# Developing a functional scheme of an IoT based module to an acoustic sensor network

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***Abstract*** **- Recent technologies of low-cost computing and low-power devices have opened researchers to a wide and more accessible research field, developing monitoring devices for deploying Wireless Sensor Networks. The acoustic sensor networks are very useful for the science and for the people- building smart home systems, detecting damages, studying the noise pollution in the cities or just making indoor acoustic measurements and acoustic calibrations. One of the most important parts in the acoustic sensor networks are the acoustic sensors. They provide "the material" that the processing unit analyzes after the measurements. It is very important these acoustic sensor networks to be improved and automated. This is the main goal of this article and it brings a solution developing a functional scheme of an IoT based module. The proposed acoustic sensor will be applied in the future research works to develop algorithms for processing, analyzing and transferring the captured acoustic information in an acoustic sensor network, using deep learning neural networks and artificial intelligence.**

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

## I. Introduction

The acoustic sensor networks are very useful. They participate in many scientific works, but also people integrate them in real life solutions. They have many applications- underwater monitoring and communication [1], environmental monitoring [2], birds localization [3], smart phone tracking [4], security systems [5], noise pollution monitoring [6], etc. In addition of the listed above applications there are also a lot of professional acoustic sensor networks applications. The proposition in this article is to apply the acoustic sensor networks for acoustic measurements in sound studios or concert halls using the acoustic sensors to collect sound levels in different points of sound studios or concert halls. The captured from acoustic sensor audio information can be then transmitted in an appropriate acoustic sensor network, processing and analyzing to estimate the whole acoustic image or situation in the measured sound studios or concert halls. Therefore, the concrete goal of this article is to develop the functional scheme of an acoustic sensor, based on IoT (Internet of Thinks) module and to be the main part of an acoustic sensor network for carried out the acoustic measurements in sound studios or concert halls. The proposed in this article acoustic sensor will be applied in the future research works to develop algorithms for processing, analyzing and transferring the captured acoustic information in an acoustic sensor network, using deep learning neural networks and artificial intelligence.

## II. Devloping Functional Scheme of IoT Based Module for the Proposed Acoustic Sensor

### A. *General description of acoustic sensor node using IoT based module*

One of the most important parts in the acoustic sensor networks are the acoustic sensors. They provide the suitable acoustic information that the processing unit analyzes after the carried out acoustic measurements. In Fig. 1 is presented the block scheme of acoustic sensor node. It shows the main units and the operating principle of one acoustic sensor node.

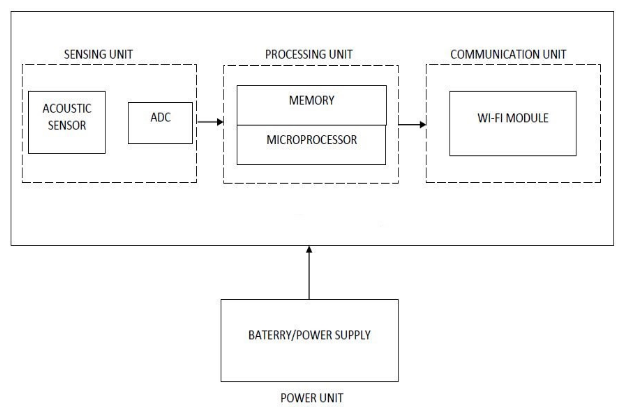


Fig. 1. Block scheme of acoustic sensor node.

The sensing unit contains mainly two parts: an acoustic sensor and analog-digital converter (Fig.1). The acoustic sensor captures sounds and noises and delivers analog signals to the system. But the system works with digital signals, so they have to be converted by the analog-digital converter. Once the signals are already digital, they are processed by the processing unit (Fig.1). This unit consists of an IoT module with a powerful processor and RAM to provide fast calculations, implementation of algorithms, as well as reading, recording and storing the acoustic parameters. The communication unit is a Wi-Fi module that connects the system to Internet and provides remote control, pairing with another acoustic sensor node and data transfer from the system to the cloud or server (Fig.1). The power unit represents the power source. It can be battery or direct power supply (Fig.1). Based on the general description of an acoustic sensor node using the base module with IoT, a specific selection of a base module with IoT should be made, in accordance with the necessary parameters and purpose as an acoustic sensor.

