Embedded Data Acquisition System for Beehive Monitoring

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***Abstract*—This paper considers architecture and functionality of the embedded data acquisition system for automated beehive monitoring. A description of constructed sensor subsystems is given. Proposed solution acquires hive temperature, humidity and weight referring this data to the mobile application via wireless network. The system also performs an analysis of collected bee noises with artificial neural network to recognize bee piping and informs the beekeeper to prevent unwanted swarming. Schematics and algorithms of proposed system are represented as well as obtained experimental results.**

***Keywords*—agriculture; apiculture automation; data acquisition; big data processing; beekeeping; embedded systems**

I. Introduction

"Smart house" or "smart farm" systems become more widespread due to the decreasing cost of embedded hardware and emergence of unified platforms such as Arduino [1–3]. These systems represent automated control and data acquisition (DAQ) devices deployed in a house or on a farm territory, which allow reducing labor and energy costs for their maintenance. One of the important fields of applications of this technology is beekeeping. A need for a regular inspection of hives located far from each other makes it difficult to increase a scale of an individual apiary by more than 150–200 hives [4]. The use of ubiquitous pesticides and chemical fertilizers, practiced in agriculture, together with spread of the pathogenic Varroa mites has an additional negative impact on apiculture [5]. Automation and informatization of the beekeeping industry will significantly reduce the number of beehive inspections by beekeepers, which will increase labor productivity and rapidity of response on emergency situations such as swarming.

At the time, several attempts to create a "smart apiary" are known. *Arnia* [6], *Bee Smart* [7], *Maja* [8] are the projects closest to our work. All of them are on early design stages for now and not available to a wide range of beekeepers. Our work is aimed to the creating an inexpensive and efficient beekeeping automation system adapted to the conditions of northwestern regions of Russia.

II. Description of the Data Collection System

The most informative beehive status indicators are weight, the internal temperature and the acoustic noise emitted by the bees. They are also the most convenient indicators to measure simultaneously [9].

The entire DAQ system is assembled on the *Arduino* hardware platform. The following devices are used to measure the abovementioned parameters: MCP9808 temperature sensors, strain gauges with INA333 instrumentation amplifier and two TSa-M30AMP microphones [10].

The system comprises two types of modules:

- Data acquisition module which is placed inside a hive and is connected to all the sensors. This module detects, amplifies and process incoming signals from sensor block.
- Transmitting module which is responsible for sending the data from each hive through mobile network. The data is sent to the remote server which forms information messages and reports for the web applications on the beekeepers' mobile devices and PCs.

Schematics of the acquisition and transmitting modules are shown in Fig. 1 and Fig. 2, respectively.

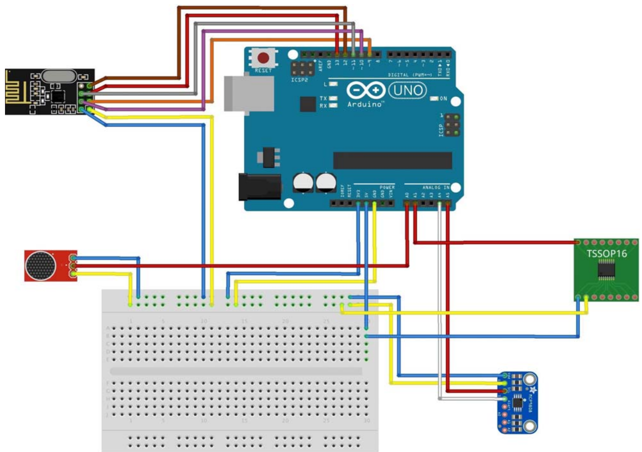

Fig. 1. Scheme of the data acquisition module

In real project the prototyping board was replaced by textolite board. For external protection the plastic body was added, incorporating transmitting module, signal processing system and power supply (Fig. 3).

To reduce the total number of wires in the system, it was decided to use NRF24L01+ radio modules for communication between the data acquisition modules and the transmitting module.

