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Low-Cost WASN for Real-Time Soundmap Generation †

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Abstract: Recent advances in technology have enabled the development of affordable low-cost acoustic monitoring systems, as a response of several fields of application that require a close acoustic analysis in real-time: road traffic noise in crowded cities, biodiversity conservation in natural parks, behavioural tracking in the elderly living alone and even surveillance in public places for safety reasons. This paper presents a low-cost wireless acoustic sensor network developed to gather acoustic data to build a 24/7 real-time soundmap. Each node of the network comprises an omnidirectional microphone and a computation unit, which processes acoustic information locally to obtain nonsensitive data (i.e., equivalent continuous loudness levels or acoustic event labels) that are sent to a cloud server. Moreover, it has also been studied the placement of the acoustic sensors in a real scenario, following acoustics criteria. The ultimate goal of the deployed system is to enable the following functions: (i) to measure the *Leq* in real-time in a predefined window, (ii) to identify changing patterns in the previous measurements so that anomalous situations can be detected and (iii) to prevent and attend potential irregular situations. The proposed network aims to encourage the use of real-time non-invasive devices to obtain behavioural and environmental information, in order to take decisions in real-time.

Keywords: wireless acoustic sensor network; acoustic sensor; soundmap; real-time processing

1. Introduction

In recent years, the advances in technology have led WASNs (Wireless Acoustic Sensor Networks) emerge as a powerful tool to survey from the acoustic health of the population living on urban areas [1] to the biodiversity conservation in forests [2]. In parallel, the development on smart-homes has allowed to include similar networks on indoor environments aiming to promote independence and well-being among the active elder population living on their own homes [3]. The advantage of WASNs compared to other monitoring systems (e.g., video surveillance systems or networks composed of wearable devices) is that they are perceived as less intrusive by users [4], specially when data is processed locally on the node and, hence, private information of the user (i.e., raw audio data) is not shared to a central node or neighboring nodes.

For this reason, several research projects have developed networks composed of multiple sensing nodes with different features and capabilities. For example, in the context of the IDEA project [5], Domínguez et al. [6] propose the usage of low-cost nodes (cost of around 50 €) to monitor outdoor environments that actively auto-check the frequency response of the microphone of each node by embedding a low-cost speaker that generates a periodical frequency sweep. This way, they are able to detect failures in the nodes. Another example of an outdoor acoustic sensor network is the one explained in [7], that is centered on the framework of the MESSAGE project. In their work, Bell and Galatioto present the results obtained on a WASN of 50 nodes in which, apart from a noise detector module, each node incorporates traffic and chemical sensor modules. As computational unit, they use a microcontroller with low processing capabilities. Regarding indoor WASNs, the homeSound project [8] proposes a network architecture with several sensing nodes that send their information to a concentrator node composed of a GPU with parallel computing capabilities.

This work presents a proof of concept of a sensor and a generic WASN aimed to acoustically monitor indoor or outdoor environments to generate a 24/7 real-time soundmap. The paper is organized as follows: Section 2 details the requirements that must be satisfied when deploying the sensing nodes, Section 3 describes the design of the proposed sensor and the network in terms of hardware, Section 4 explains the evaluation carried out in the design in order to validate the feasibility of the proposal and, finally, Section 5 discusses the main conclusions of the work.

2. Requirements

Regarding the sensors location, the following requirements must be satisfied according to the ISO 1996-2 [9]. For outdoor measurements, microphones must be located at a height of 4.0 ± 0.5 m from the floor in high building areas, and 1.2 ± 0.1 m in residential areas. The distance between the microphones and reflecting surfaces should be from 0.5 to 2 m. Regarding indoor measurements, microphones should be placed 0.5 m apart from walls and 1 m apart from significant sound-transmission elements. Distance between sensors should be greater than 0.7 m. Furthermore, before deployment, sensors should be calibrated to get reliable measurements in all nodes. All sensors should be tested with 94 dB level at 1 kHz at 1 m distance in a controlled environment such as an anechoic chamber, by means of a calibrator.

3. Hardware Design

All units of the WASN are identical to simplify the scalability in number of nodes. Concretely, each node contains a Raspberry Pi 3B+ [10] (RPi) as its computational unit. Since the system has been designed to be steadily active, the node may reach high temperatures. To avoid heating problems, a heat sink has been placed to cool it down. It is important to highlight that the heat sink should not include a fan, as it would generate noise, thereby affecting the measurements conducted by the microphone.

