Development of an IoT-based Noise Monitoring Network

Aram Mohammad Abdulqadir[1], Mohammed Hussein Shukur[2]
Department of Computer Science
Cihan University - Erbil
Erbil – Iraq
E-mail: {[1]aram.m@cihanuniversity.edu.iq, [2]m.kurd@hotmail.com}

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***Abstract*— In this paper, we proposed an IoT-based sound pollution checking system. It is a method of an economical acoustic sensor developed on the Raspberry-Pi, for its use in the analysis of the noise level in the classroom. This prototype is connected to an online server to share results in the actual time. This experiment has shown the Raspberry-Pi as an impressive and low-cost computing core of an affordable device to evaluate the environmental sound pollution that affects student satisfaction and performance in higher education classrooms.**

***Keywords-** Noise Monitoring; Smart Classroom; Noise Awareness; IoT; Raspberry Pi*

I. INTRODUCTION

While at university students are exposed to various types of noise including external, environmental noise and noise generated within the classroom. Earlier researches have shown that sound-pollution has detrimental effects upon students' performance at university, including reduced memory, motivation, and learning capability. The noise impact on student and their lecturers have been inspected by researchers in the past 40 years. It is generally accepted that noise has a detrimental effect upon the cognitive development of students.

Noise pollution is the inordinate noise measure or pesky sounds that unsettle students and distracting them in the lecture halls and workplaces. This kind of pollution has different effects on students' health, physically and psychologically [1]. Main sources of noise pollution inside campus are high volumes of outside traffic and human-based sounds.

Recently, there has come into a new concept of computers. These new devices are also known as Single Board Computers (SBC) [2], being smaller than classic computers and with the differentiating feature of being more economical and affordable. This new kind of small computers has illustrated its computing power together with its scalability for real projects [3]. There are different SBCs in the market with different capabilities of connectivity, computing power, size or power efficiency. Raspberry-Pi, ASUS Tinker Board, Intel Edison, Arduino are widely used in this development area [4].

The role of acoustic researching in the smart classes has a series of applications and advantages such as having more control of noise levels by permanent and real-time control, detecting new noise sources or using these tools as a showcase to warn the lecturers and responsible people. From the view point of classroom-administration, it helps lecturers to have plan to more control and try to get concentration of students' within the lecture time. The investment and maintenance costs in this kind of devices are more economical than carrying out strategic noise maps repeatedly.

In classrooms, the noise levels are equal to residential environments and accepted are those which not exceed 65 dBA during the day [5]. Accepted standards for recommended permissible exposure time for continuous time weighted average noise, stated that for every 3 dBA over 85 dBA, the permissible exposure time before possible damage can occur is cut in half, e.g., 85 dBA is linked with a permissible exposure time of 8 h; 88 dBA for 4 h, 91 dBA for 2 h [6]. The use of percentile levels in the acoustic analysis helps to have an understanding of the noise fluctuations over time. These are commonly used for environmental noise monitoring, such as road traffic or community noise assessments. With the use of long-term measurements, changes on the levels can be observed from the data, and more advanced studies can be performed in order to evaluate the noise volume.

Monitoring these sources of noise pollution is crucial for the comprehension of how these sounds evolve with time, in order to study it, control it and prevent it.

The work presented in this paper describes the creation of an advanced acoustical sensor connected to a Raspberry-Pi-3. It aims to fill the gap in the noise sensors research and developing field, with the analysis and monitoring of the noise signal in the audible bandwidth. It also calculates the environmental audio parameters done on-board instead of in a remote server. The device also shares the results in an Internet-of-Things (IoT) publishing online platform. The result of the research and development carried out in this paper is a reliable prototype, developed utilize low-cost components, of an advanced acoustic sensor for environmental noise analyzing.

II. MATERIALS AND METHODS

A. Design and Requirements

The design of the device had to perform few necessities for obtaining the final proposed aims. Some statements have to be achieved in until to follow the economic, but dependable, final device. The requirements for this prototype were:

- The device has to utilize cheap parts to develop and make low-cost sensor networks of several devices with a reasonable cost.
- The device has to have trustworthy for long-term measurements.
- The device should have capability to be connected to the cloud for remote updates of the software and for sharing results.
- The quality of the measurements has to be enough for advanced audio parameters' calculation.
- The device has to have enough computing power to do on-board calculations.
- The device has to be able to connect to the peripherals needed for the purposes of the project (e.g., a microphone).
- The device has to be able to interpret Python programming language.
- The sound flow acquisition has to have the less noise inputs as possible, for avoiding extra filtering steps.
- The final device has to be protected against outdoor conditions using a protective housing.
- The device needs to have different connectivity options (i.e., Wi-Fi or Ethernet).
- The distance from the nodes to the Access Point (AP) should be a maximum of 200 m.

