Distributed Sensor Network for Noise Monitoring in Industrial Environment with Raspberry Pi

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***Abstract*— Monitoring the noise in working places is essential to protect the health of workers. There are two main factors that must be taken into account, and thus controlled, when considering noise exposition during the working hours: the level of perceived noise and the time exposed to that level of noise. In industrial environments, these two factors represent a high priority due to the quantity of equipment inside the factory. In this paper, we present a low cost system to measure and monitor noise conditions in an industrial environment. The proposed solution is based on ad hoc wireless probes and a server in the cloud, which acts as a centralized data sink. Specifically, the probes are based on Raspberry Pi 3, while the server may be placed anywhere on the Internet. The proposed system helps to detect critical levels of noise for workers, sending warning messages to predefined contacts by means of a text message or email when hazardous situations occur.**

Keywords- Wireless Acoustic Sensor Network (WASN); Raspberry Pi 3; Industrial environment; Monitoring; Ad hoc networks.

I. INTRODUCTION

According to the findings of the World Health Organization (WHO), noise is the second largest environmental cause of health problems, just after the impact of air quality (particulate matter) [1].

Different regulations about noise monitoring in working environments have appeared along the years. Among them, apart from the aforementioned [1], from the World Health Organization / Europe, we highlight [2], which was published by the International Labour Organization (ILO) in 1977.

Particularly, noise exposure is higher in industrial working environments due to ambient noise produced by machines. Possible side effects resulting from high noise exposure are due to both the amount of sound energy received and the duration of exposure.

In this scenario, the levels and durations of the supported noise are difficult to predict because of the inherent characteristics of audio waves. Therefore, monitoring the real exposure to noise is very helpful to prevent negative health effects and to improve working conditions.

In this sense, usually sound level meters are used to analyze workplaces exposure to noise. However, the measures collected by these devices are not in real time, but they are taken at certain intervals of time instead. In this paper, we propose the use of a low-cost Wireless Sensor Network (WSN) in order to continually monitor workplaces and, therefore, obtain a better picture of the noise exposure of workers.

In the literature we can find several proposals about WSN. For instance, [3] presents a WSN for industrial environments and proposes different strategies to improve the link quality. Unlike [3], our solution is based on Raspberry Pi. In this sense, [4] presents an industrial application using Raspberry Pi in order to carry out the maintenance of a machine. Another use case for acoustic WSN with Raspberry Pi, apart from industrial environments, is the monitoring of noise in smart cities, as proposed in [5].

The rest of the paper is structured as follows. Section 2 presents the system architecture, which is composed of three main blocks: sensor network, cloud and user interface. Section 3 explains the experimental results obtained. Finally, Section 4 presents the conclusions and the future work.

II. SYSTEM ARCHITECTURE

An example of the proposed system can be observed in Figure 1. As the figure depicts, there are three main elements in the architecture: the WSN system installed in the factory; the cloud; and the user interface, used to monitor the state of the network.

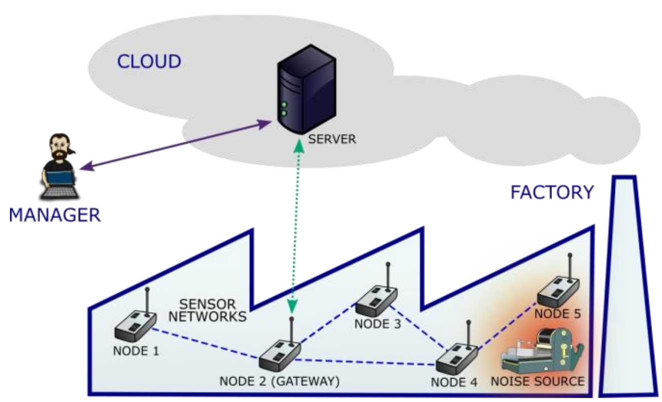

Figure 1. Example of the proposed system architecture.

The figure shows a distributed sensor network composed of five nodes creating an ad hoc Wi-Fi network. As the figure depicts, there is a main node (in the example, the node

2), which acts as a gateway. That is, the main node is in charge of communicating with the rest of nodes and with the server located in the cloud. To that extent, the main node has Internet connection (for instance, direct connection with the local area network of the building or by means of a 3G/4G connection). In an ad hoc network, each node is part of the routing by forwarding data to other nodes until finding the main node (the gateway), which will upload the data to the server. In this way, each node performs functions of router and host.

