Technical Sciences
Academy of Romania
www.jesi.astr.ro

Journal of Engineering Sciences and Innovation
Volume 9, Issue 3 / 2024, pp. 335-342

F. Electrical, Electronics Engineering, Computer Sciences and Engineering

Received ***20 May 2024*** *Accepted* ***3 September 2024***
Received in revised form ***25 July 2024***

A preliminary estimation of an implementation of the network of acoustic sensors for the monitoring of wild area

OLIMPIU POP, LACRIMIOARA GRAMA, CORNELIU RUSU*

Signal Processing Group, Faculty of Electronics, Telecommunications and Information Technology, Technical University of Cluj-Napoca, G. Baritiu street, no. 26-28, Cluj-Napoca, Romania

Abstract. For quite some time there has been a permanent interest in environmental monitoring. A special attention and a greater effort is necessary in the case of monitoring wild natural areas. The problems raised in this context are multiple and diversified, from the choice of identification algorithms to the actual implementation on the ground. In this work, the objective is to estimate as much as possible the required effort and the costs of such monitoring based on acoustic sensors. We review the already established solutions and analyze the solution previously proposed by the authors. A cost assessment is discussed, then the issues involved in remote control are discussed. Accuracy, robustness and reliability are also addressed.

Keywords: acoustic sensors network, wild area monitoring.

1. Introduction

The monitoring of the environment in general and the monitoring of protected wild areas in particular are among the most important concerns of civil society, and thus also of governments. As a rule, reliable and robust solutions are used for this purpose, where low energy consumption is paramount [1, 2]. Isolated geographical areas do not always have access to electricity supply, and data network coverage is sometimes poor. Image sensors, which are otherwise quite widespread in the field of monitoring, do not represent a solution in conditions of variable light, i.e. when we have fog or dense vegetation [3]. In this context, audio monitoring becomes an alternative worthy of consideration.

---

*Correspondence address: Corneliu.Rusu@ieee.org

To begin with, we focused on the problems related to the processing of the audio signal captured directly from the wild environment and by applying the specific techniques of processing the vocal signal, it was shown that audio monitoring can be a solution for the detection of intruders in such an area. At the same time, the possibilities of interaction and communication between the audio sensors and their central monitoring unit were studied, a problem that can be solved in several ways, depending on the concrete situation. The next natural step would be an implementation of the system on the ground and before that a first estimate of the effort and costs involved is welcome.
To have an initial idea of the costs of a monitoring system for isolated geographical areas, we refer to the information available in [4, 5]. Vodafone started a smart forest project, connected to the Internet and located in Covasna county. The real-time monitoring and signaling system of the sounds specific to forest exploitation is quite expensive and, according to our information, it has not yet been replicated in other areas of Romania. However, an association of three companies (Orange Romania, Vodafone Romania and RASIROM, signed up for an auction organized by the Ministry of the Environment, Water and Forests for the purchase of a national monitoring system for Romania's forests. The contract was estimated at 44.42 million RON, without VAT, i.e. approximately 9 million euros. Without being involved in this project and without knowing the details of its implementation, the information we are going to present seems consistent with the evaluations of the respective proposal.
In this work we are interested in a preliminary estimation of an implementation of the network of acoustic sensors for the monitoring of wild areas. The paper is organized as follows. First a preliminary evaluation of costs is discussed (Section 2), then the problems involved by remote control are analyzed (Section 3). Precision, robustness and reliability are presented in Sections 4 and 5 respectively. An overall evaluation of the proposed solution is finally described in Section 6.

2. Costs

An important parameter in the case of sensor networks (acoustic in this case) is the profitability/cost ratio which must obviously be as high as possible. The system must be built on open source technologies, made with materials and parts that allow low-cost development and maintenance.
Ambient sound is a valuable data source for assessing the health of an ecosystem. Scientists typically use expensive and robust acoustic monitoring equipment to acquire data. Environmental acoustic analysis is a growing area of research in ecology [6]. Usually the approaches are based on the analysis of the stored data sets of the sound thus acquired. Datasets are typically compiled from audio recordings made with mains-powered equipment or battery-powered Passive Acoustic Monitoring (PAM) devices. The WWF (World Wide Fund for Nature) Guide to Passive Acoustic Monitoring in Ecology and Conservation [7] provides a comprehensive list of current hardware and software options.

