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Visualization of nuisance information in acoustic environments using an IoT system

Segura-Garcia, Jaume [1], López-Ballester, Jesus [2], Pastor-Aparicio, Adolfo[3], Felici-Castell, Santiago [4], Cobos-Serrano, Máximo [5], Pérez-Solano, Juan J. [6], Soriano-Asensi, Antonio [7], García-Pineda, Miguel [8]
Computer Science Dept. - ETSE
Universitat de València

ABSTRACT

Nowadays, the application of WASN and IoT systems for noise and annoyance monitoring is a hot-topic in soundscape research. The problems in the evaluation of psycho-acoustic parameters are mainly related to the efficiency of the implementation to be implemented into the nodes. In this work, an approach to the full Zwicker's psychoacoustic annoyance model is developed, by computing all the psychoacoustic parameters in the node (i.e. loudness, sharpness, roughness, fluctuation strength and tonality), and the information gathered using an IoT system (based in FIWARE). The information gathered is visualised in a virtual environment using the Unity graphical engine.

Keywords: Psychoacoustics, Annoyance Visualization, Virtual Environment
I-INCE Classification of Subject Number: 79, 72
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1. INTRODUCTION

Real-time mapping systems for environmental noise monitoring is a challenging issue that has been addressed in different research works [1, 2]. In this context, the study of noise pollution in urban environments has aimed at developing networked monitoring systems combined with spatial statistical models for representing noise or nuisance levels is not straightforward.

[1]jaume.segura@uv.es
[2]jesus.lopez-ballester@uv.es
[3]adolfo.pastor@uv.es
[4]santiago.felici@uv.es
[5]maximo.cobos@uv.es
[6]juan.j.perez@uv.es
[7]antonio.soriano-asensi@uv.es
[8]miguel.garcia-pineda@uv.es

In general, the European Commission recommends a high granularity for noise data representation both in space and time. In this case, Wireless Acoustic Sensor Networks (WASNs) are an interesting alternative to sound-meters overcoming the drawbacks produced by the present noise data collection procedures. WASNs are composed of autonomous nodes with sensing capabilities (with a microphone). The nodes communicate using multi-hop routing protocols and at least one node (named sink) acts as a gateway for external connection. In the last decade, several studies have been conducted using WASN for environmental noise monitoring. All of these studies are based on the equivalent SPL over time.

Several works have considered the use of WASNs for noise monitoring. In [3, 4], authors have evaluated a WASN using Tmote-Sky motes [5] and Tmote Invent (TmI), to monitor traffic noise using the equivalent level, Leq,T and to count the number and type of vehicles. In this deployment, they used a sampling frequency of 8 kHz. In their study, they found that Tmote-Sky had excessive self-noise and TmI (with an integrated microphone) had apparently good audio features. In the references, the authors do not provide a specific calibration. In [6, 7], a WASN deployment in Ostrobothnia (Finland) is discussed. In these references, the authors report different tests to evaluate the noise impact. They measured the Leq,T with T=125 ms using a sampling frequency of 33 kHz, with 14 calibrated motes (MicaZ from Crossbow -now this company is MEMSIC- with an ad hoc acquisition circuitry to allow a dynamic range of 60 dB), globally synchronized during 96 h with good results.

Other works such as [8, 9] have used mobile phones for environmental noise monitoring. Although the results are interesting, there is a lack of information about the recording conditions which avoids getting accurate noise measurements. When evaluating noise parameters, the location of the measuring devices should follow specific rules based on norms [10].

In terms of the traditional study of the environmental noise, the presentation of maps with sound pressure levels (SPLs) has been tackled in [11], where authors measured SPLs with Raspberry Pi (Rpi) and represented the information with spatial statistics, measuring 5 minutes SPL equivalent values with a WASN and also evaluated spatial cross-validation using the kriging method in a small city. Here the Rpi with a microphone is used as a sound-meter measurement system connected to a information gathering system based in RStudio. In [12], the authors also evaluated the environmental noise with a mobile application and display the results in a map using the kriging method.