B. Selection of the Components

The main component of the device is the main-board processing unit, which is also used for the attainment of data and the connectivity. For reaching the requirements, the design of the noise checking and analyzing device was based in a Raspberry-Pi-3 Model B single board computer [7]. The Raspberry Pi platform offers a number of superiority as its good computing power, its high versatility and the existence of libraries of Python functions. The power efficiency and the cost give opportunity to create numerous devices based on this platform, resulting in economic and long-range nodes. Those capabilities made the Raspberry-Pi-3 the most suitable SBC for the development of a working prototype.

In this project, by the help of General-Purpose Input/Output (GPIO) which is a generic pin on the integrated circuit of the Raspberry-Pi-3, a microphone which integrates an audio capture card itself, was chosen and connected through the GPIO ports.

- The Raspberry Pi

The advantage of using the Raspberry-Pi-3 is the capability of working under a free OS. Here for this device, a Raspbian distribution [8], a GNU/Linux OS distribution for Raspberry-Pi-3, has been installed. The algorithms were developed in Python. The Internet connection of the device also provides the possibility of remote connection, with the help of SSH (Secure SHell) [9]. Through a terminal by typing a command it is possible to have access to the Raspberry-Pi-3 and modify the algorithms, software maintenance jobs or checking the system can be done from remote places. pyAudioAnalysis library [10] controls the audio configurations, managing the audio in an optimized way.

Based on the bandwidth requirements for continuous information transmission, the board allows different options. In the case of this device and its deployment, the option of the Wi-Fi (IEEE 802.11n) connection was chosen. The use of a Wi-Fi connection in the deployment instead of an Ethernet LAN seeks for two main objectives: first, while a wireless connection is subject to more freedom degree to than a wired connection regarding the location of installing device. And Ethernet cables may make untidy and cost more than Wi-Fi connection, so for proper communications and avoid these problems wireless connection is preferable.

In this way, a microphone with integrated board has wired to the Raspberry-Pi-3 board. A wireless Access Point (AP) is responsible for establishing the connection between the device and the Internet.

The Raspberry-Pi-3 board has powered by a 5 volt -2.5 amps power supply. And the whole microphone board getting the power from the Raspberry-Pi-3 board. The connection and arrangement in figure-1 has shown as follow.

Figure 1. Operation scheme for RB-Pi-3, Sensor (Microphone) and connectivity via Internet.

The code has developed in Python programming language. In Figure 2, a complete block diagram of the whole acoustic device is presented, where all the functioning blocks of the system are shown. One of the inputs of the system is the acquisition of the sound by the microphone sensing and capturing the environment sound and converting the analogue-sound-signal to a digital-signal with the sound card integrated in the microphone. Then it goes to the Raspberry-Pi-3 processing stage for the parameters extraction. Next, the data are formatted to send the parameters in real time to the server if noise level crosses the threshold. Then the lecturer gets awareness from the server.

The notification to the lecturer receives notification on his Computer or Mobile including status of his classroom and which parameters of his classroom have exceeded from the standard level.

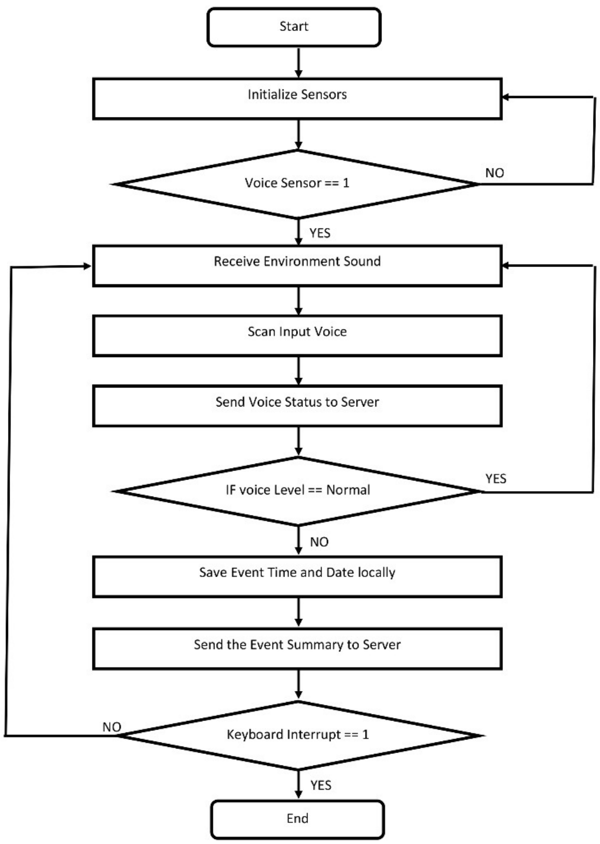

Figure 2. Block diagram of the complete system. The inputs of the system are the sound acquisition that goes through the T-Bone GC100. Raspberry-Pi-3 Model B, is in charge to remove power line noises. Then it analyzes the signals and in case of abnormal situation it sends the status to the server.