Traditionally passive acoustic monitoring is done using commercial devices such as Song Meter [8]. These portable commercial devices provide excellent recording quality. Although the cost of these devices is significantly lower than complex mains-powered equipment, they are still an expensive research tool, with a starting price of around 800 $. The cost of covering a large area may limit use for certain applications.

For some projects, such as biodiversity monitoring or hunting, cheaper units with greater coverage may be more useful, even if some sound quality is sacrificed to reduce costs [9]. Over the past three years, there has been a significant increase in customized, fit-for-purpose solutions made with low-cost technologies [10]. For example, the Raspberry Pi is a minicomputer that revolutionized the acoustic monitoring market by releasing open-source modules for passive acoustic monitoring. Self-built modular devices, which can cost less than 100 $, are limited by their high power consumption, which may require a car battery for longer-duration deployments. Additionally, building each device requires software and electronics knowledge.

Currently there are low-cost monitoring and surveillance devices adapted to more or less punctual requirements. An example is the device called AudioMoth [11]. This is card-sized device. It includes a circuit board, a microcontroller and an electromechanical system that acts as a microphone. The equipment is compact, with a robust case. It can be deployed remotely for long-term monitoring, and with a modular extension it can be used for acoustic detection. It also has the processing power of a microcontroller.

The main advantages of AudioMoth over existing tools are low cost, low power consumption, small size and ease of use [12]. The cost of a single unit is about 50 $, which is about ten times less than existing commercial equivalents. Its compact size allows multiple devices to be carried in a single field pack, making it easy to deploy. The software is easy to use and allows users to configure a device for multiple applications. It can capture both audible and ultrasonic sounds from a single microphone and can be installed in custom enclosures. Improvements are made possible by optimizing low-level audio processing for low-power applications, using a unique board design, and providing an easy-to-use software interface. AudioMoth uses an energy-efficient ARM Cortex M4 microcontroller instead of a Linux-based processor, which makes it easier to optimize for power consumption.

AudioMoth supports multiple sampling rates, making it ideal for monitoring sounds from various sources: anthropogenic (such as gunfire, chainsaws, heat engines, where the sampling rate is 8 kHz), audible wildlife (frequency of sampling rate of 48 kHz) and wildlife with ultrasound (bats or amphibians with sampling frequency of 384 kHz). The device is suitable for a variety of deployment scenarios, including remote acoustic monitoring, large-scale monitoring, long-term monitoring, environmental monitoring for education and scientific projects [13].

From the description of this audio monitoring equipment we note that its use is however limited due to the constructive parameters of [13]. For sound capture, a MEMS (microelectromechanical system) microphone is used, omnidirectional (360 degree directivity characteristic), glued to the surface, inside the case with a silk screen protection. Due to the polar pattern this microphone has a relatively low signal to noise ratio and the captured sound does not provide any information about the direction of arrival, i.e. the nature and position of the audio source. Another aspect is that this equipment does not have a transmission unit (wireless, data network, telephony, etc.). The data is acquired in an audio file format and recorded on an external memory drive. The analysis of the collected data requires the physical transfer of the memory card to another processing unit. To increase the performance of the system in terms of data collection that indicates the type of signal source and its position, a sensor capable of providing such information is needed.

Recently we used a structure of audio sensors adapted to the proposed purpose starting from the shape, dimensions and functioning of the human head [14, 15]. The processing of the data recorded by the network of sensors was carried out by implementing an open source software Audacity. This audio signal processing program was installed on a Raspberry Pi 5 minicomputer. The cost of the equipment used is under 300 euros.

For data transmission, a LoRa Module RFM96, 868MHZ, ultra long range, 3.3V for Raspberry Pi, with the 868 MHz frequency band (for Europe) and a Yagi directional antenna was used. For the electrical energy supply of the device, we used a solar kit with a 100W photovoltaic panel and a battery with a capacity of 17 Ah.

