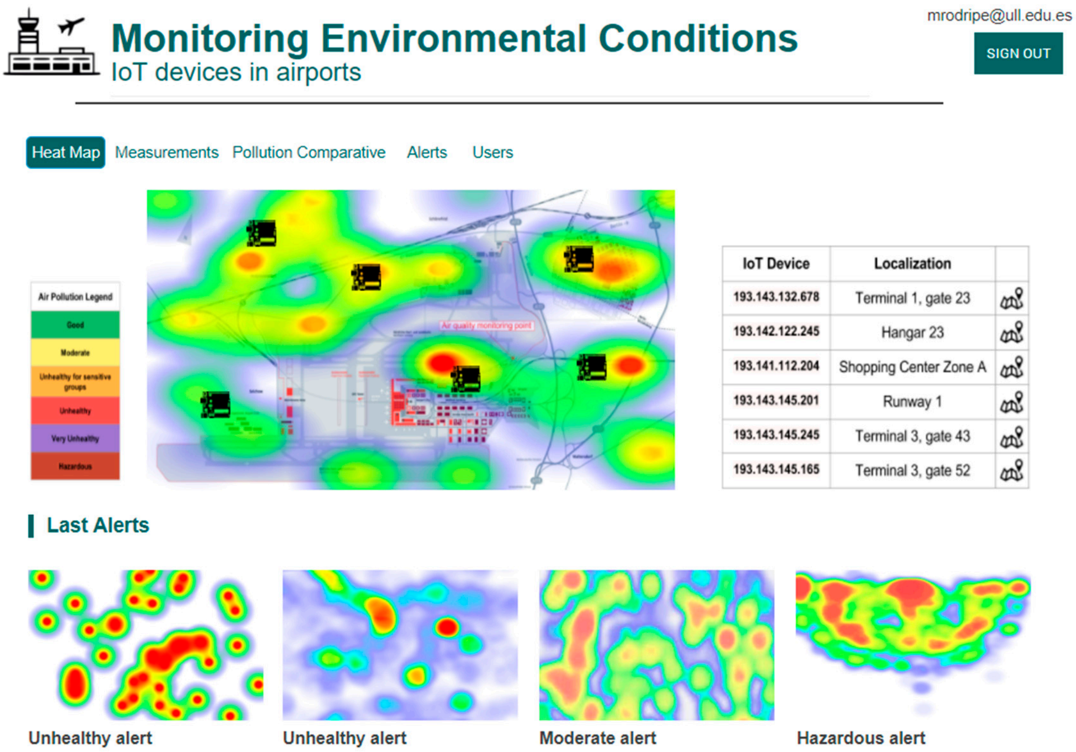

Figure 2. Web Application.

Different charts are used to represent the collected data. The main chart type is a heat map that represents the air quality of each zone through an Air Quality Levels (see Figure 3). The air quality values of each area are represented by different colors in a heat map and the environment measurements in a linear chart. The combination of both factors is useful to determine the level of possible alerts.

In addition, multiples charts are used to show each pollutant gas and a comparison of gases variables. Every graph shows the evolution of the different measurements that have been registered by each different sensor over the time. In particular, there is a relevant chart that includes different comparisons among the different air pollution gases and other ambient variables registered by the IoT devices and sensors. Linear graphs have been used to represent all the environment measurements of each monitored variable (temperature, air humidity, carbon dioxide and carbon monoxide). These interactive elements are composed of dotted lines in charge of displaying every value of all measurements registered by the IoT devices and sensors. In addition to this, it is possible to group these ambient measures taking into account different time periods (days, minutes, months, etc.). Application user (airport staff) can also filter by specifying a start and end date in order to make a specific measurements group. In this way, it is possible to carry out a comparative study and assessment of air quality at airports.

Air Pollution Level	Health Implications
Good	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	Air quality is acceptable. However, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for sensitive groups	Member of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	Everyone may begin to experience health effects. Members of sensitive groups may experience more serious health effects.
Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.
Hazardous	Health alert, everyone may experience more serious health effects

Figure 3. Air Quality Levels.

The Firebase platform has been used to update the data in real time (through Real-Time Database), which allows the synchronization process of all the changes of the environment variables. Then, the information is synchronized automatically and immediately for all users. In addition, this system allows generating notifications from the web service to the mobile application. Every mobile device should be authenticated through a specific token that is generated specially for sending notifications to the authenticated user.