On the other hand, the manager of the system will access the server located in the cloud to get the information provided by the sensor network. The manager will consult this information by means of a web user interface and will be able to change the audio recording configuration of the nodes.

The following sections present the main details of each one of the three blocks that compose the system proposed.

A. Overview of the sensor network

The sensor network is in charge of continuously monitoring the noise levels and generating alerts when the measured noise levels exceed a certain limit. In the example shown in Figure 1, the noise source generates a critical noise that is detected by node 5. This node sends the information of the sound pressure level, which is routed by the ad hoc network until the main node (node 2). The gateway sends this information to the server. In addition, the server can generate an alert by means of a text message or email.

As previously explained, the sensor system is an ad hoc network, which uses Optimized Link State Routing (OLSR) as a routing protocol. OLSR, defined in RFC 3626 [6] and updated in RFC 7181 [7], is a proactive link-state protocol. OLSR uses an optimized system to broadcast routing control and TC (Topology Control) messages by means of special nodes called MPRs (Multipoint Relays). The MPRs selection is carried out through metrics of willingness, connectivity and symmetry of the links with the neighbor nodes.

The main advantages of this kind of deployment are the scalability and the fact that nodes can move freely maintaining the connectivity and updating routing information. As a drawback, we highlight the autonomy of the nodes, which makes them dependent on batteries or power supply. In the study case, nodes can be located in those places with potential risk noise situations. In this way, nodes are connected to the power line, thus avoiding the need to use batteries, although they can work with them, allowing location independence.

Figure 2 shows the appearance of a node, in which the main components can be seen. The base component of each node is a Raspberry Pi 3 model B. This board has a built-in Wi-Fi 802.11n card to create the ad hoc network without needing an external antenna.

As the Raspberry Pi models do not have an integrated microphone input, it has been necessary to use an external USB microphone, which provides its own sound card. Also, in order to provide geolocation, the GPS can be connected through the USB interface. Note that, in order to show the possibilities of the system, the GPS module has been added to the solution presented. The use of this module can be optional in static indoor installations if nodes are in fixed positions.

In this way, a solution based on the use of low-cost components leads to a very cost efficient system. Sensors run Raspbian OS. It is important to note that the service executed on the boards, called agent, has been the focus of the main development carried out. Specifically, the agent has been developed using Python 3 language for the main tasks of the service (such as the application lifecycle, multithreading, recording and reporting the measurements). In addition, in order to process the recorded audio data, Octave through Oct2py interface has been used.

Figure 2. Picture of the node.

Moreover, a piston phone is used to calibrate the microphone in the sensors. First, the difference between the measurement taken by the piston phone and the one obtained with the chosen microphone is calculated. Then, this difference is used in all audio samples to show the correct value of the sound pressure level in the application.

The proposed system captures audio and processes the samples, calculating the sound pressure level in fragments of time. It is worth highlighting that this process is carried out by the Raspberry Pi 3, thus minimizing the data transmitted (and saving bandwidth) because only the processed data values are sent.

B. Cloud

Another block of the proposed system architecture (as shown in Figure 1) is the cloud. Data values of the audio recordings are stored on a server in the cloud.

The server receives the sound pressure level from the raspberries in the ad hoc network and saves the data of each node in a database. Apart from the sound pressure level and the node identifier, the database also stores the timestamp of the beginning and the end of the recording.

The database is composed of different tables that allow to organize the collected data in an appropriate way. Sensors can be classified into groups, which can be rather useful to interpret the information. For example, in the industrial environment each node can be assigned to different groups, such as the floor where the node is, the department, the type of machine, etc. Thus, each node can belong to more than one group and it is possible to add as many nodes and groups as required to the network.

C. *User interface*

The last block of the proposed system is related to the management of the architecture. A manager will be able to monitor the network, the audio configuration of the nodes and the database.

To that extent, a web user interface was developed, which is used to consult and manage the data. The web page is structured in two different parts: the monitoring section, and the administration part. The former shows a page with a list of groups and, when selecting a specific group, a table with the properties of the sensors belonging to that group is shown. An example is depicted in Figure 3. Also, the web site shows a map with the geolocation of the nodes. As we can see in the figure, each marker referred to the position of each node has a certain color, depending on the noise level detected in that particular moment: green, for sound pressure levels among 0 and 65 dB_{SPL}; yellow, for sound pressure levels higher than 65 dB_{SPL} and lower than 100 dB_{SPL}; and red, for sound pressure levels higher than 100 dB_{SPL}.