In conclusion, for the entire proposed equipment the cost reaches somewhere around hundreds of euros. In this calculation, we did not take into account the additional costs due to human resources and those specific to any product in the development, production and distribution phase, we limited ourselves to the material expenses only.

3. Remote control

Although the audio sensor network can be used in inhabited areas, our objective is for its use in natural environments. Without being the main objective of this work, the implementation methods and costs of the sensor network must be remembered, in the perspective of a more accurate evaluation of the final implementation costs.

The existence of coverage with a data network of a mobile phone company allows us to manage the transfer of a large volume of data, bi-directionally if necessary. It is also possible to monitor the network in order to track its proper functioning. Of course, the transfer of a large volume of data involves significant costs. Depending on the number of sensors and their arrangement, this cost increases significantly. The advantage in this situation lies in the fact that the data processing can be performed centrally, in which case we have a much higher computing power and speed, using programs of increased complexity.

By transferring the received data and by not using an equipment to process them *in situ*, the energy consumption decreases, making it possible to use smaller electrical energy capture and storage elements or to ensure the continuous operation of the sensor cell. The cost for a single cell to use the mobile phone data network, depending on the provider, is around 5 euros/month. For the surveillance of an area of 1 km^2, using sensor cells at a distance of 500 meters, arranged in the corners of a square, 9 cells would be needed. The cost of data transfer in this case would be 45 euros/km^2.

In the situation where the area to be monitored is not covered by a data network and the transmission of a large volume of information can be a difficult, even impossible mission, it is necessary to minimize it. The solution is to process the data *in situ* using a Raspberry Pi-type minicomputer on location. In this case, a point-to-point transmission technique is used using one of the wireless communication protocols (LoRa). With the help of this communication protocol, data transfers of the order of tens of kbits/s can be carried out, at a distance of 5-10 km, using a directional radiant system. In this case the data transfer rate would have costs close to zero, instead it would significantly increase the cost of a sensor cell by adding the minicomputer to the structure and increasing the energy capacity required to maintain the sensor's operation, under conditions that would significantly increase consumption (approximately 5 times).

4. Precision

Detecting intruders in a wild environment requires precise and robust signal processing techniques in conditions such as a low signal-to-noise ratio, multiple sources, etc. In this way, false positive or false negative results, which represent an inconvenience, can be eliminated. A solution that we used [16] consists in the use of several sensors arranged in a network in well-established positions (a square-type structure), with the help of which the type of acoustic source can be determined with a much optimized precision and its position.

Following the measurements carried out in real conditions, in open fields, hilly areas, forested areas, we determined that the average effective distance of the sensor is approximately 250 m. In conclusion, to cover an area of 1km^2, 9 cells would be needed of sensors. If the monitored surface increases, the number of sensors needed per km^2 will decrease. Thus for 2 km^2, we would need 15 sensors, for 4 km^2 25 sensors are needed.

By using a number of 9 sensors/km^2, the accuracy of determining the direction and position of the sound source is high. In the situations where we can admit a less precise determination of the position and only the identification of the sound source is a priority, a reduced number of sensors per km^2, i.e. 5 sensors, can be used.

In conclusion, to cover an area of 4 km^2, the number of sensors can vary between 13 and 25. The cost of a surveillance system can vary between 3600 Euro and 7500 Euro. The average price per km^2 would be 800 euro - 1870 euro, depending on the number of cells used.

5. Robustness and reliability

Among other imposed requirements, the acoustic sensors placed in the environment must work as long as possible and with reduced human intervention. In addition, they must work in conditions of variable temperature (freezing or hot), fog and high humidity (precipitation in the form of rain or snow).
The sensor made and proposed in the works [15, 16] fulfills these conditions, and the location of the microphones and their type provide very good protection in extreme weather conditions. The materials used in the construction of this sensor have good resistance in conditions of increased humidity and extreme temperatures. Placing the microphones inside the structure, in PVC tubes at a distance of 4 cm from the external surface from which they are separated by an anti-wind sponge gives them increased protection against rain or dust. The outer surface of the sensor is treated with a rubberized silicone paint, as well as weather resistance. The electronics are housed in a sealed enclosure with rubber gasket to prevent moisture and dust from entering. A problem in winter can be covering the solar panel with snow, which is why it would be useful to use a solar panel with a heating system.

