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BUILDING A SMART CITY IOT PLATFORM - THE SUSCITY APPROACH

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ABSTRACT

The Internet of Things is being used in several application domains and is identified as one of the key enablers of the Smart City paradigm. Notwithstanding some efforts have been carried out to advance in the adoption of Web standards and Cloud and Fog computing technologies, developing a Smart City IoT platform remains a challenge.
This paper describes our experience building a Smart City Internet of Things platform framed on the SusCity project. The proposed platform allows the gathering, processing, and visualization of typical gauges in Smart City scenarios, such as water and air quality, temperature, humidity, mobility, and noise levels. The data is standardly collected from different sources and then displayed in a dashboard to the final users.

Keywords: Internet of Things, Smart City, Environmental Noise.

1 INTRODUCTION

The permeation of technology in everyday activities has led to the evolution of the Smart City paradigm, where the Information and Communication Technologies (ICT) and the Internet of Things (IoT) are brought together to provide solutions to manage city's resources and handle citizens' daily activities. In a Smart City, sensors automatically gather information that is analyzed so actuators can execute automated short-term actions, and also more long-term actions can be made by companies, organizations, governments, and citizens.

To ease the long-term actions decision-making, several tools have been developed in order to help in the analysis of different gauges that influence the decisions aimed at the efficient resource management in the cities. Many research projects are focused on the design and development of tools to handle information related to Smart Cities' processes; this is the case of the SusCity project. The SusCity project is targeted at the development and integration of new tools and services with the objective of promoting the efficient use of resources with minimum

environmental impact while contributing to promote the economic development of the cities in Portugal [1]. The end product of the SusCity project will be a dashboard where government, organizations, and citizens can analyze different environmental indicators and define strategies to enhance the resource usage and the activities in the city.
Among the environmental gauges to display and evaluate with the SusCity dashboard is the data related to noise. Nowadays, urban noise is considered a public health problem [2][3]; thus it becomes an important information to report in an urban dashboard. For this work, the particular case of the city of Coimbra, Portugal is evaluated.

There are two important academic events in Coimbra each year, where students, citizens, and visitors from other cities participate. During these events, which elapse during a week each, there are several activities including music concerts each night of the week that generate high noise levels. The impact of the noise, and how it is reported in the dashboard in the context of a Smart City is explored in this research.

This paper is structured as follows. Section 2 defines the Smart City paradigm, its services and importance. An overview of data gathering, processing, and visualization ins Smart Cities dashboards is also presented. Section 3 describes noise as a relevant gauge for Smart Cities, how the noise influences the city and its citizens, using the city of Coimbra, Portugal as case study. Finally, Section 4 concludes the paper, outlining future research lines.

2 SMART CITIES

Today half of the world's population is living in urban areas [4], and cities are expanding their infrastructures and services to be up to date. In the past decades, the European Union (EU) has developed many projects with the intention of allowing a smooth transition of their cities to the new paradigm of Smart Cities.

The term Smart City, which is presented to discuss the use of modern technologies in everyday urban life [5], does not only include ICT but also incorporates other aspects such as modern transport technologies and its logistics and, in general, a more sustainable use of resources, from water to energy and others. A Smart City includes the possibility to combine different components (technologies) with the aim of creating a productive and autonomous environment to support an urban development model. Two technologies have been essential to bring up the paradigm of Smart Cities: the IoT and the Cloud/Fog computing.

There are two basics ideas behind the IoT; the first one is that any object could be identified and recognized unequivocally; the second one is the use of the Internet infrastructure to enable communication between objects. According to Tan and Wang [6], the IoT could be defined as a global network infrastructure integrated by a huge number of devices connected that rely on sensors, actuators, communication, networking, and information processing technologies. From the Smart City perspective, the main benefit of the IoT is the possibility to read, recognize, address and control these objects or things anytime and anywhere. Thus, it is possible to collect data that could be processed and analyzed by applications to provide services.