3.3. Mobile Application

An Android mobile application is used as a fundamental part of the proposed system to represent the locations of IoT devices, and measurements and averages for each variable monitored through graphics that the users could easily interpret. In addition, this application is responsible for synchronizing notifications and alerts that have been sent from the server. In fact, one of the most important elements is the alert control panel, which is used to represent all notifications and alerts activated from the server when a measurement involves a danger to the health of airport users. Each alert notification received informs about the exact area associated with the hazard, the variable (s) that have determined the alert, and a description to identify exactly what danger it implies (see Figure 4).

The developed system includes an alarm management component that is updated every time a new measurement arrives at the server. To this end, the system checks whether the value associated with each monitored variable (CO_2, CO, temperature, humidity, etc.) represents a potential danger to the health of users who are nearby. For this reason, some limits and reference intervals are used for each variable so that each time a new measurement is received, it is checked whether it exceeds these thresholds to determine if an alert is activated.

After the server has verified whether an alert has been detected, the next step is to register it in the system and transmit the new data in real time to all connected application users (airport staff) through notifications in the mobile application and/or to update the information in the panels included in the web application. The creation of a new alert implies the declaration of some attributes, such as the alert level, the involved IoT devices, the values of the variables that have activated the alert, a description and the activation date of the alert.

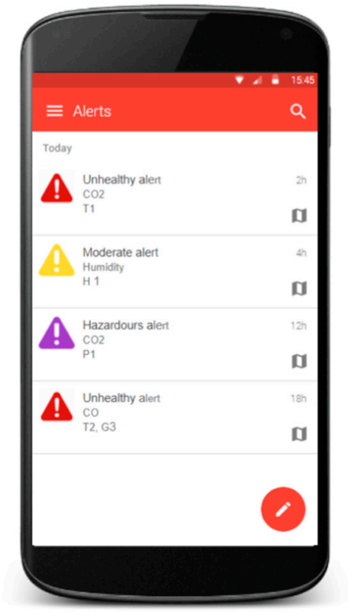

Figure 4. Mobile Application.

In addition to receiving alerts from the Web service, airport staff can access the measurements registered by every IoT device through tables of ambient data disposed on the mobile application interface. The information is managed in real time through Firebase platform that notifies the mobile application when new ambient measurements have been stored in the Firebase database; so ambient information is always updated. In this sense, users can select any IoT device and access to their registered measurements, in addition to analyze in real time the new ambient variations.

4. Alerts Management

Every time some of the registered measurements by the IoT devices and sensors are out of the permitted range, the system generates an alert in order to prevent and detect the presence of high levels of polluted air in a certain zone. In this sense, the alert system has got as main purpose to manage alerts that will be activated depending on the air quality and other ambient variables that could favour the appearance of health risks among airport passengers or workers, such as temperature or air humidity.

In terms of behavior after an alert, airport staff must comply with a protocol for action in situations of high atmospheric pollution. Inside the airport it is possible to take restriction measures by ventilating the different zones, generating air movement or enabling new zones for the movement of airport users. Depending on the city in which an airport is located, it must comply with the external protocol established by the relevant entities. Based on the level contamination, an action protocol is initiated when the alert threshold exceeds the permitted legal limit and affects human health.

One of the most important elements for this work is the measurement of air pollutant gases, such as CO_2 and CO (measured in ppm or parts per million). These chemicals can cause serious health problems for people, and therefore an excessive increase in their concentrations are relevant factors when considering the activation of an alert. Carbon monoxide is fixed in the hemoglobin of blood and stops oxygen transport, so it can cause death in people when its value is too high. The limit value considered in a period of 8 h is around 10 ppm [14], so this is the reference to activate an alert in this regard. With respect to CO_2, the activation of an alert has been set at 350 ppm, taking into account the results that establish this value as the limit to be considered to avoid harm to health [15]. However, CO concentrations above 100 or 200 ppm can involve serious headaches, nauseas, mental symptoms, vomiting or very harmful health risks such as going into coma or death when people is exposed to extreme CO levels above 1100 ppm.