6. Overall evaluation of the proposed solution

The four acoustic sensors, in our case, are (cheap) omnidirectional electret microphones, but whose directivity diagram was modeled by the mechanical construction of the sensor and by the acoustic, sound-absorbing characteristics of the materials used. The proposed goal was to obtain a relatively inexpensive sensor with very good directivity characteristics over a frequency range and a high signal-to-noise ratio. All these characteristics determine a good quality of the recorded sound signal without the need for sophisticated methods of noise reduction and other types of interference that require complex signal processing. In this way, an algorithm that does not require a lot of computing power can be used, which is a very big advantage in terms of the hardware used and energy consumption, both of which are limited for such a sensor.
By using this type of sensor and the autocorrelation method to determine the signal maximum in the four directions and establish the angle of arrival of the signal, we obtained a direction estimation accuracy between 5^o and 15^o. The accuracy of determining the direction of arrival is influenced by the distance at which the sound source is located and the signal-to-noise ratio.
The results obtained by the autocorrelation method were more accurate than those obtained by the other methods (amplitude calculation), knowing that this method has a high immunity to noise, which is indicated for filtering signals from highly noisy environments.
The maximum distance for which correct evaluations can be made, within the tolerance allowed depending on the application, was between 300-500 m, of course this distance varies greatly depending on the nature of the sound source and its

intensity. Following the experiments carried out, the accuracy of the estimation of the arrival direction according to the distance is represented graphically in Fig. 1.

According to measurements made in real conditions (ambient noise, wind, etc.), the accuracy of determining the direction of arrival, with both measurement methods (amplitude and autocorrelation) is good up to a distance of 250 m, after which the autocorrelation method becomes superior to the other method. This is due to the fact that the autocorrelation method has an increased immunity to noise, the results obtained even in low signal-to-noise ratio conditions being better than those obtained by other methods.

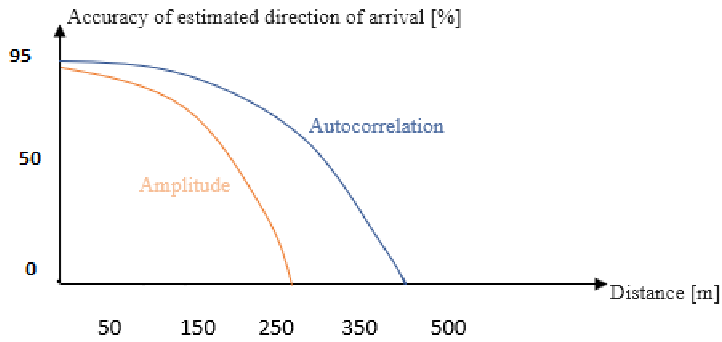

Fig. 1. Accuracy of estimated direction of arrival as a function of distance.

7. Conclusion

Complete monitoring of wild or protected areas by means of video or imaging means is almost impossible due to the fact that the respective techniques cannot retain information under any conditions. In addition, there is a limit to seeing beyond certain obstacles. From these points of view, acoustic monitoring of natural environments can be a solution. However, it should be taken into account that exhaustive acoustic monitoring requires a large number of sensors and their interconnection network, and thus the cost increases substantially.

Among the ways to reduce the cost of such audio monitoring would be to eliminate the claim of total monitoring through a partial and still effective monitoring. For example, instead of spreading the sensors over the entire surface to be monitored, the sensors can be distributed only on a well-defined contour and thus the sensors can detect intruders entering a certain protected area. As usually all the targets of such monitoring are mobile, the proposed scenario could be satisfactory and cheaper.

References

[1] Trifa V., Girod L., Collier T. C, Blumstein D. & Taylor C. E., *Automated Wildlife Monitoring Using Self-Configuring Sensor Networks Deployed in Natural Habitats*, UCLA: Center for Embedded Network Sensing, 2007.