The selected computation unit (i.e., RPi) has four USB ports and a 40-pins GPIO header to connect different peripherals and a WIFI modem to transmit data. As a lowcost alternative of an acoustic sensor, a plug-and-play USB Microphone with an external ADC integrated in the serial bus has been chosen. The sensor has an omnidirectional acoustic pattern that allows to capture all possible sound sources from any direction at a maximum sampling rate of 48 kHz at 16 bits [11]. This electret condenser microphone is USB powered. Thus, it increases the electrical power consumption of the unit. To ensure a correct full functionality, the node requires a 5 V 3 A power supply. Figure 1 shows the elements that compose each node of the network. In order to make the nodes suitable for a real-world deployment, all the elements are integrated in a small 3D printed rectangle box designed with SketchUp [12] with holes for the power wire, the microphone capsule and heat dissipation. The box integrates all the parts into a single node element minimizing the size to the maximum and protects the node.

Figure 1. Hardware description for each node of the network.

Table 1. Main features and components of the nodes of the network.

Component	Model	Main Features	Price
Lavelier USB 16 bits/sample 48 kHz	Microphone	LYM00002	11€
SDRAM 1 GB 64 bits CPU at 1.4 GHz WiFi connection	Computational unit	Raspberry Pi Model 3B+	37€
Power supply	UGREEN CD122	18W/5V/3A	12€
USB wire	USB to microUSB	3€	
Total	63€		

4. Design Process and Evaluation

The sensor design has to balance a low component price and a good performance to obtain an accurate and reliable WASN. The microphone features will limit the accuracy and sensitivity of the measurements. For this reason, different microphone models were compared in order to ensure that the microphone used in the setup is economical and has a frequency response as flat as possible. Concretely, authors compared the following models: (i) Micro Electro Mechanical System (MEMS) were discarded as the frequency response of the microphone was not flat enough; (ii) a high-precision measuring microphone (Behringer ECM8000) was discarded as well as it is too big for the purpose of the project (it doubles the size of the RPi) and requires and external ADC; (iii) the KY-038 microphone was discarded too as its output is analog, therefore requiring an external ADC; (iv) a USB plug-and-play Microphone (LYM00002) has a flat frequency response, enough sensibility and incorporates an ADC. Hence, the USB microphone specifications together with its reduced price make this microphone ideal for the project.

Regarding to the selection of the CPU module, another comparison was done to ensure that the nodes are capable of locally processing data to avoid sending raw data streams to another node. Models such as Jaguar One or Banana Pi were discarded as their support community is not as big as the one offered by Raspberry. Those CPUs offering extra characteristics not needed for this project (e.g., Hummingboard, Cubieboard5) were discarded too. Finally, models lacking of a WiFi module (PcDuino4, ODROID-C2, Beaglebone Black) were discarded as well. Raspberry pi model 3B+ offers good computer capabilities at a reasonably low-cost and a wide support community. To test the capabilities of the acoustic sensors, each node has been programmed to process an audio stream sampled at 22.05 kHz, with a bit depth of 16 bits and in 4 s windows. Specifically, the sensors calculate continuous acoustic descriptors such as the equivalent loudness level each 4 sec. As the audio streams are processed locally, sensitive information (i.e., raw audio data) is kept in the node and only non-private data is sent through the network. The nodes of this work run OS Raspian Lite, and conducted test have shown that the system uses the 100% of CPU and 20% of RAM when running the software test, which is continuously (i) acquiring 4-s windows of raw audio data, (ii) processing the audio streams to obtain acoustic descriptors such as the equivalent level, and (iii) storing the data descriptors in the node’s memory and sending them to a cloud server together with a time-stamp.

To synchronize the different nodes of the network, the Network Time Protocol (NTP) has been chosen. To validate the correct functioning of the synchronization, a test software was programmed to be executed automatically in the nodes after booting the system. In this test software, the node waits until a specific minute to start recording a *.wav file. Once the recording started, some acoustic impulses were generated at the same distance of two microphones and, later on, the two *.wav files were manually analysed. Results on the analysis validate that the delay between both files impulses was about 1 ms.

5. Conclusions

A low-cost WASN has been designed for acoustic indoor and outdoor monitoring. Each node of the WASN includes a Raspberry Pi 3B+ which processes in real-time the audio captured by an USB microphone, to evaluate several acoustic features, which afterwards are sent to the cloud. The minimum requirements to draw a soundmap of the environment using the data sent by the nodes have been also analysed depending on the environment. Conducted tests ensure the synchronisation between the nodes, thus avoiding the need of a hub. The decentralised design together with the use of non-sensitive features, allow us to envisage the application of the proposed WASN in surveillance of active elderly in their own homes or in the street for noise monitoring solutions. Moreover, the proposal has taken into account scalability, so a more complex signal processing could be done in the nodes in the future. The authors set as future lines the detection of acoustic events of interest, which could be implemented in the nodes, and predefined alarms could be triggered accordingly.

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Abbreviations

The following abbreviations are used in this manuscript:

ADC: Analog to Digital Converter
MEMS: Micro Electro Mechanical System
NTP: Network Time Protocol
WASN: Wireless Acoustic Sensor Network

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