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WSN for Forest Monitoring to Prevent Illegal Logging

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***Abstract*—Illegal logging is in these days widespread problem. In this paper we propose the system based on principles of WSN for monitoring the forest. Acoustic signal processing and evaluation system described in this paper is dealing with the detection of chainsaw sound with autocorrelation method. This work is describing first steps in building the integrated system.**

I. Introduction

LOGGING represents in presence environmental problem. Human used to utilize wood, sometimes in nonsense wasting, so the quantity of forest area is decreasing. This problem is growing with illegal logging without plan. This human behaviour endangers not only economical market, because the costs for producing materials from legal logging is usually higher, but also it endangers flora and the species of animals in danger, that they loosing their natural environment.

In our case, we decided to guard the forest using the WSN. Nodes are spread trough the whole area of guarded forest. We decided to use WSN because the reliability of one node is not sufficient. Other reason is that with WSN we are able to increase the monitored area and increase the reliability of the system with decreasing number of false alarm. For easy and fast recognition of chainsaw we use autocorrelation method.

II. Acoustic Signal Processing

Forest is a very nice and calm place for relax but from the acoustic point of view it is noisy environment with numerous sound sources which are making chainsaw sound detection not so easy. These sources includes birds, wild animals, ambient environment sounds (streams, wind) and human produced sounds.

Sound detection can be done using several means of signal processing including Fourier analysis or methods of template matching implemented by for example Dynamic Time Warping algorithm or Hidden Markov Models. The main priorities while designing the integrated sensor network for described purpose were:

- low power consumption of sensors. This implies using simple and easy to implement algorithms for acoustic signal aquisition, processing and analysis
- low cost of sensors
- small sensor size to prevent rising suspition
- very low probability of false alarms
- high reliability

Chainsaw sound is produced mainly by internal combustion engine with 6000 - 18000 rpm. This results in acoustic signal with fundamental frequency $f_0 = 100 - 300$ Hz or period $T_0 = 3 - 10$ ms. ($T_0 = 26 - 80$ samples for sampling frequency $f_s = 8$ kHz). After considering the properties of acquired signal the autocorrelation method of analysis was chosen for evaluation for its simplicity and implementation possibility in integer. It can be defined as follows [1]:

$$R(m) = \sum_{n=-\infty}^{\infty} x(n)x(n+m) \qquad (1)$$

where $x(n)$ is analysed signal of length N and $R(m)$ is the autocorrelation sequence of length $2N - 1$.

Autocorrelation sequence is odd function with maximum value at $R(0)$ witch stands for the energy of analyzed signal $x(n)$. Several local maximums are occured at the indexes $m = T_0, 2T_0, 3T_0, \ldots$ where T_0 is the period of analyzed signal in samples. Autocorrelation sequence $R(m)$ of chainsaw sound $x(n)$ is shown at "Fig. 1".

III. Signal Processing Implementation

Acoustic signal acquisited from ambient environment by microphone is transferred into digital form using Pulse Coded Modulation with sampling frequency $f_s = 8kHz$ with 12-bit precision.

Intensity of acquisited sound signal ensures waking up the microcontroller using interrupt request. Thereafter time window of 1024 sound samples (128ms) is being stored in memory and analyzed for fundamental frequency presence using autocorrelation method. Because of autocorrelation sequence symetry only positive indexes m are computed.

The higher the index value i the higher the probability of engine fundamental frequency presence in analyzed time window.

If 3 analyzed time windows in sequence are declared with presence of engine fundamental frequency, the sensor will sleep until the next global network communication occures

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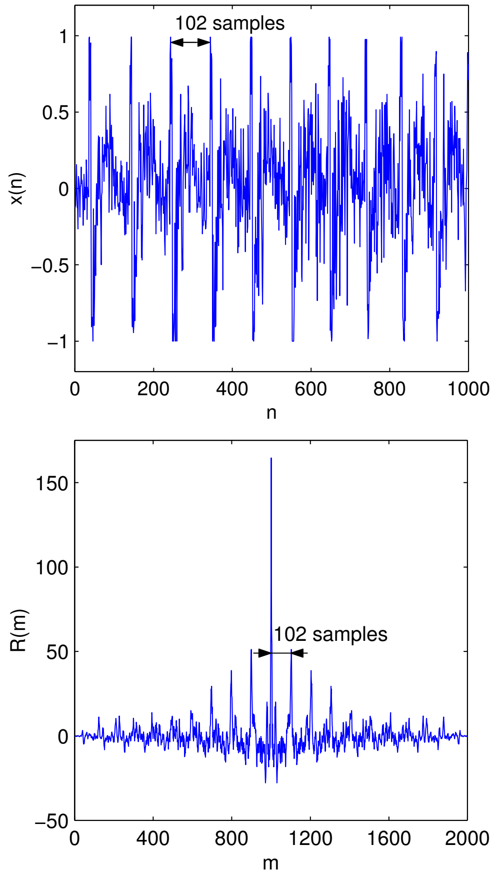