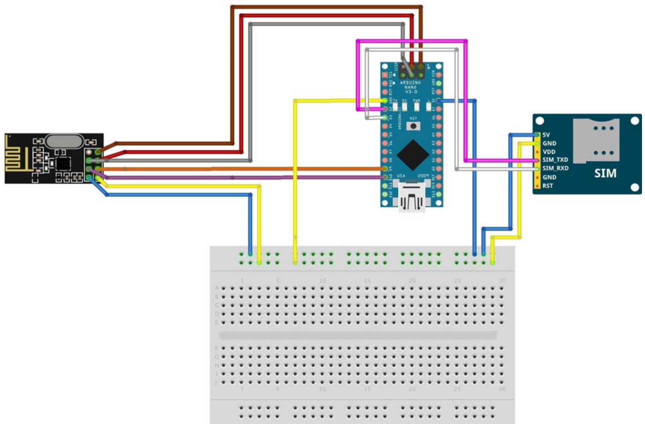

Fig. 2. Scheme of the transmitting module

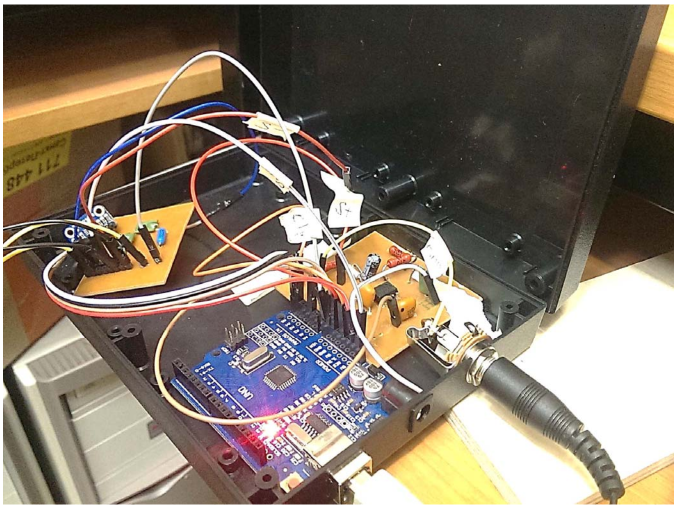

Fig. 3. Electronic components of the system in a plastic body

NRF24L01+ radio modules allow connecting up to 256 hives with built-in DAQ modules to a single transmitting module in a radius of up to 30 meters without using an external antenna. Since radio module NRF24L01+ can address only 6 independent devices, the system provides additional addressing information in the transmitted data packet. In addition, each collecting module acts as a signal repeater for remote modules connection that allows increasing the distance between adjacent beehives up to 30 meters. In this case, the transmitting module can be located anywhere within the apiary area.

III. A NEURAL NETWORK FOR SWARMING DETECTION

This section is dedicated to the design and training of the artificial neural network to recognize the *bee piping*. Swarming is one of the main problems of beekeeping, which harms the honey production in the apiary. Hives, which did not begin swarming bring several times more honey. Capturing swarms and attempting to stop swarming consumes a lot of beekeeper labor [11].

Swarming can be detected using information from the acoustic signals obtained from the DAQ system microphone. Usually, *bee piping* is the sign of the swarming approaching. Bee piping is a special sound, emitted by young queen bees.

Processing sound data is a complex non-trivial task, which can be solved by a neural network learned to recognize the bee piping.

The artificial neural network learned on a certain number of samples is able to assign the signal to the classes of bee piping or regular hive noise. Amplitude spectra of bee colonies sound in a normal condition and in a state of swarming are represented in Fig. 4 [12].

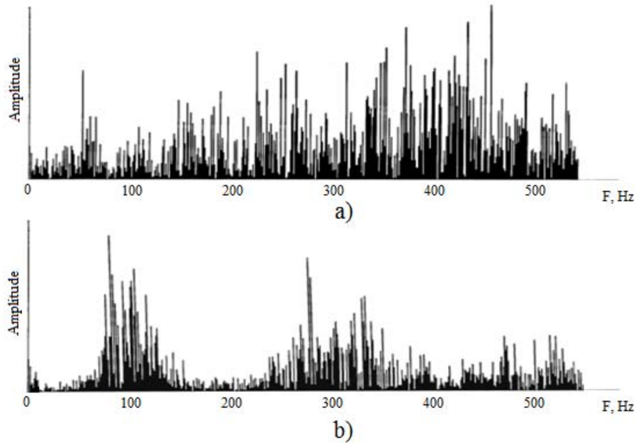

Fig. 4. Amplitude spectra of bee colonies noise: (a) bee colony is in a normal condition, (b) bee colony is in a state of swarming

The artificial neural network with a direct signal transmission (Fig. 5) was used to recognize the bee piping. The neurons are organized into three layers. The input layer is used to receive values of the input variables. Each of the hidden and output neurons is connected to the all elements of previous layer.

