Acoustic Sensor Network for Acoustic Measurements in Closed Rooms

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***Abstract*— Due to the ever-increasing processing power of the acoustic nodes, Wireless Acoustic Sensor Networks (WASNs) are being assign more complicated and computationally demanding tasks. Recent research has started to exploit this increased processing power in order for the WSNs to perform tasks pertaining to audio signal acquisition and processing forming so-called wireless acoustic sensor networks (WASNs). Wireless acoustic sensor networks are a next-generation technology for audio acquisition and processing. In order for WASNs to cope with these increased demands, it is incontrovertibly apparent that efficient algorithms need to be develop. These algorithms must not only be computationally efficient but must also take into consideration several network wide design constraints in order efficiently allocate the limited resources of the nodes. The main aim of this article is, therefore, to incorporate these constraints into the design of Acoustic Sensor Network for Acoustic Measurements in Closed Rooms.**

***Keywords*— acoustic sensors, acoustic sensor network, Internet of Things (IoT), IoT modules, algorithms, neural networks with artificial intelligence**

I. Introduction

Wireless acoustic sensor network is an emerging information technology that promises great potential for both military and civilian applications. One of its applications is to generate an acoustic picture of an enclosed room and to calibrate the room's acoustics. Most of the measuring methods that exist depend on three types of physical variables derived from sensor readings: time delay of arrival (TDOA), direction of arrival (DOA) and received signal strength (RSS). Energy (intensity) based method of acoustics measurements is an appropriate choice and has been studied intensively in recent years since it can reduce the computation burden as well as communication bandwidth. One controversial concept is the usage of A-weighted measurements. There are studies putting forth the pros and cons of using this weighing. Other important factor is the acoustic environment, how to characterize or analyze it.

The criteria's that should be included are mainly, the ambient noise present in the space, the separate noise sources, the nature of each different source of sound, the number or presence and the weight of sound sources and the history of the sound environment. Such factors should be handle in close contact with the objective factors as both objective and sonic factor guide and give clues about one another [1].

The main purpose of this article is to develop acoustic sensor network for acoustic measurements in closed rooms.

II. Proposition and General Description of Acoustic Sensor Network Block Schema for Acoustic Measurements in Closed Rooms

In Fig. 1 is present general description of the proposed acoustic sensor network block-schema for acoustic measurements in closed rooms. The purpose of this acoustic sensor network is to create an acoustic picture doing the necessary acoustic measurements in a given closed room, concert hall, studio, etc.

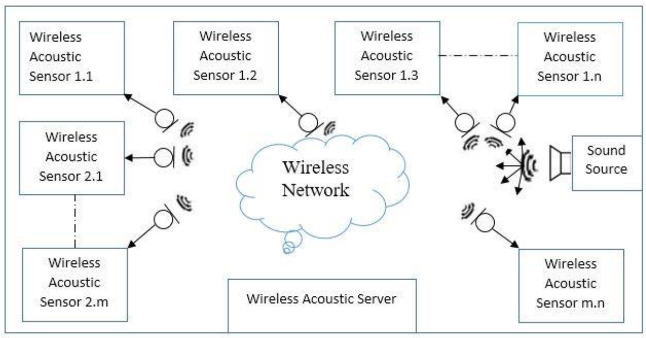

Fig. 1. General description of the proposed acoustic sensor network block- schema for acoustic measurements in closed rooms.

The proposed acoustic sensor network consists from a lot of acoustic sensors named and numbered in Fig.1 as "Wireless Acoustic Sensors 1.1, 1.2, 1.3,…..2.1,…..2.m,…..mn". All "Wireless Acoustic Sensors" are chosen to be the corresponding IoT modules, in this case based on Raspberry PI 4, with the abilities to capture sound received from microphone and to send the received sound signal to the "Wireless Acoustic Server" via "Wireless Network", as it is shown in Fig.1. For the purpose of the proposed acoustic sensor network, to carry out the acoustic measurements in closed rooms, it is necessary to have many test sound signals. These test sound signals are generating from the "Sound Source" as it is show in Fig.1.

In the next part of this article are presented the equations corresponding to each of the received from microphones and to send the received sound signals to the "Wireless Acoustic Server" via "Wireless Network".

III. Basic Equations Describing All Signals of the Block Diagram of the Proposed Acoustic Sensor Network.

The equations, presented below, illustrate every signal of the block scheme on figure 1. The equation of the signals of the "Sound Source" is as follows:

$$s_{source}(\text{t}) = \{s_{source}^{mic}(t), s_{source}^{sine}(\text{t}), s_{source}^{media}(\text{t}), s_{source}^{signal}(\text{t})\} \quad (1)$$

where:

$s_{source}(\text{t})$- a function of the transmitted signal of the sound source;

$s_{source}^{mic}(t)$ - a function of the transmitted signal of the microphone;

$s_{source}^{sine}(\text{t})$ - a function of the transmitted signal of the sound wave generator;

$s_{source}^{media}(\text{t})$ - a function of the transmitted signal of the multimedia file;

$s_{source}^{signal}(\text{t})$ - a function of the transmitted signal of the workspace.