In a Smart City it is often required to run these services in real-time and frequently it is necessary to process an enormous amount of data. Given that the components in the IoT have processing constraints, many times it is not possible to achieve real-time or low latency requirements only using the devices deployed in the IoT layer. The Cloud and Fog computing paradigms allow to tackle these barriers, enabling heavy calculations that run in remote data centers (i.e., for complex data analytics) or user-nearby cloudlets (i.e., for real-time or low latency processing) depending on the paradigm applied, this is Cloud or Fog respectively.

In a Smart City scenario, two key aspects must be considered: (1) how to collect the data on the city? (2) how citizens or stakeholders have access or visualize the data gathered? In the rest of this section, a discussion about these aspects is presented.

2.1 Data Gathering in Smart Cities

Big amounts of data can be generated in a Smart City environment, and it will need to be transmitted to some repository to be analyzed. Thus, the IoT infrastructure becomes a critical point in the architecture, since the accuracy of the results reported highly rely on the prompt availability of the collected data.

Within the scope of the SusCity project, an IoT Smart City architecture was designed to allow the deployment of smart applications guaranteeing support to the main features of an IoT and Smart City environment. This architecture is depicted in Figure 1 [7]. At the IoT Infrastructure level, sensors and actuators could be attached to Arduinos and Raspberry Pi devices to collect environmental data (e.g., temperature, light, noise) using Paho, a client implementation of the Message Queue Telemetry Transport (MQTT) protocol for communication among constrained devices; the data is in turn aggregated and preprocessed by a device running Kura, a framework implementation for IoT gateways.

At the Fog and Cloud levels, the data processing, storage, and analytics takes place. Kapua is used as a middleware to deal with the heterogeneity of the infrastructure level and to support the workflow between the applications and the physical devices; inside the middleware, Hono (API for interacting with devices using arbitrary protocols) and Mosquitto (MQTT broker) are used for connectivity and message routing, Leshan for device management (e.g., firmware updates), hawkBit for device registry, and Birt to provide support for dashboards and data reports. On top, MongoDB and Cassandra are used for data storage, Hadoop for data analytics, and Docker for the standardization of the resulting applications. A RESTful API is provided as a pass way for the upper level of the architecture, where the smart applications (such as the USD) reside.

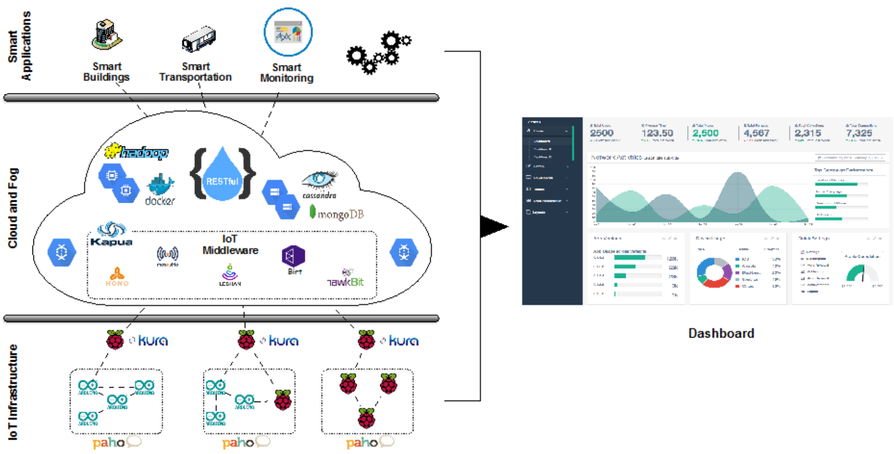

Figure 1. An IoT Smart City Architecture for Data Gathering and Visualization [7]

The proposed architecture allows the integration of different sources of data, thus providing a complete set of variables for the final users. A prototype of the architecture has been configured as a proof-of-concept. The main goal is to create a dashboard that allows monitoring environmental parameters, including noise.