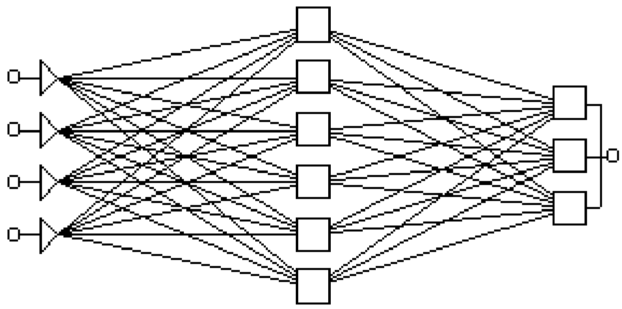

Fig. 5. Neural network for recognition of bee piping

The sound signal recognition algorithm (Fig. 6) implements the following stages:

- The signal is sampled with a certain sampling frequency.
- The resulting set of samples is divided into millisecond-length fragments.

- Wavelet transform of a signal converts the signal from the time domain into the time-frequency domain.
- The input layer of the neural network receives a set of signal fragments. Then the input set is classified, which signal – piping or noise, it represents [13].

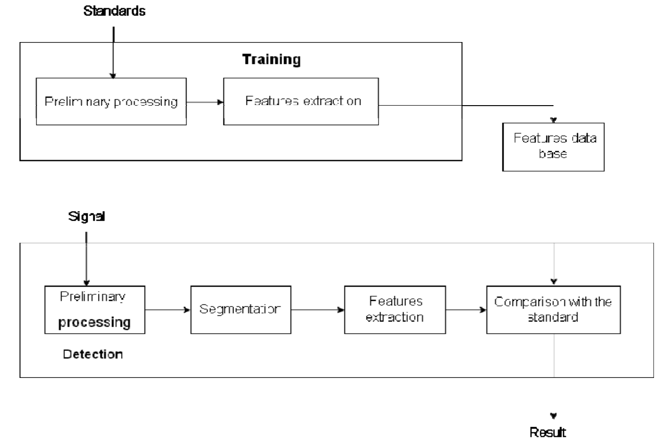

Fig. 6. The general scheme of a bee piping ANN recognition system

MATLAB environment has been chosen as a platform for prototype implementation providing ample opportunities for acoustic signals processing and carrying out laborious mathematical calculations. The *Neural Network Toolbox* included into MATLAB system provides the large set of functions for neural network processing that allows you specifying the network architecture and choosing learning algorithms. The implemented unidirectional three-layer network has the following parameters: 63 input layer neurons, 44 inner layer neurons and 2 output neurons.

The neural network learning is as follows:

- 20 fragments with a length of 2000 samples from the sample audio signal are successively selected, then the wavelet decomposition of the fragments is applied in 3 levels (the Daubechies basis 8 is used). The neural network input data is the resulting wavelet coefficients vectors of the third detailing level.
- A network learns on a sample consisting of 20 wavelet coefficients of bee piping or noise.
- After the processing of each training sample ANN coefficients are adjusted. The training stops when the network becomes able to clearly classify every training audio record [13].

Sound recognition by means of the neural network occurs as follows:

- 20 fragments with a length of 2000 samples from the incoming audio signal are sequentially selected, which are then applied to wavelet decomposition into third level.
- The calculated coefficients are given on the input of the neural network, which determines to which class a fragment belongs.
- The program displays 20-character string as a result, which can be used to assign the signal to the classes of bee piping or noise. If the row consists the letters "0" it is likely to be the noise, otherwise it is the sound of bee piping.

The network was tested on a library of sounds different from training sequence. Some results of ANN testing are represented in Table 1.

TABLE I. RESULTS OF THE ARTIFICIAL NEURAL NETWORK RUNNING

№	Bee piping	Noise
1	10010111011111101101	00010001010100101110
2	11111111111111111111	00000001010100111110
3	01101110101110111110	01000001010000111110
4	01110101010100111110	00000000000000000000
5	00000011111111111111	11100000000000001111

It can be seen that the neural network produces a sufficiently reliable result. For example, a result of a “bee piping” output neuron is a string “01101110101110111110”, which contains fourteen “1” characters and six “0” characters , indicating that the sound is closer to the bee piping. The testing results in Table 1 prove that the developed neural network is suitable for bee piping sound recognition. In the future research implementation of the neural network on a data processing server is intended.

IV. CONCLUSION

At the moment, we have completed a valuable part of our “smart hive” system. The implemented integrated beehive DAQ system collects the most important data from the hive, performs its primary processing and transmits it to a web server. Beekeeper is able to monitor apiary status online and react only if necessary.

The selected hardware platform is a cheap and efficient platform to perform considered tasks.

The most important and complicated part of the proposed system is an artificial neural network used for bee piping recognition in acquired acoustical signals. It is shown that the relatively simple neural network can reliably detect bee piping, allowing the system to warn the beekeeper about the approaching swarming. Further research will cover the hardware ANN implementation, energy-saving algorithms to ensure autonomy of electrical power and software end-user application design.

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