The equation of the signals of the "Wireless Acoustic Sensor" is:

$$s_{sensor}(\text{t}) = \{s_{sensor}^{mic}(t), s_{sensor}^{sine}(\text{t}), s_{sensor}^{media}(\text{t}), s_{sensor}^{signal}(\text{t})\} \quad (2)$$

where:

$s_{sensor}(\text{t})$ - a function of the received from the sensors signal;

$s_{sensor}^{mic}(t)$ - a function of the received from the sensors signal, in case of source=microphone;

$s_{sensor}^{sine}(\text{t})$ - a function of the received from the sensors signal, in case of source=sine wave generator;

$s_{sensor}^{media}(\text{t})$ - a function of the received from the sensors signal, in case of source=multimedia file;

$s_{sensor}^{signal}(\text{t})$ - a function of the received from the sensors signal, in case of source=signal from the workspace;

The equation of the signals of the "Wireless Acoustic Server" is:

$$s_{server}(\text{t}) = \{s_{server}^{mic}(t), s_{server}^{sine}(\text{t}), s_{server}^{media}(\text{t}), s_{server}^{signal}(\text{t})\} \quad (3)$$

where:

$s_{server}(\text{t})$ - a function of the received from the server signals;

$s_{server}^{mic}(t)$ - a function of the received from the server signal, in case of source=microphone;

$s_{server}^{sine}(\text{t})$ - a function of the received from the server signal, in case of source=sine wave generator;

$s_{server}^{media}(\text{t})$ - a function of the received from the server signal, in case of source=multimedia file;

$s_{server}^{signal}(\text{t})$ - a function of the received from the server signal, in case of source=signal from the workspace;

The equations of the input signals for processing in the "Acoustic Network Server" are:

$$s_{server}^{mic} = s_{sensor}^{mic} = A_{i,j} s_{source}^{mic}(t, \varphi_{i,j}) \quad (4)$$

$$s_{server}^{sine} = s_{sensor}^{sine} = A_{i,j} s_{source}^{sine}(t, \varphi_{i,j}) \quad (5)$$

$$s_{server}^{media} = s_{sensor}^{media} = A_{i,j} s_{source}^{media}(t, \varphi_{i,j}) \quad (6)$$

$$s_{server}^{signal} = s_{sensor}^{signal} = A_{i,j} s_{source}^{signal}(t, \varphi_{i,j}), \quad (7)$$

where:

$A_{i,j}$- amplitude of the signal, for $i = 1{:}m$, $j = 1{:}n$

$\varphi_{i,j}$- phase of the signal, for $i = 1{:}m$, $j = 1{:}n$

The above equations of the signals are use in the development of a Matlab program to visualize an acoustic picture.

IV. MATLAB SIMULATION OF THE PROPOSED ACOUSTIC SENSOR NETWORK FOR ACOUSTIC MEASUREMENTS IN CLOSED ROOMS.

In Fig. 2 is presented the developed model in Matlab Simulink software system [2], for model and simulation of the proposed acoustic sensor network for acoustic measurements in closed rooms.

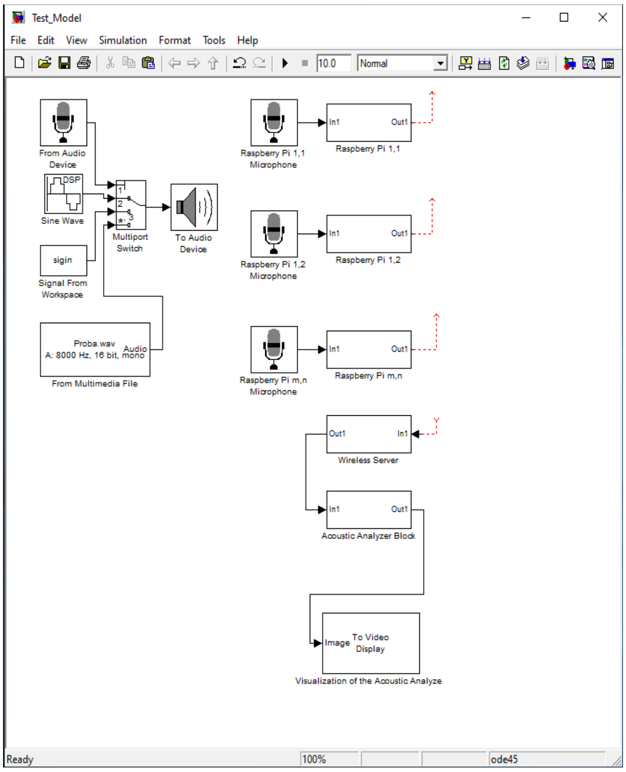

Fig. 2. Block scheme of the developed model in Matlab Simulink software system, for modeling and simulation of the proposed acoustic sensor network for acoustic measurements in closed rooms.