If a certain node collects a measure higher than a specified limit of the sound pressure level, a warning will be shown in the web page. In addition, it is possible to send an alert by means of a text message.

On the other hand, the administration section is only for registered users. Apart from the functionalities of the monitoring section, registered users are able to interact with the database and modify the existing nodes or groups. Moreover, the section allows to load a specific configuration for a node, modifying the configuration table of the nodes. This table contains different parameters related to audio recording (such as the record time or period) and for calculating the audio sound pressure level (such as the integration time or the weighting mode).

III. EXPERIMENTAL RESULTS

The evaluation of the nodes for testing the Wireless Acoustic Sensor Network (WASN) with Raspberry Pi 3 have been carried out inside the Universitat Politècnica de València (Figure 4). The network is composed of three nodes located in a small area without obstacles and with direct view. As the figure depicts, there is a source of noise, specifically, noise coming from construction works. This noise source is found nearby of node 1, and further away from the two other nodes.

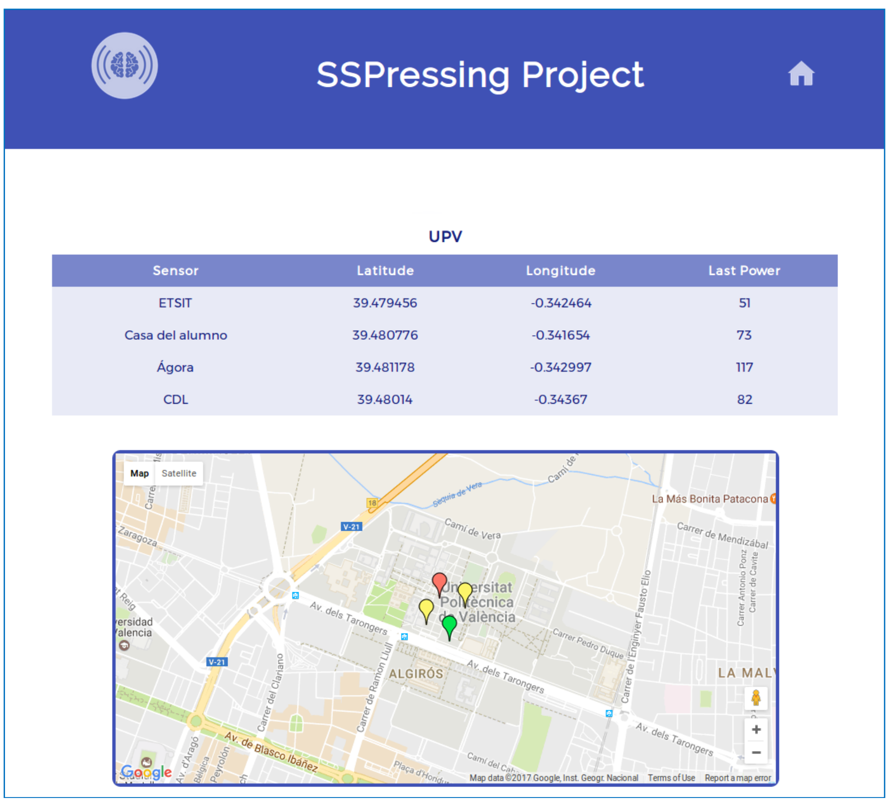

Figure 3. User interface of the monitoring section.

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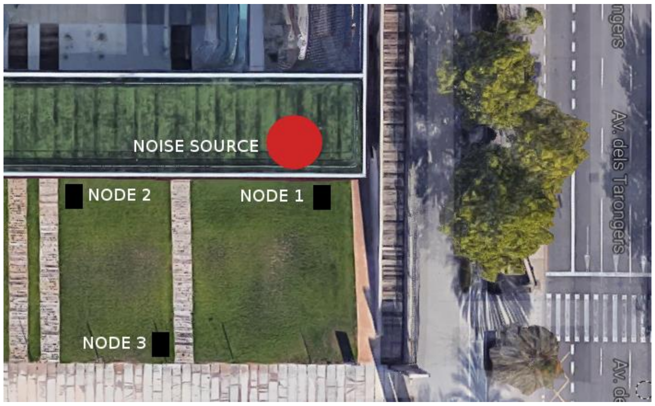

Figure 4. Detail of the network deployment at the Universitat Politècnica de València.