[2] Wang H., Chen C.-E., Ali A., Asgari S., Hudson R., Yao K., Estrin D., Taylor C., *Acoustic sensor networks for woodpecker localization*, Proceedings of SPIE - The International Society for Optical Engineering 5910, Advanced Signal Processing Algorithms, Architectures, and Implementations XV, 591009, 2005.

[3] Vergara L., *Audio signal processing for surveillance applications*, 2007, accessed 28 nov 2023, url: www.iaria.org/conferences2007/filesSECURWARE07/SECUREWARE2007_LuisVergara.pdf.

[4] Neagu L., *Vodafone România a lansat un proiect de monitorizare a pădurilor*. Cum funcționează, 2021, accessed 28 mar 2024, url: www.economica.net/vodafone-romania-a-lansat-un-proiect-de-monitorizare-a-padurilor-cum-functioneaza_501939.html.

[5] Dumitrache A., *Orange, Vodafone și RASIROM vor să monitorizeze pădurile României*. Buget - peste 44 milioane lei, 20024, accessed 28 mar 2024, url: www.profit.ro/stiri/orange-vodafone-si-rasirom-vor-sa-monitorizeze-padurile-romaniei-buget-peste-44-milioane-lei-21463038.

[6] Briggs F., Raich R., Fern X. Z., *Audio classification of bird species: A statistical manifold approach*, Proceedings of Ninth IEEE International Conference on Data Mining, 2009, p. 51–60, 4736, doi:10.1109/ICDM.2009.65.

[7] Browning E., Gibb R., Glover-Kapfer P. and Jones K.E., *Passive acoustic monitoring in ecology and conservation*, Woking, UK, WWF-UK, 76pp. (WWF Conservation Technology Series 1(2)), 2017, doi: 10.25607/OBP-876, accessed 28 mar 2024, url: www.wwf.org.uk/sites/default/files/2019-04/Acousticmonitoring-WWF-guidelines.pdf.

[8] Wildlife Acoustics, *Song meter micro wildlife recorder*, 2023, accessed 28 nov 2023, url: www.wildlifeacoustics.com/products/song-meter-microf

[9] Watson I., Novelly P., *Making the biodiversity monitoring system sustainable: Design issues for large-scale monitoring systems*, Austral Ecology, **29**, 2004, p. 16 – 30.

[10] White T., Understanding and improving the cost-effectiveness of biodiversity conservation, Ph.D. thesis, University of Cambridge, March 2023, doi:10.17863/CAM.100259.

[11] Hill A. P., Prince P., Pina Covarrubias E., Doncaster C. P., Snaddon J. L., Rogers A., *Audiomoth: Evaluation of a smart open acoustic device for monitoring biodiversity and the environment*, Methods in Ecology and Evolution, **9**, 5, 2018, p. 1199–1211.

[12] Prince P., Hill A., Pina Covarrubias E., Doncaster P., Snaddon J. L., Rogers A., *Deploying acoustic detection algorithms on low-cost, open-source acoustic sensors for environmental monitoring*, Sensors, **19**, 3, 2019, doi: 10.3390/s19030553, url: www.mdpi.com/1424-8220/19/3/553.

[13] Open Acoustics Devices, Audiomoth, 2023, accessed 28 nov 2023, url: www.openacousticdevices.info/audiomoth.

[14] Pop O., Pop O. A., *Acoustic sensor for surveillance of isolated geographical areas*, Proceedings of 43rd International Spring Seminar on Electronics Technology, 2020, p. 1–6.

[15] Pop O., Rusu C., Grama L., *Acoustic monitoring of outdoor areas by a sensor consisting of four microphones*, Proceedings of International Symposium on Signals, Circuits and Systems, 2021, p. 1–4.

[16] Pop O., Rusu C., Grama L., *Acoustic sensor for detecting intruders in wild environments*, Carpathian Journal of Electronic and Computer Engineering, **11**, 2018, p. 56–59.