### B. *Selection and description of the base module*

All of the base modules for the sensor networks, including the considered in this article the acoustic sensor networks, need the powerful processing unit. It can be a personal computer or laptop. Recently, there has emerged a new concept of computers. These new devices, named briefly IoT (Internet of Thinks) modules, also known as Single Board Computers (SBC), being smaller than classic computers and with the distinguishing feature of being more economical and affordable. This new kind of small computers on IoT technology has demonstrated its computing power together with its scalability for big projects. There are different SBC's computers or IoT modules in the market with different features of connectivity, computing power, size or energy usage like Raspberry Pi [7], BeagleBone [8], Arduino [9], Odroid [10], which are used in wide range of development fields. Usually some of them have disadvantages like no wireless connectivity, low or insufficient computing power or difficulties for real time tasks execution. Therefore, the preliminary goal in this article is to overcome these disadvantages and in this way to correctly select and choose the needed base module for development of the proposed in this article acoustic sensor module. To do this it is necessary to carried out the appropriate comparative analysis on the base of which to decide and choose the type of base IoT module. On the basis of a detailed research and comparison of the characteristics of different models of IoT modules as Raspberry Pi, BeagleBone, Arduino, Odroid, the most suitable for the needs of the study is Rasberber Pi 4. It has small dimensions and many communication ports. Its quad core processor and four gigabyte RAM make it very powerful. Provides Gigabit Ethernet connectivity, WiFi, Bluetooth and three options for power supply via USB-C connector, GPIO port and PoE (Power over Ethernet). From the results of this comparative analysis it is possible to decide and to propose the usage of the popular IoT module Raspberry Pi 4 [7] as IoT based module in development of the functional scheme of acoustic sensor module with IoT technology, which is the main goal in this article. The main arguments to this choice are the existence of Wi-Fi communication facility in Raspberry Pi 4 and the sufficient processing power mainly necessary in development of algorithms with deep neural networks and artificial intelligence for processing, analyzing and transferring acoustic information in the next development of the whole acoustic sensor network.

In Fig. 2 is presented the block scheme of the proposed Internet of Things module, illustrating the existing main functional units in the internal structure of the single board computer "Raspberry Pi 4".

From software point of view the benefit of using the Raspberry Pi 4 is the possibility of working under a free operating system (a Raspbian distribution, a GNU/Linux OS distribution), which is installed on a SD card. The operating system, based on Linux, includes ALSA library that controls the audio sensors or microphones configurations, managing the audio in an optimized way. Other benefits are the good computing power, thanks to the powerful quad core processor and the 4GB LPDDR4 memory, the existence of libraries in MATLAB as functions and Simulink functional blocks. Based on the bandwidth requirements for continuous information transmission, the board allows different options, principally Ethernet, Wi-Fi and Bluetooth.

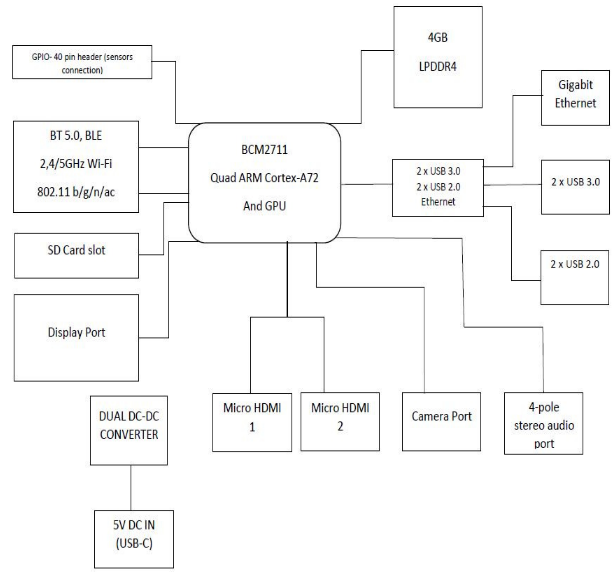


Fig. 2. Block scheme of the chosen IoT module Raspberry Pi 4 proposed to be used as base in the developed acoustic sensor node.