In the simulation of the developed model of the proposed acoustic sensor network for acoustic measurements in closed room, created as Simulink model in Matlab programming system, are included three parts: the left part of the simulation is the Sound Source and on the right are the acoustic sensor nodes and the wireless acoustic server.

The sound source is composed of six blocks: “From Audio Device”, “Sine Wave”, “Signal From Workspace”, “From Multimedia File”, “Multiport Switch” and “To Audio Device”. The “Multiport Switch” switches between the different audio sources- a signal from an audio device; from a sine wave generator, generates a real or complex, multichannel sinusoidal signal with independent amplitude, frequency, and phase in each output channel; from workspace and from multimedia file. In real practical experiments, for a sound generator, a MIDI synthesizer can be use, as done in the article “Development of a MIDI synthesizer for test signals to a wireless acoustic sensor network” [4]. To the “Multiport Switch” is connected a speaker to reproduce the selected audio signal.

The acoustic sensor nodes include a microphone (RaspberryPi 1,1 Microphone, RaspberryPi 1,2 Microphone, RaspberryPi m,n Microphone) and a RaspberryPi single-board computer (Raspberry Pi 1,1, Raspberry Pi 1,2, Raspberry Pi m,n). The microphones capture the audio signal from the Sound Source and RapberryPi- modules process the acoustic information from the microphones and upload it wirelessly to the Wireless Acoustic Server.

The Wireless Acoustic Server includes three blocks- “Wireless Server”, “Acoustic Analyzer Block” and “Visualization of the Acoustic Analyze”. Once the acoustic information is upload to the wireless server, the acoustic analyzer reads and analyzes the information. After that, the necessary information can be display to a video display.

The model developed in the Matlab Simulink software system for modeling and simulation of the proposed acoustic sensor network for acoustic measurements in closed rooms can be connect via an interface and executed in real time via the Raspberry Pi 4 module, as shown in Fig. 3 [3].

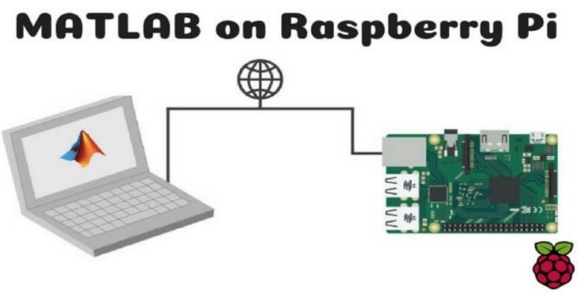

Fig. 3. Connection between the simulation model of acoustic sensor network for acoustic measurements in closed rooms and a RaspberryPi 4

V. EXPERIMENTAL RESULTS OF A SPECIFIC EXAMPLE OF ACOUSTIC MEASUREMENTS FOR THE PROPOSED WIRELESS ACOUSTIC SENSOR NETWORK

Based on the developed model, specific values of the sound pressure are collecting in a certain closed room with “m x n” wireless acoustic sensors.

The processing of the measurement results was performing with the following Matlab program:

```
% Clear Matlab Work Space

clear all
clc
clf

% Open and read the Sound Source Signal
% preliminary saved in file

fd=uigetfile('*.wav');
sigin=wavread(fd);
figure(1)
% Plot as information the just read
% Sound Source Signal
% preliminary saved in file

plot(sigin)
pause(3)

% Define the Length and Width of the
% Closed Room under the Acoustic
% Measurements and Acoustic Analysis

rmL=6;
rmW=4;

% Define the Number in Horizontal and
% Vertical Direction of Acoustic Sensors
% in Wireless Acoustic Sensor Network
% for Acoustic Measurements in a Closed
% Room under the Acoustic
% Measurements and Acoustic Analysis

m=16;
n=12;

% Define the Matrix of Captured from
% Acoustic Sensors Test Signals, which
% then are Transmitted, Received and
% Ready to Processing for Acoustic
% Analysis

sigm(m,n)=0;
rnd=rand(m,n,'single');
for i=1:m
    for j=1:n
    if rnd(i,j)<=0.7
        rnd(i,j)=0.9;
    end
    end
end
for i=1:m
    for j=1:n
    sigm(i,j)=rnd(i,j);
    end
end

% Display as Closed Room Acoustic
% Picture the Results from Carried out
% Acoustic Analysis

[x,y] = meshgrid(1:m,1:n);
x=x';
y=y';
figure(2)
surf(x,y,sigm);
pause(3)
```

```
figure(3)
bar3(sigm,'detached')
pause(3)
```

On the next figures are present the results from the processing with the above presented Matlab program of the measurement sound pressure in a certain closed room with "m x n" wireless acoustic sensors.