2.2 Data Visualization in Smart Cities

Usually, a Smart City project includes a city benchmarking approach aimed at comparing intra- and inter-urban performance and monitoring resource usage. More recently, the data related to a Smart City development has started to become more open to citizens, and displayed via dashboards that can be accessed via the Internet [8]. These dashboards become instruments that are used to verify if and how much a smart set of city policies affects people living in a city, for instance, revealing noise values that could affect citizens' health.

The visualization of data via dashboards represents a key challenge due to the variety of data streams, data formats, and data sources involved in the different processes in a Smart City [9]. The data needs to be standardized to be displayed in a uniformed fashion to final users. Also, tools such as plots and graphs should be included to ease its visualization and understanding. This section describes our experience on the IoT setup and dashboard design and development, focused on the noise gauge.

During the dashboard development process, several data sources have to be taking into consideration. In the SusCity environment, the data comes from (1) the experimental setup (i.e., Raspberries connected to several different sensors – temperature, sound, barometer, humidity, among others) and (2) third-party data (project partners). In the first case, the data is fully managed by the project members, being easier to send to the database in a specific format. Also, the preprocessing methods are simpler because the data is in a controlled environment and constantly under reviewing (to guarantee that the values sent to the database are correct). In the second case, there is a degree of uncertainty in the data because it is not possible to fully know what the partners implemented on their side (for privacy reasons). For instance, one partner can use a simple JSON file with only timestamps and values, but another partner might use a complex CSV file that has the values, timestamps, specific components, etc.

External or legacy data sources need to have a special treatment. Thus, the data first needs to be retrieved from the sources to be processed and converted to a standard format (e.g., JSON) before inserting it to the database. After this process, the data is retrieved for visualization proposes via the frontend. Taking into consideration our experience in the frame of the SusCity project, the backend must be able to perform the following tasks:

1. Open the data and retrieve the content (tags, in JSON and XML, or columns, in CSV);
2. Program the retriever bot to fetch the data (FTP, SFTP, direct access through an API);
3. Preprocess the data to correspond to the format that is being stored in the database and then fetch it to build the dashboard;
4. Convert the preprocessed data (i.e., list with the correct content defined in the first step) to the Suscity's data format (JSON).

These tasks are important when dealing with external and legacy data sources in order to guarantee a standard storage of the data. Thus, the database could be filled with data from internal and external sources, using the same format and preprocessed according to the standards defined by the project.

Regarding the frontend, for the project a template called Gentelella[1] was used. With the template settled, one of the challenges was completed because the color palette used is appealing and it may captivate the users while they are navigating through the dashboard. To construct the graphics, a special javascript add-on was used called chart.js. It is open-source and free to use; it is also modular in every way allowing to build smooth, simple, but very informative charts.
Another issue to address is which graphic fits best for specific data. Different plot templates could be used depending on the data. For example, in the experimental setup there is a temperature sensor, inside a specific room. Since the location is fixed, a simple bar chart is sufficient to show the data (also having a title and axis subtitles to help to interpret the values). Although in the setup there is a sound sensor, its sensibility is low compared to modern sound sensors that allow studying a city sound's behavior. For the case of external sources, the bar chart might not be the best choice; a better option could be a map with the geotagged data to better understand how is the noise behaving throughout the city and, for that, GPS coordinates are needed.

Visualizing data correctly is not straightforward and it always depends on the data. To minimize this constraint, the preprocessing/processing (on the backend) and the post-processing (on the frontend) are critical so the data can be used to not only in one type of chart (e.g., bar, lines, dots, pie charts, among others).

Giving the importance of the noise levels in the context of a Smart City, in the next Section a discussion about it is presented, as well as some measurements processed and depicted via our dashboard solution.

3 NOISE AS A GAUGE FOR SMART CITIES

There are several factors that can have a negative impact on the quality of life in urban agglomerations. Noise is recognized as one of the main disturbing elements, clearly jeopardizing people's well-being. Nowadays, in Europe, populations tend to be concentrated in the urban centers, thus increasing the number of residents in cities. The increase in economic and leisure activities is associated with a clear increase in the environmental sound level. Consequently, the number of people exposed to noise in cities has also increased.