The Internet connection of the device provides the possibility of working remotely, thanks to the SSH (Secure Shell). Through a command terminal it is possible to access the device and update the algorithms, software maintenance tasks or checking the system, remotely. Raspberry Pi 4 provides many communication interfaces: GPIO (40 pin header) and four USB ports for connecting acoustic sensors, microphones and other peripheral devices. The use of a LAN connection is more reliable than a wireless system for two main reasons: first, a wireless connection is subject to more interference than a wired connection, Ethernet cables can be properly shielded, avoiding these unwanted effects; and second, wireless connectivity is more vulnerable to hacker attacks. The main parts of the presented in Fig. 2 block scheme of the proposed Internet of Things (IoT) module- Raspberry Pi 4, are very important for the implementation of an acoustic sensor node in an acoustic sensor network, which are the subject of detailed development in this article.

### C. *Functional scheme of the developed acoustic sensor using Raspberry Pi 4 as base IoT module*

In Fig. 3 is presented the functional scheme of the developed acoustic sensor using Raspberry Pi 4 as base IoT module.

The microphone (MIC in Fig.3) with integrated analog-digital converter, connected to the GPIO port of Raspberry Pi 4, captures sounds and noises (Fig.3). Then the preamplifier (PREAMP in Fig.3) converts a weak electrical signal into an output signal strong enough to be noise tolerant and strong enough for further processing. Without this, the final signal would be noisy or distorted.

After that the processor analyzes the amplified digital signals with software, installed on the SD CARD, and extracts acoustic parameters and other acoustic information. The acoustic information can be stored on the IoT module, but this requires a SD CARD with more memory (Fig.3).

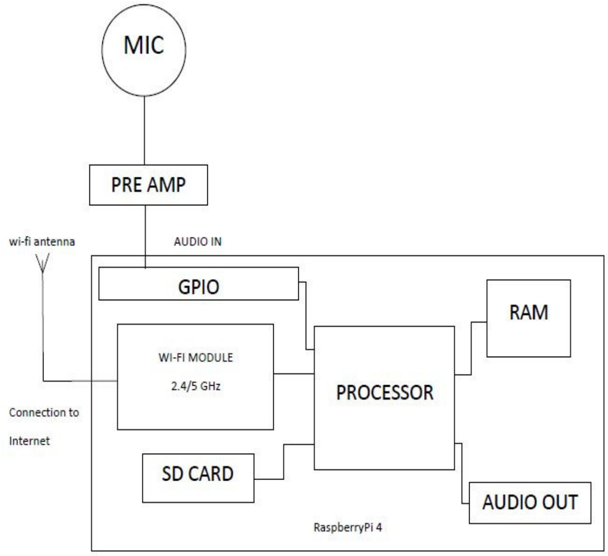


Fig. 3. Functional scheme of the developed acoustic sensor using Raspberry Pi 4 as base IoT module.

Thanks to the Raspberry Pi's Wi-Fi system, the IoT module has a wireless connection to Internet and can upload the database with the acoustic information to a cloud or a private server (Fig.3). Also the wireless connectivity to Internet provides remote control of the module- additional configuration, hardware and software checking, updating audio acoustic software, updating the version of the operating system of the module, etc. Based on the developed functional scheme of an acoustic sensor using a Raspberry Pi 4 base module with IoT, a corresponding structural scheme of an acoustic sensor network can be synthesized.

## III. Synthesis of Acoustic Sensor Netvork Block Scheme Using Raspberry PI 4 IoT Base Module

In Fig. 4 is presented the proposed block scheme of acoustic sensor network using the Raspberry Pi 4 IoT base module. It comprises multiple nodes named in Fig.4 as ACOUSTIC SENSOR 1, 2, 3,…., n, n+1.