Fig. 1. Autocorrelation sequence of analyzed chainsaw acoustic signal

Algorithm 1 Chainsaw voice detection algorithm

1: $i = 1$;
2: Coefficient $R(0)$ is used as an referency to set up the detection algorithm sensitivity;
3: i^{th} local maximum for $m = 20 \dots 85$ of $R(m) > \frac{R(0)}{5}$ is then found;
4: **if** the result of local maximum search is $\emptyset$ **then**
5: break;
6: **else**
7: index of i^{th} local maximum m_i is stored in memory(retained);
8: **end if**
9: Afterwards first m_i autocorrelation sequence coefficients are stripped of, index i is raised by 1 $(i++)$ and we continue with step 2;

and the interrupt requests form the microphone are masked during this time.

The information output from single sensor includes these data:

- fundamental period (if present in analyzed time windows)
- acquisited sound intensity
- no. of local maximums found (i value) which stands for probability of engine fundamental frequency presence ($T_0 = 3 - 10$ ms) in analyzed time window.

IV. Experiments and Results

The following experiment was performed with the development board shown in “Fig. 3” in the real forest environment [2], [3]. This development board was recently used for similar application [4]. Sound of chainsaw lasts for 10 seconds 5 times from different distance. The Results of chainsaw sound evaluation correctness depending on distance are shown in “Fig. 2” During testing there was no time window evaluated with presence of engine fundamental frequency when this event has not really occured (no false alarm appeared).

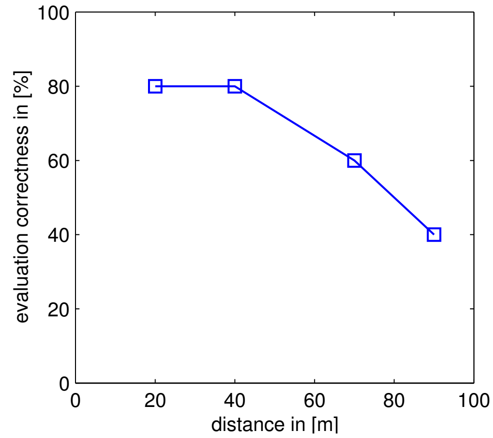

Fig. 2. Chainsaw sound evaluation correctness depending on distance

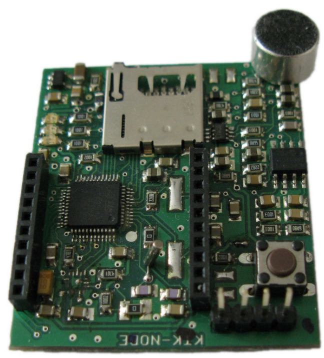

Fig. 3. Node of WSN

V. Proposed WSN For Forest Monitoring

We propose the network, where the sensing ranges of nodes are overlapped. The sensing range is lower than communication range, so there is no problem to communicate between nodes also in situation, when some of nodes can damage or is unable to pass the message.

The sensors in the “Fig. 4” are spaced in that way, that they cover the whole forest and they ensure redundancy, scalability and increase reliability of decision. The probability of illegal logging is bigger on the forest peripheries so the density of nodes is higher there.

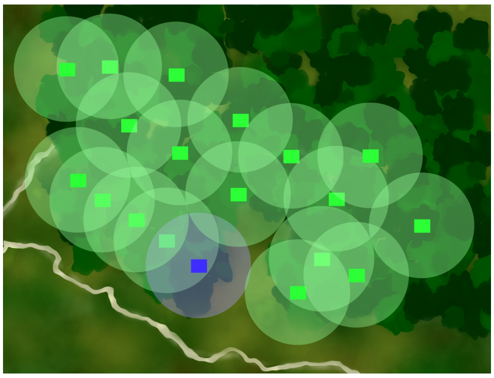

Fig. 4. Proposed WSN with sensing range of each node

A. *Principle of Data Collection*

When we determined the method of communication, we considered two methods: broadcast for message transmission and addressed message transmission. Because the communication is the most energy consuming, we decided to use the addressed message sending. The means of on-line actualisation software can be the other saving energy method [5]. Addressed message sending method of communication will be used in that way that the number of sending messages will be the lowest and we will avoid the loop. The nodes in network generate the rooted tree of the graph, where the vertices are the nodes and edges connect the nodes which communicate together. The node sends the message to the node which has the common edge with this node and the node is in lower level of the tree –it is closer to root ("Fig. 6"). Root is always the gateway(GW) of the WSN. The tree is announced to each node in the period of time.