In 2010, the European Environment Agency released a series of indicators that relate noise exposure to the health and well-being of populations [10]. Subsequently, the World Health Organization issued a report [11] concluding, on the basis of evidence, that exposure to noise poses a serious risk to populations. The report presents the health effects of environmental noise (the environmental burden of disease due to environmental noise). For the determination of these effects, some noise descriptors and indicators are used.

Thus, noise is a key component to take into account in the current Smart Cities concept. With the implementation of this concept, citizens are given access to a wide range of information with the objective to improve resource usage. This information comes from several sources that make them available and update them more or less regularly. It is necessary that the information be reliable, credible and presented in a way that is easily understood by the citizens.

[1] https://colorlib.com/polygon/gentelella

In the case of the acoustic component of the environment, there are currently devices that enable the acquisition in real-time and make it available in a format appropriated to be broadcasted through online platforms. These online platforms, however, are usually exclusive to the manufacturers of the acoustic monitoring systems and are only made available to duly authorized users.

With regard to this capacity, ADAI has developed specific equipment [12] that has been in operation since 2009 up to the present date. This continuous monitoring system allowed to obtain a set of data, currently available for use and analysis, making possible its integration into a dashboard displaying the environmental conditions of an urban area.

Here are two different examples of the type of information that can be made available through the platform: characterization of the acoustic component of a given location and characterization and identification of specific temporary events, which are described below.

Regarding the characterization of the acoustic component of a given location, the set of data gathered by ADAI allows for a historical analysis of the evolution of noise levels relating to other data collected in the city (see Figure 2). On the basis of these data, it is possible to know with high precision the characteristics of the temporal evolution of the noise throughout the whole day, as well as the long-term noise indicators for which annual representativeness is required [13].

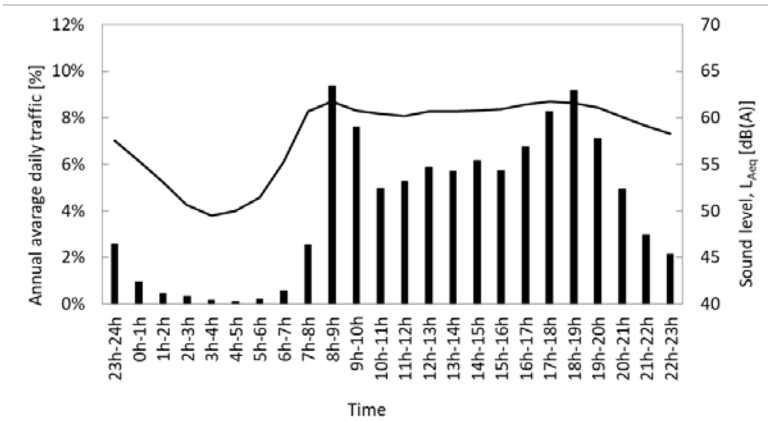

Figure 2. Relation between the traffic distribution (bars) and the temporal evolution of noise (solid line) – adapted from [14].

The availability and knowledge of these indicators offer the possibility to carry out, in a sustained way, a more efficient and economically advantageous management of the acoustic component of the environment. Citizens are now given the possibility of being able to intervene in their city environment, for example by changing their mobility patterns.

About the characterization and identification of specific temporary events, let's think of leisure activities, which are naturally present in the life of a city. When they are associated with specific events, they usually have a fixed duration and occur at a known periodicity. In the city of Coimbra, there are some events with these characteristics that, at night, are often generators of complaints by a large group of citizens [15] because of the high levels of noise (see Figure 3).