The acoustic sensors (ACOUSTIC SENSOR 1, 2, 3,…., n, n+1) in Fig.4, are placed in different positions in the measured sound studio or concert hall. All of the acoustic sensors have, via Wi-Fi antennas, the wireless connectivity to Internet to ensure real time acoustic data transferring, monitoring, remote access to the database and uploading acoustic information to the acoustic network server (Fig.4). Each of the acoustic sensors have ability to capture sounds in their corresponding position. Then, the captured from each acoustic sensor acoustic information, is processed using the appropriate algorithms with applying in them deep learning neural networks and artificial intelligence. The processed acoustic information from each acoustic sensor is then transmitted to the acoustic network server (ACOUSTIC NETWORK SERVER in Fig.4).

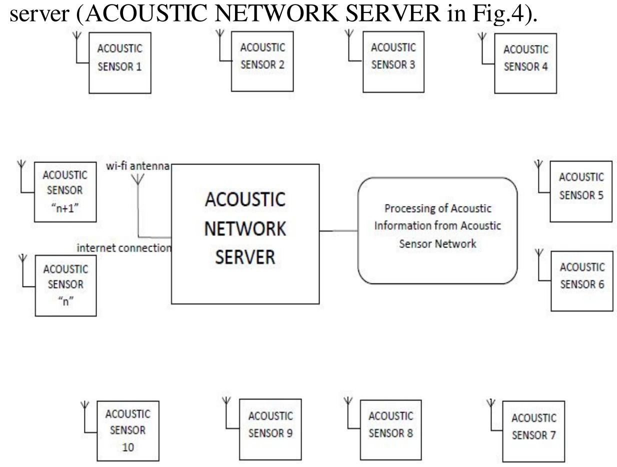


Fig. 4. Block scheme of the acoustic sensor network using the RaspberryPi 4 IoT base module.

The whole acoustic information, received and collected in acoustic network server from all acoustic sensor nodes, is transferred to the block named in Fig.4 as "Processing of Acoustic Information from Acoustic Sensor Network ". The results from processing of whole acoustic information from all acoustic sensor in the block "Processing of Acoustic Information from Acoustic Sensor Network " can give the suitable and useful information for the general view of acoustic situation or acoustic image and for sound propagation measured in concrete audio studio or concert hall and also information of local sound level, which is directly related with sound perception in each point in the measured sound studio or concert hall.

## IV. Creating the Simulation Model of the Developed Acoustic Sensor

In Fig. 5 is presented the created simulation model of the developed acoustic sensor using Raspberry Pi Simulink Library in Matlab programming system.

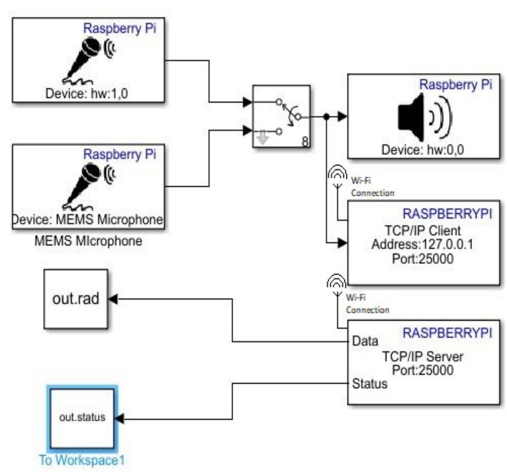


Fig. 5. The creared as Sumulink model developed acoustic sensor using the Raspberry Pi 4 IoT base module.