III. ALGORITHMS IMPLEMENTATION

The Raspberry-Pi-3 Model B platform was chosen as the core of the device because it is multi-propose and has high versatility. Implementation is easy and the algorithms using a known and wide spread programming languages. Here Python language has used for this propose. The audio acquisition was made through pyAudioAnalysis which uses a portion from the Raspbian kernel meant to prepare and supply the system with audio functionalities, e.g., automatic configuration for sound-cards and the controlling of devices using one Linux system [10]. It is possible to configure features for the audio capturing like the rate of sampling and the size of the frame, which is the number of samples in each sliding window. Once the audio capturing is configured, analyzing the sound level starts in order to monitor the noise level of environment.

To calculate the audio level, the signal is acquired in a linear way, i.e., instant pressure values. So next step is conversion to a logarithmic scale. In order to summarize how sound is heard and measured.

Sound Pressure Level (L_p) - Sound is usually measured with microphones responding proportionally to the sound pressure. The power in a sound wave goes as the square of the pressure. (Similarly, electrical power goes as the square of the voltage.) The log of the square of x is just 2 log x, so this introduces a factor of 2 when we convert to decibels for pressures. Sound Pressure Level can be expressed as: [11]

$$L_p = 10 \log (p^2 / p_{ref}^2)$$

Where

L_{eq} = *equivalent sound level (dB)*

T = *time period (s)*

p_A = *sound pressure (Pa, N/m²)*

p_{ref} = *reference sound pressure (2 10⁻⁵ Pa, N/m²)*

The maximum acceptable sound pressure level in classrooms which is acceptable is less than 30 *dBA* based on L_p equation. [12]

For this first prototype, it has been equipped with Internet connectivity through an Ethernet connection and this capability has been exploited to store and show the results of the extracted acoustics parameters. This task has been carried out using an online platform called Cayenne. It is a free IoT application and Application Interface to store and retrieve data from the devices using the Hypertext Transfer Protocol and MQTT over the Internet [13]. Moreover, the platform enables the creation of sensor logging applications with status updates.

IV. RESULTS AND DISCUSSION

In this work, the design of an acoustic sensor designed which is low-cost but reliable. All of the components and its deployment in a pilot test have been presented.

At the first part, the design of sensor and its components has shown. The methodology to build the algorithm and the cloud connection in real time are explained.

The audio capturing in high resolution allows us to get more advanced results, like the psychoacoustic parameters as a future outcome. Also the power of the Raspberry-Pi-3 as the core of the device gives the possibility of doing the calculations on-board, instead of sending the raw data to a sink node or a server for doing the calculations. So even in the case of network loss still the lecturer will be aware of high level of noise in the classroom.

In a second part of the paper, a pilot test where two devices were deployed was validated. In this deployment, the two devices were working and publishing the results in the real-time in an IoT publishing platform. The analysis of the sound field in long-term measurements inside the device with on-board calculations and the sending and publishing of the data obtained with ease and precision have been achieved. Like an innovative challenge, and through a research process, this sensor has been used for environmental acoustics parameters calculation and for being a platform where the inhabitants of the neighborhood could check the noise levels of their place. This makes the deployment as a tool for noise awareness, apart from simply a tool for gathering data with research purposes.

The platform and methods have chosen for the software development offers some advantages such as a great versatility, a low price for the components and a big simplicity for integrating the final device in classroom, being capable of turning into part of a sensor network as a node.

V. Conclusions

In other studies of the authors [4], low-cost platforms for ambient noise acquisition were proposed without on-board calculations without connectivity. In this work, a fully functional sensor with cloud connectivity has been proposed and tested. Extra features of on-board calculations, real-time data presentation and online access has included as well.

The Raspberry-Pi-3 has proved to be a powerful, versatile and economic computer that can be integrated in a sensor network scheme. Thanks to its connectivity options and the GPIO pins, a standalone computing device for premium sound acquisition and noise monitoring platform connected to the internet have been proved to be feasible. Based on the hardware and the software development for the algorithms and connectivity, it has been exhibited by creating a full functional which developed and tested and it is capable of creating a sensor network with Raspberry-Pi-3-based nodes and even more environmental sensors. We implemented a simple customized sensor node for achieving a high level of quality in teaching classrooms also these sensors can be used for detection of accidence of emergency cases.

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