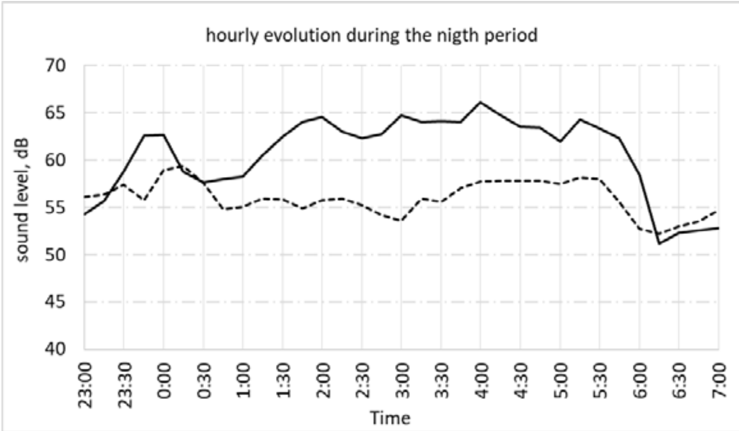

Figure 3. Comparison between the evolution of noise during the event (solid line) and without it (dashed line) – adapted from [16].

The available dataset enables various types of analysis. For example, it is possible to focus on the influence of the low-frequency components produced by musical events (see Figure 4), since these are often the cause of complaints of the resident populations in the vicinity of places where these events occur.

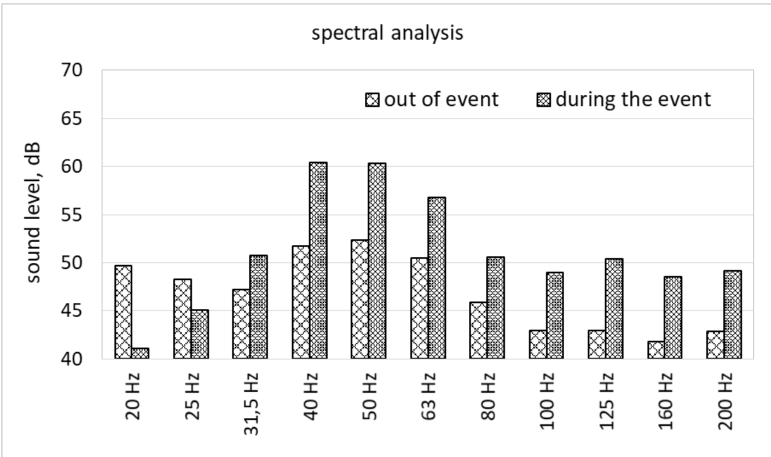

Figure 4. Comparison between the low frequency components of noise, during the event and without it – adapted from [16].

Regarding the data acquisition, the sensor was working at the Laboratory of Industrial's Aerodynamics. To send and store the values on a Mongo Database, a RESTful service was developed to allow communication between the database (and dashboard) server and the sensor server. Two small scripts were developed to complete the path between both ends:

- Although the sensor's data is stored every minute, the developed script collects data every 15 minutes. It will process the file and get two different values: (1) the time when a specific measure was stored in the local file, and (2) the corresponding LAeq (Equivalent Continuous Sound Level) value for that measure. The data is then aggregated in the same file and sent through the RESTful server.
- On the database end, the developed script will listen to new information every 15 minutes and if a completed file is found, it will get all the parts, join them together and send them to the database. With all the processing made on the sensor's end, the computational weight in the database's end is minimal and it will not substantially affect

other communications between the database and the dashboard itself (that is on the same computer).

After gathering the data, a set of steps was defined to develop the dashboard correctly. For instance, showing temperature information does add extra complexity when displaying the data or other derivatives (averages, maximum values, among others), but regarding sound, several aspects were analyzed and are important to mention.