In [13], authors explored the options offered by WASN for subjective annoyance computation in terms of the psycho-acoustic parameters and SPL. They found that common nodes devoted to SPL, such as TmI, could not afford the psycho-acoustic parameter computation and the audio sampling was quite poor for the audio reconstruction, from recorded audio chunks. Nevertheless, the tendency for the relationship between the psycho-acoustic parameters (Loudness, Sharpness, Roughness and Fluctuation Strength) computed from the audio signal gathered with these TmI had good correlation with the SPL in terms of subjective annoyance.

In [14], the authors implemented a edge-computing system by using different Raspberry Pi 3 (Rpi3) nodes in order to perform an evaluation of performance when computing the binaural loudness directly on the Rpi3 nodes. An improvement of this work was done in [15], where authors added the computation of binaural sharpness to the set of binaural psycho-acoustic parameters. Also, a simplified version of the Zwicker's psycho-acoustic annoyance model was evaluated (assuming specific conditions), oriented to assess the spatial distribution of the subjective nuisance in indoor and outdoor environments.

The amount of data generated with this kind of information systems can be dealt with Big Data systems. A useful environment to work with is RStudio, a framework based on R statistical language that allows the use of multiple statistical tools to any kind of information source. Also, for data visualization, Virtual Reality (VR) is a field that can be very applicable [16].

In this paper, we show a VR-based system oriented to visualize psycho-acoustic annoyance information collected by an Internet of Things (IoT) system, using WASN. In this system, the information from the WASN is collected in a FIWARE framework and connected to RStudio environment for spatial statistical data processing. The processed information is sent to the Unity graphical engine to visualize the information as a color map in a transparent plane in the environment.

2. MATERIAL AND METHODS

The measurement system is based on a WASN, composed by Rpi3 B+, connected to a FIWARE framework. Each Rpi3 has a C++ program that computes different psycho-acoustic metrics (specifically Loudness, Sharpness, Roughness and Fluctuation Strength), and also SPL. The node records 1 second of audio, and after 1.5 seconds of computing time, sends the information to the FIWARE framework, using MQTT protocol, and it is stored in MongoDB, a no-SQL database. The psycho-acoustic information is then used by the RStudio plugin, a statistical framework which was configured to be connected to the FIWARE framework. A statistical script using kriging technique (which will be explained later) process the information as a matrix with the information of the psycho-acoustic annoyance according to the Zwicker's annoyance model. This information matrix is sent to the C# script integrated in the model of the environment in Unity graphical engine via a JSON query. The C# scripts also represents this nuisance matrix as a color map in a transparent surface that can be navigated inside the virtual model of the environment. Figure 1 shows a schema of the whole system.