On the other hand, the alerts controller is also configured to be activated depending on the measurements of temperature and air humidity. Regarding the first ambient variable, the most comfortable values for the human health are situated around 18–20 °C (in a resting state). Taking into account the air humidity as the other important monitored ambient variable, the most comfortable measurement values are situated between 50% and 60%, although air humidity percentages between 40% and 70% are considered as normal, acceptable and not unhealthy for the human people. Air humidity is directly related to the thermal sensation and the temperature. Extreme air humidity measurements (both close to 100% and 0%) can cause serious problems in the health of people such as dry skin problems, itching of the eyes and the irritation of the respiratory tract or mucous membranes.

5. Security

A study and analysis of the necessary security to be applied to the information used are carried out. The proposed system includes a security layer to protect the confidentiality and integrity of the transmitted data, and the authenticity of the users.

Point-to-point encryption is used to make sure that unauthorized users cannot access any transmitted information. Thus, after a new measurement is obtained with the sensors, such a value is encrypted using the standard symmetric AES 256-bit key algorithm [16]. To allow it, a pre-shared-key is distributed in advance to all IoT devices when the system is set up for the first time. This key distribution process is done after the activation of the IoT device and before the first data measurement. The encryption process with AES algorithm is executed under the Cipher Block Chaining (CBC) mode in order to increase efficiency of communications. CBC mode involves that each block of plaintext is XORed with the previous ciphertext block before being encrypted so that each encrypted block depends on all plaintext blocks processed up to that point. When encrypted data reach the server, they are decrypted using the same algorithm.

Secure communication through HyperText Transfer Protocol Secure (HTTPS) and Secure Sockets Layer (SSL) connections is also included in the system to protect data in external networks such as the Internet. In particular, the SSL encryption has been introduced using OpenSSL. This protocol allows the encrypted exchange of information in form of requests and responses between a client and a server.

The requirement of data integrity ensures that it is not possible to alter the original data obtained and sent by sensors because it guarantees that received data are kept during their transmission exactly as they were originality sent. To protect the integrity of transmitted data, in the proposal the Secure Hash Algorithm 3 (SHA-3) was used. SHA-3 is the latest member of the Secure Hash Algorithm family of standards. Encrypted data are transmitted together with SHA-3 digest so that receiving users can verify the received data digest, and if the verification is valid, their interpretation is that no alteration has happened during transmission.

Strong authentication of users has been developed both on the web and mobile applications. Identification tokens are used so that the server can identify each mobile device whenever it is necessary to notify and synchronize a new alert so that only mobile devices associated with the location of the received alert receive a notification.

Furthermore, in order to guarantee user authentication, the security guidelines set out in the Open Web Application Security Project (OWASP) [17] have been followed. OWASP is a guide to rules and good practices that can be used to improve software security in web applications. Many security rules set out in OWASP have been taken into account in this work in order to protect the web system that is in charge of displaying the environmental data registered by IoT devices and sensors in real time. Some of the most relevant security guidelines integrated in the system are:

- the use of HTTPS requests and user authentication tokens configured through an encrypted signature available on the server
- the execution of all authentication mechanisms on the server (and never in the client)
- the application of encryption routines to guarantee that user passwords are strong enough
- the encryption of all used API keys
- the registration of any security bug in the system for possible future security audits.

6. Conclusions

Airports are one of the biggest sources of air pollution in any city in the world. This paper presents an Arduino-based system that takes advantage of IoT deployment to monitor and control environmental conditions in airport environments. The proposed system, composed of a web service and a mobile application, allows managing notifications and alerts when dangerous conditions are detected. Due to the importance of security requirements in these critical infrastructures, the proposal includes several cryptographic measures to provide encryption of information and robust authentication. In particular, the proposal includes a security layer to protect the confidentiality and integrity of transmitted data through point-to-point AES encryption and the SHA-3 hash function, and the strong authenticity of users based on identification tokens.

This proposal is part of a work in progress, so there are several lines of work still open. First, we will try to add new sensors in the system to control more environmental variables. Besides, interaction with emergency teams will be added to gather more data, such as multimedia information in real time. Moreover, a mechanism to control the number of people in different areas of the airport is proposed to be implemented. To this respect, it is possible to design a feedback procedure aiming at improving the system aforementioned presented.

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