- There are three different periods of the day that show how the sound behaved: (1) morning period (Ld), between 7h and 20h; (2) evening period (Le) between 20h and 23h; and (3) night period (Ln), between 23h and 7h of the next day.
- Having three different periods, the objective was to show them to the user and have them calculated in real-time, with the data from the current data being added to the database while also having them stored in the database for quick access. This decreases the time that the dashboard needs to show information to final users. To achieve this, when getting the time of a specific measurement (during the communication between the two ends), we check the hours and label them, to then enable quick access to that information (i.e. having three graphics showing the different periods of day, describing how the sound behaves during the different periods).
- With the periods of the day completed, it is possible to calculate the Lden (Day-evening-night equivalent level), taking into account the constraints that this operation adds, such as, during the night period a 10dB penalty needs to be added and during the 19h and 23h a 5dB penalty needs to be added to the levels.
- Showing every minute what the sound sensor collected was unnecessary, so the data is shown every 15 minutes, being the value the Lden of the previous 15 minutes (i.e., the point at 15h00 is the Lden from 14h46 to 15h00, and so on).

With all the restrictions and details settled, the development of the dashboard continued. The backend (developed in Python) contains plenty of pre-processing mechanisms so that the frontend (HTML and JavaScript) does not have to freeze while the data is being taken care of. A sample screen from the dashboard is shown in Figure 5.

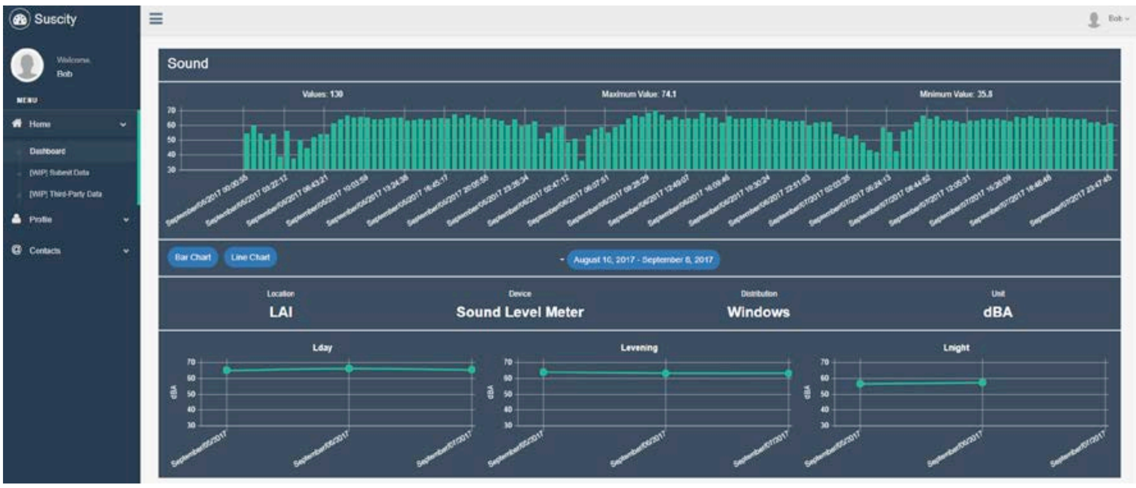

Figure 5. Sound data visualization via the SusCity dashboard.

4 CONCLUSIONS

The recent Smart Cities paradigm encompasses several areas of society centering on the idea that citizens' intervention and involvement brings benefits and gains, not only economic but also social when the citizens are called upon to participate and engage in the management of their regional areas.

The current technology allows for real-time availability of a vast set of parameters of the most distinct nature. It is, therefore, demonstrated that the information on the acoustic component could be made available in real-time to citizens, allowing them to "feel the heartbeat" of their city. This knowledge passed on to the citizens augments their capacity to intervene, together with the administrative decision makers, to find a balance between their interests and the life dynamics in cities. Knowledge is thus gained in order to facilitate decision making and the implementation of more appropriate and effective measures to reduce the population exposure to environmental noise.

However, all the information gathered would be useless without a proper visualization tool that easily allows its interpretation to users regardless their background. In this work, it was shown how the data could be collected, processed, displayed, and used in order to aid citizens in every-day activities. As future work, more gauges are to be included and analyzed in our dashboard, including air quality, CO_2 concentration, and health. With, these, different analysis can be incorporated, for instance, using machine learning algorithms to identify patterns in different parts of the city.

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