In the simulation of the developed acoustic sensor, created as Simulink model in Matlab programming system, are included the following Simulink blocks from Raspberry Pi Simulink Library: two types of Microphones, Switch, Speaker, Wi-Fi TCP/IP Client, Wi-Fi TCP/IP Server, out.data and out.status. One of the microphone is with USB-port microphone and other microphone is based on Micro Electrical Mechanical System (MEMS) technology. Each of these two types of microphones can be chosen using the appropriate switch, shown in Fig.5. Testing the developed acoustic sensor with this simulation model is possible to compare the work of two types of microphones and to decide which of them is the best to be used in real work of acoustic sensor. The audio information for correct work of the model can be controlled via Speaker and also via blocks named on Fig.5 as out.data and out.status. The communication between the acoustic sensor and the acoustic network server is realized in the model on Fig.5 as Wi-Fi TCP/IP Client, Wi-Fi TCP/IP Server.

## V. Connecting MEMS Microphone to Acoustic Sensor with Raspberry Pi 4 Base Module Using I2S Interface

### *A. Connecting, using I2S interface, of MEMS microphone and Raspberry Pi 4 IoT base module of the developed acoustic sensor*

In Fig. 6 is presented the proposed I2S interface for connect MEMS microphone and Raspberry Pi 4 IoT base module of the developed acoustic sensor.

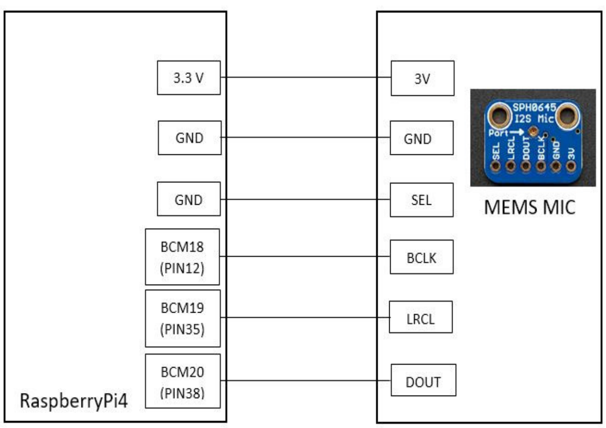


Fig. 6. The proposed I2S interface for connecting MEMS Microphone to the Raspberry Pi 4 IoT base module of the developed acoustic sensor.

The I2S connection (Fig.6) of MEMS microphone to Raspberry Pi 4 is through Raspberry's 40-pin GPIO port [11]. Captured audio data from MEMS microphone are in DOUT and are transferred via pin BMS20 to the Raspberry Pi 4 base module of the developed acoustic sensor.

### *B. Configuration of I2S interface between MEMS microphone and Raspberry Pi 4 IoT base module of the developed acoustic sensor*

The following steps as commands in Linux are used for configuration of I2S audio interface between MEMS microphone and Raspberry Pi 4 IoT base module of the developed acoustic sensor: downloading I2S Raspberry Pi 4 audio module (Fig.7) ; compiling I2S Raspberry Pi 4 audio module (Fig.8) and - verifying that the I2S Raspberry Pi 4 audio module was loaded correctly (Fig.9).

```
git clone https://github.com/PaulCreaser/rpi-i2s-audio
cd rpi-i2s-audio
```

Fig. 7. Downloading I2S Raspberry Pi 4 audio module.

```
make -C /lib/modules/$(uname -r )/build M=$(pwd) modules
sudo insmod my_loader.ko
```

Fig. 8. Compiling I2S Raspberry Pi 4 audio module.

```
lsmod | grep my_loader
dmesg | tail
```

Fig. 9. Verifying that I2S Raspberry Pi 4 audio module was loaded correctly.

## VI. Conclusion

The following conclusions can be listed: it is very important to carefully select the base IoT module (in this case Raspberry Pi 4), considering its audio interfacing ability, high audio information processing performance and Wi-Fi communication with acoustic sensor network. It is expected in future researches to achieve new results, using deep learning neural networks and artificial intelligence, about whole operation of acoustic sensor network with he developed acoustic sensor based on Raspberry Pi 4 IoT module. This will give the information of acoustic situation in audio studio or concert hall and is related with sound perception in each point in the measured sound studio or concert hall.

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