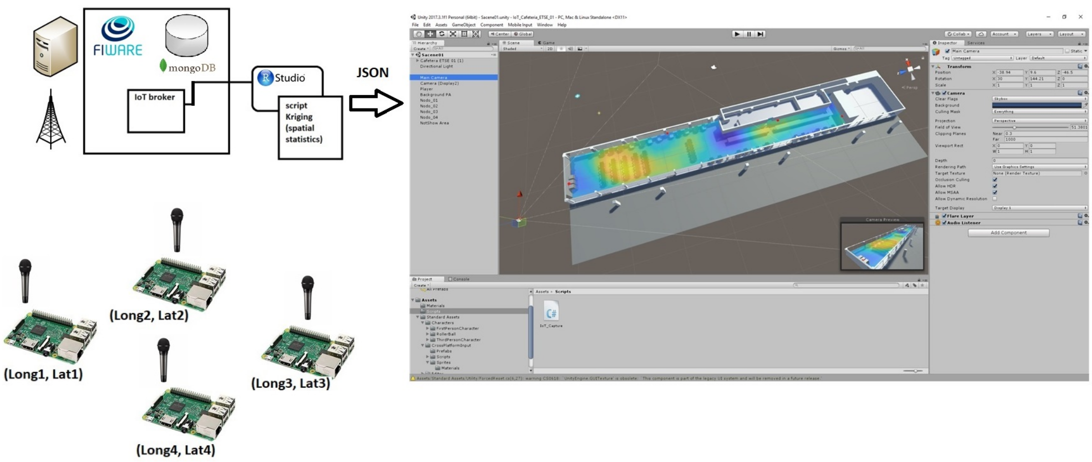

Figure 1: Schema of the whole system

2.2.1. Node Network

The core of the processing part of the node is a Rpi3 Model B+, that it is used in the acquisition and publishing stages. The technical characteristics of the Rpi3 include a 1.4 GHz 64-bit quad-core ARM Cortex-A53 CPU, 1 GB RAM, 40 GPIO pins, 4 USB ports, a full HDMI port, an 10/100/1000MB Ethernet port and integrated 802.11ac/n Wireless LAN, and also Bluetooth 4.2 Low Energy (BLE). Also, the USB ports and the GPIO pins are a good solution, providing the Rpi with the possibility to have a range of peripherals available, such as WiFi antennas, ZigBee modules, microphones, cameras and connections with other devices, e.g., Arduino.

In the software section, the Rpi3 platform has a Linux-based OS used for the programming in a high-level programming language, such as Python or C++. The main tasks of the developed algorithm are: acquisition and windowing of the audio signal, psycho-acoustic metrics calculation, monoaural signal creation, third-octave band filtering stage, sound pressure level calculation, storage, publishing and processing of the results. Also, a copy of the different evaluated (psycho-)acoustic metrics is stored in the internal memory of the Rpi3 B+ sensing device.

2.2.2. FIWARE IoT collection framework

FIWARE is an open-source platform, developed by Telefónica I+D and driven by the European Union (in different EU projects), for the development and global deployment of Future Internet applications. FIWARE aims to provide a fully open, public and free architecture as well as a set of specifications that enable developers, service providers, enterprises and other organisations to develop products that meet their needs, while remaining open and innovative.

The FIWARE IoT architecture[9] deployment of the Service Enablement is usually distributed between a number of devices, several gateways and the backend. As defined, a device is a hardware entity, component or system that measures properties of a thing/group of things or influences the properties of a thing/group of things or both measures/influences. Sensors and actuators are devices.

IoT Resources are computational elements (software) that provide the technical means to perform sensing and/or actuation on the device. The resource is usually hosted on the device. IoT GEs have been spread in two different domains: Gateway and Backend. While IoT Gateway GEs provide inter-networking and protocol conversion functionalities between devices and the IoT Backend GEs, the IoT Backend GEs provide management functionalities for the devices and IoT domain-specific support for the applications.

The use of FIWARE allows to have an autonomous and off-the-shelf IoT service for complex applications. A basic Fiware IoT architecture is shown in Figure 2.

2.2.3. Spatial statistics through RStudio

FIWARE allows the data connection to RStudio plugin. In this statistical framework, the spatial statistical processing can be done. The most common methods in spatial statistics are Inverse Distance Weighted (IDW), spline and kriging. IDW is a simple and intuitive deterministic interpolation method based on principle that sample values closer to the prediction location have more influence on prediction value than sample

[9] https://forge.fiware.org/plugins/mediawiki/wiki/fiware/index.php/FI-WARE_Architecture