Fig. 4 presents the time diagram of the input signal as Sound Source Signal preliminary saved as a file in WAVE format.

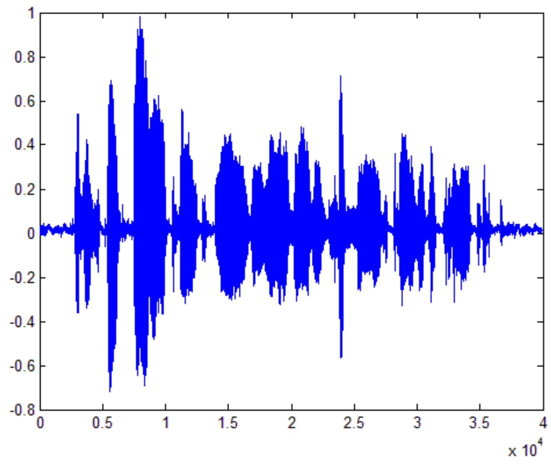

Fig. 4. Time diagram of input signal as "Sound Source" signal in the proposed in Fig.1 acoustic sensor network block-schema for acoustic measurements in closed rooms

In Fig. 5 is shows a 3D model of the sound levels distribution in different points in the closed room. There are some different colours and each colour means different sound level.

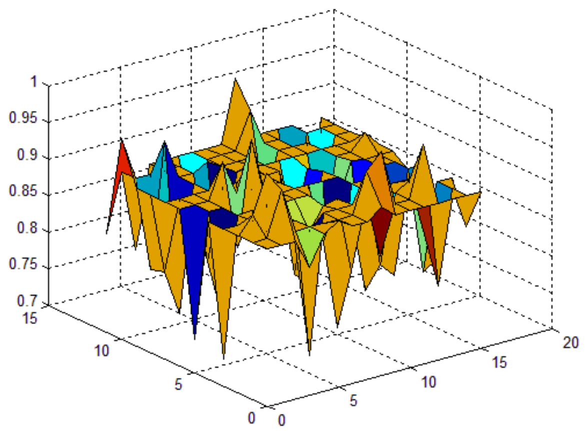

Fig. 5. The ackieved in the experiments 3D model of sound levels distribution in the room under acoustics measurements with the proposed wireless acoustic sensors network

The next Fig. 6 is the same as Fig. 5, but it presents the sound levels and sound distribution in 3D column bar view.

This study and measurements can help to improve the acoustic of a closed room, to calibrate other sensors to detect sounds more precisely or to use a wireless acoustic sensor network to detect acoustic events and to serve like a security system, baby protect system or other IoT integrated systems.

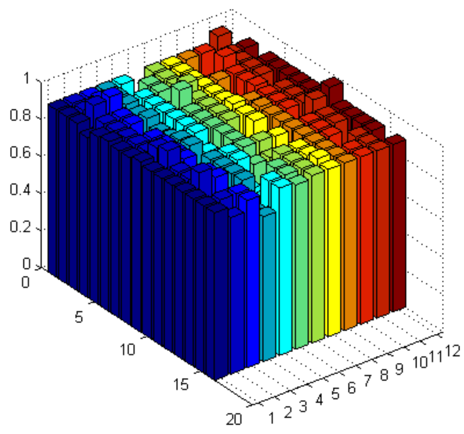

Fig. 6. A column bar 3D model of the sound levels distribution in the room under acoustics measurements with the proposed wireless acoustic sensors network

VI. Conclusion

The following conclusions can be important:

- it is proposed acoustic sensor network for acoustic measurements in closed rooms, which is tested for properly work as it seems from the simulation;

- in real life situation, not only in simulation, the real test signals are produced from a MIDI synthesizer as a sound source in the proposed acoustic sensor network;

- the detailed description of MIDI synthesizer as a sound source in the proposed acoustic sensor network can be found in the article "Development of a MIDI synthesizer for test signals to a wireless acoustic sensor network" [4];

- the captured from acoustic sensors signals are processing to achieve a real 3D acoustic picture of a closed room;

- the achieve real 3D acoustic picture is an important base for quality analysis of acoustics and sound propagation in the closed room and also to decide whether or not are necessary some steps, maybe for all room or only for some places with decreased sound levels, doing the appropriates corrections of acoustic architecture for this closed room under acoustics measurements.

Acknowledgment

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