In the evaluation carried out, each node has recorded each second the sound level pressure measured during more than 1 hour (specifically, 74 minutes). The sampling frequency has been 44.1 kHz. The noise level of the three nodes over time is shown in Figure 5. In the *x* axis, it is shown the hour in which the measure has been taken (from 16:18 until 17:32 in intervals of 1 second). In the *y* axis, the sound pressure level in dB is displayed. This pressure level is also reflected in the figure by different colors: green tonalities indicate areas with acceptable sound pressure levels, whereas orange and red ones indicate dangerous areas in terms of noise level.

As expected, the node 1 is the node that measures the highest noise level, since it is the nearest node to the source of noise. Specifically, the average sound pressure level measured by node 1 is 83.35 dB, which represents a rather high noise level. In this sense, node 2 and node 3 present a similar evolution over time, although with sound pressure levels much lower (an average noise level of 69.32 dB and 62.46 dB, respectively). These results are in consonance with the distance from each node to the noise source.

In the figure, we can see three alerts corresponding to instants of time when the noise level exceeds 100 dB (specifically, instants of time 16:18, 16:20 and 17:30). Although these noise peaks are detected by the three nodes, only node 1 considers these peaks as alarms, since the measured value exceeds the defined threshold, as the Figure 5 depicts. As previously mentioned, these high sound pressure levels for a long time exposure can be harmful to the health of workers. In this way, the proposed system can help manage the noise level suffered by the employees during their working hours.

IV. Conclusion and Future Work

This paper has presented a system for monitoring the noise exposure in industrial environments. The proposed system is based on an ad hoc network and the use of Raspberries Pi 3. The solution hereby presented represents a low-cost system for audio monitoring which can be considered as a general model that allows to be extended (by adding new functionalities) and used in other environments related to Internet of Things.

As presented, one of the main advantages of the proposed system is the capacity to expand the WASN with more nodes in order to create a network tailored to users' needs. In addition, the network deployment is autonomous and rather portable, because of node size. Finally, remote monitoring allows to manage the information in real time, such as configuring the nodes or checking the warnings.

As a future work, in order to improve the benefits of the prototype proposed, further work to exploit data processing possibilities (such as machine learning for automatic noise classification) will be carried out. Among other improvements, we highlight the use of algorithms for classifying the audio in order to identify the source of the noise, thus better detecting certain alarming situations.

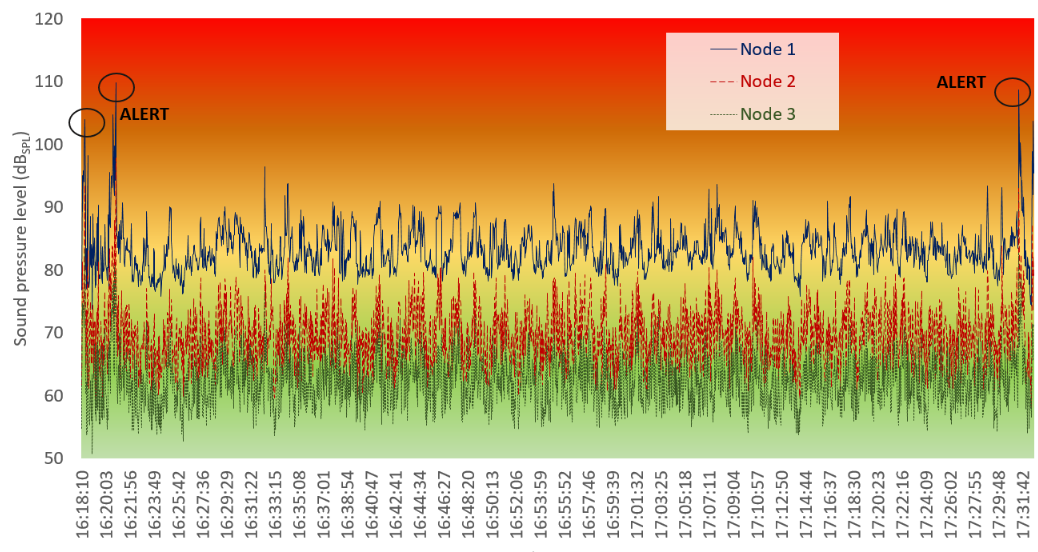

Figure 5. Evaluation of the sound pressure level, inside the UPV, measured outdoors.

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