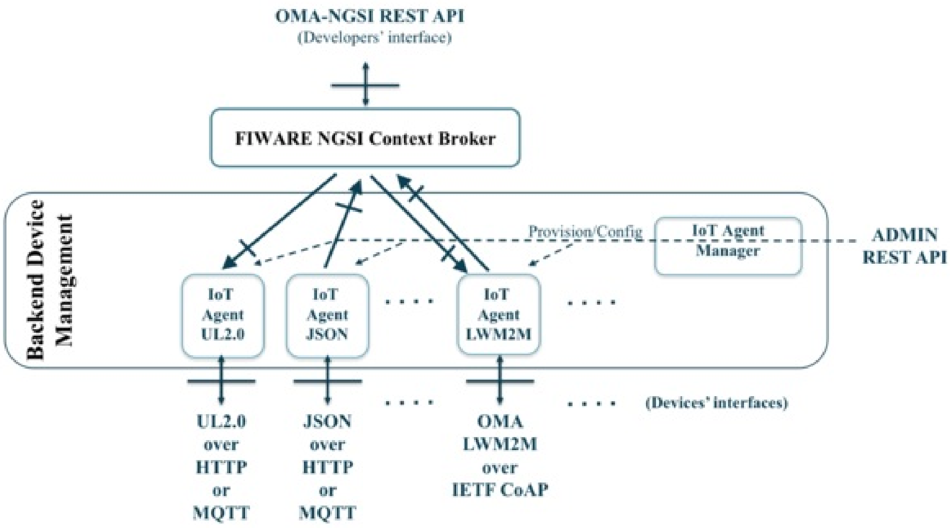

Figure 2: Basic FIWARE IoT architecture

values farther apart. The major disadvantage of IDW is "bull's eye" effect and edgy surface. Spline is also a deterministic interpolation method which fits mathematical function through input data to create smooth surface. Kriging is a method based on spatial autocorrelation [17].

The computed PA from the measurements of binaural loudness and sharpness establish a data set considering the locations in terms of GPS coordinates. By denoting the PA computed with the Zwicker's model at a location x as $Y(x)$, this data set is defined as $\{Y(x),\ x \in \mathcal{D}\}$, where $\mathcal{D}$ are all the locations of the modelling sets, following the kriging technique [18].

In this context, the objective of this proposed model is the prediction of Y(x0) in any location x0, particularly those within the validation set. The annoyance reports contain information of the set of covariables included. Therefore, Y(x) is modeled as a tendency function of the covariables better involved in the process which explains its variability in a large extent plus some random error which is explained by the short term variability, i.e.,

$$Y(x) = \mu(x) + \delta(x), \tag{1}$$

where $\mu(x) = E[Y(x)]$ and $\delta(x)$ is a stationary Gaussian process with zero mean, whose spatial dependence characterization is given by the variogram γ [19]:

$$2\gamma(h) = \mathrm{Var}\left[Y(x+h) - Y(x)\right] = \mathrm{Var}\left[\delta(x+h) - \delta(x)\right], \tag{2}$$

where Var denotes the variance and h is an offset. This variogram represents the main function of the kriging method, which presents different procedures such as simple kriging, ordinary kriging, universal kriging, indicator kriging, co-kriging, etc, attending to different statistical aspects considered in the covariable set. Ordinary kriging is the most widely used kriging method. It is used to estimate a value at a point of a region for which a variogram is known, using data in the neighborhood of the estimation location and also can be used to estimate a block value [20].

2.2.4. Unity for VR nuisance presentation

Unity[10] is a cross-platform graphical engine used as a game engine. This tool allow users the ability to create games in 2D and 3D. The engine offers a primary scripting API in C#, for both the Unity editor in the form of plugins, as well as drag and drop functionality. The last release is Unity 2018.

This platform also allows connection with other programs and provides different Software Developer Kits (SDKs), as *XR* SDK. *XR* is an acronym that encompassess virtual reality (VR), augmented reality (AR), and Mixed Reality (MR). *XR* SDK allows the use of virtual reality devices directly from Unity, without any external plug-ins in projects. It provides a base API and feature set with compatibility for multiple devices.

3. RESULTS AND DISCUSSION

In this study, we have used the Unity platform to show a model of a premise in our Engineering School. We have programmed a C# script to pass the kriging processed matrix computed from the PA information, collected, computed, averaged each 2 minutes by each one of the 4 nodes in the cafeteria, shown in Figure 3.