B. *Creating the Tree*

If we know which nodes are able to communicate, we know that only between these vertices we can put the edge.

So at first we need to know the graph, from which we are going to create a tree. This can be done through the broadcast messages. Before monitoring the forest, when the nodes are mounted on the trees, the gateway sends the broadcast. The nodes that hear the message, they check, whom they heard. Then they send the broadcast and so on. It is obvious that when one side hears the second, it is possible also vice versa. So each side hears and waits some amount of time. If the message doesn't come, it means that no one else is in the network. When the last nodes do not get the message from new node, they make the graph of the network, create the tree and then send the graph through the edges of the tree to the each node and also to gateway. Gateway can get more types of graphs because none of the nodes from the biggest level has the whole information about the network. But it is easy to join graphs together ("Fig. 5"). Thanks to this graph, gateway is also able to evaluate, which nodes are able to sound the same noise. Probability that the chainsaw was used in the forest is higher, if more nodes inform about this situation.

$$G(WSN) = (V, E) \tag{2}$$

$$T(WSN) = (V_T, E_T); V = V_T, E_T \subseteq E \tag{3}$$

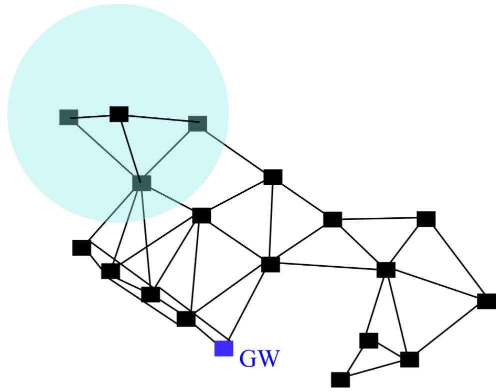

Fig. 5. Graph of WSN with transmission range of one node

The tree of the graph is made with Breadth-First Search ("Fig. 6") [6]. After first step, the gateway is creating the tree according to changes in network. We assume the nodes do not change their positions, so the communication between two nodes is possible, if it was possible before. But we need to know, whether all nodes are in good condition and if they are able to communicate or monitor the area. As it was mentioned, nodes send the message after some time, when they hear something, what can be the saw. But all other nodes do not send anything. If we want to know, whether the node is always up, after some time all nodes sends message, with the announcement of saw hearing or the empty announcement. Then the gateway knows, which nodes are up and it can create new tree.

C. *Synchronization in WSN*

Because the nodes communicate in some time windows, in reality it is necessary to synchronize the nodes. For synchronization the Cristian's algorithm is used [7]. According to this algorithm, each node of WSN is able to synchronize its clock

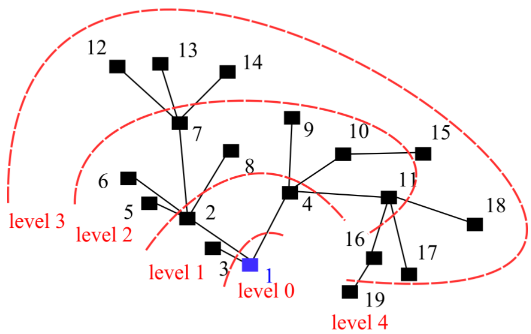

Fig. 6. WSN tree with levels of the tree

from the central point of synchronization. In our case, this point is the gateway of WSN. The main condition is that the gateway responses immediately.

The principle of algorithm is, that the node requests the server (in this way our gateway) to send its current time. Node is counting the time of communication and to the sented time, it adds the half of the time of communication ("Eq. 4"). We assume that request time is the same as the time of response.

$$T_{syn} = T_s + 1/2 * T_c \tag{4}$$

where T_{syn}.. synchronizing time, T_s.. sented time and T_c.. communication time.

We can say, that our WSN is divided by the number of hops to the gateway – through the levels of the tree. It is obvious, that gateway is synchronized always. In predetermined time block, the nodes, which are on one hop from the gateway tries to synchronize. In other time block, the nodes from other hop synchronizes, etc. The time for synchronization should be set in that way, that the inaccuracies cannot influence the synchronization process. That is why we set the time of synchronization after 10 communication times and for each hop level we set the time for synchronization for 2 seconds.

VI. Conclusion

An approach for the forest monitoring based on wireless sensor network to prevent illegal logging was proposed in this paper. Acoustic signal evaluation and the principals of network nodes communication were proposed with the focus on low power consumption and reliability of the system. This is still far from being final version of forest monitoring system and there is lot for us to improve.

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