ETSE cotas.png

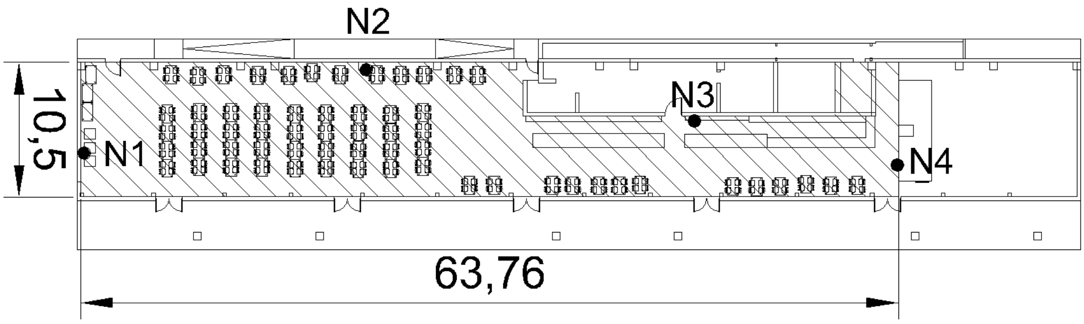

Figure 3: Plan of a premise (ETSE cafeteria) with 4 nodes

The PA information, processed by RStudio, is passed to the Unity platform, as a kriging matrix, through a JSON object. This object is collected by the C# script and processed in order to show a color map of the psycho-acoustic annoyance in a transparent plane inside the premise model. Figure 4 shows a perspective view of the Cafeteria model with the color map representing the PA in the environment. In this model, we have configured a first person navigator in order to visualize the annoyance information in each part of the room using a VR Head Mounted Display (HMD) configured with *XR* SDK.

The graphical rendering of the PA information has been tested and provides good performance to know the nuisance in this environment.

4. CONCLUSIONS

This paper explain an IoT system for psycho-acoustic annoyance computation and visualization. This visualization is made by using a Unity platform. A C# script has been programmed to receive the kringing matrix, from the RStudio plugin, as a JSON object

[10] https://unity3d.com/

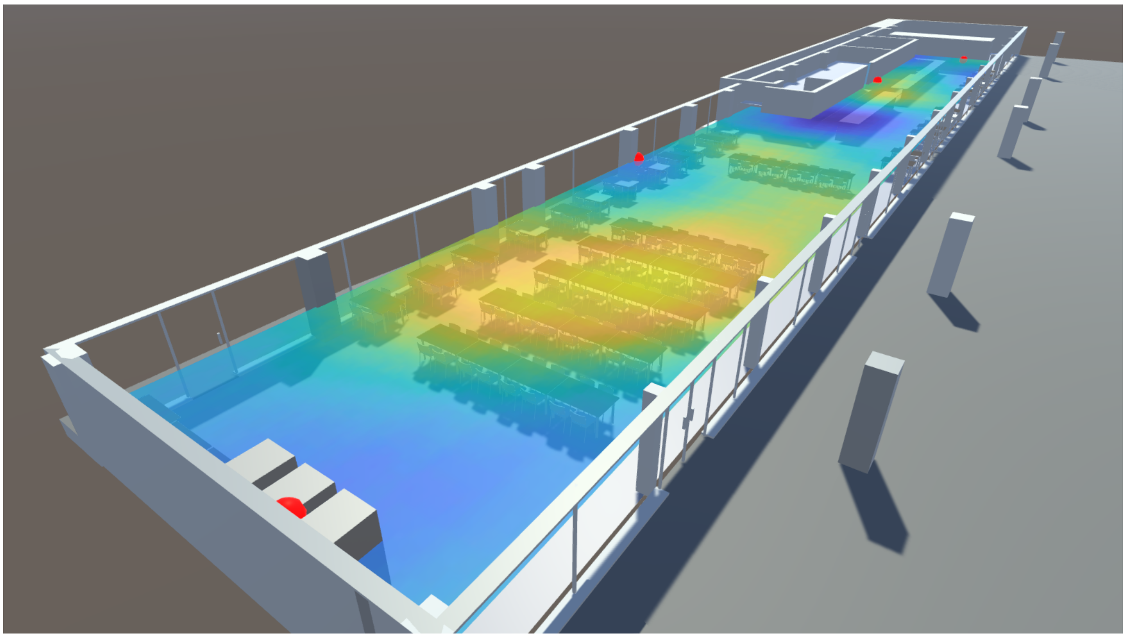

Figure 4: View of the premise model with the kriging matrix shown as a color map in Unity

and to represent it over the model. The navigation is made with a first person controller using a VR viewer.

The navigation has shown its effectiveness in the visualization of the psycho-acoustic annoyance in this environment. Future work will be done for a 3D visualization of the nuisance as a color mist.

5. ACKNOWLEDGEMENTS

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