Development of cloud-based bioacoustics monitoring system for supporting Integrated Pest Management in agriculture production

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Abstract. Integrated Pest Management (IPM) is a conception or way of thinking about Management of Plant Pests with a multidisciplinary ecological approach to managing pest populations by utilizing a variety of compatible control tactics in a coordinating management unit. Acoustic signals produced by insects can be used as a source of information about their presence and behaviour. Problems encountered in observing acoustic signals produced by animals in the context of integrated pest control are supporting equipment factors that can facilitate data acquisition, data management, and species identification based on audio recordings (species identification). The objective of this study is to design microcomputer-based bioacoustics monitoring system that is integrated with the cloud. In more detail, the specific objectives are (1) Designing microcomputer-based bioacoustics monitoring system as a supporter of data acquisition systems with cloud integration features, (2) Testing the performance of a bioacoustics monitoring system for field observations. Bioacoustics monitoring system based on a microcomputer with cloud integration has been developed to support the implementation of integrated pest management. The developed system uses a raspberry pi as a central processing unit in local for data acquisition systems that are connected to the cloud using the Internet connection. As a result of the laboratory-scale test in indoor and outdoor setup, the system could record sample insect sound (Katydid and Cricket) clearly for both conditions, although noise from environment also appears in data analysis affecting the insect identification in future utilization.

1. Introduction
One effort to meet food needs in the future by implementing a modern agricultural production system adopts the concept of precision agriculture by minimizing the impact of outside climate change and
limited land resources. The concept of precision agriculture will optimize management at the field level by considering aspects of plant physiology (suitability of the soil, plants, and water), suitability and protection of the environment (restrictions on the use of chemicals), and economic aspects (efficient use of resources) [1–3]. Besides, an external factor that needs to be considered in agricultural cultivation is the presence of plant pests.

Integrated Pest Management (IPM) is a conception or way of thinking about controlling Plant Pests with a multidisciplinary ecological approach to managing pest populations by utilizing a variety of compatible control tactics in a coordinating management unit. Acoustic-based control can be one of the methods in integrated pest control. This method uses sound waves, and or signals in the form of vibrations for monitoring and studying the behavior of insects since early 1900 [4]. Acoustic signals are effective for pulling (trapping), detecting, and disrupting insect communication. Sound waves with a frequency of 24 kHz, in general, can reduce the potential for bark beetles [5]. For many groups of organisms, their acoustic signals serve as a signature for their presence, and monitoring them acoustically is more viable than doing so by physically collecting or observing them [6].

Acoustic signals produced by insects can be used as a source of information about their presence and behavior. Al-Manie and Alkanhal [7] succeeded in detecting sago beetles (Rhynchophorus ferruginous) that attack palm trees using ultrasonic sensors. Besides, it was also explained about the detection of the infestation of larva beetle (Callosobruchus maculatus) larvae through ultrasonic signals. Ultrasonic signals are produced by C. maculatus when consuming substrate and are captured by sensitive transducers at a frequency of 40 kHz. Enormous progress in audio signal processing and pattern recognition in recent years makes it possible to incorporate automated methods into the detection of bird vocalizations [8].

Problems encountered in observing acoustic signals produced by animals in the context of integrated pest control are supporting equipment factors that can facilitate data acquisition, data management, and species identification based on audio recordings (species identification). The commercial monitoring systems available today include: SM4 Acoustic Recorder Song Meters, Ultrasonic Recorder SM4BAT Song Meters, Echo Meter Touch 2 PRO, but in its application for small-medium scale research, the price is still relatively high, especially for observations at several points. Besides, the process of downloading data manually is still needed for data management, because the device is only a data logger with a certain interval. Therefore, we need a low-cost system that can be used to handle data acquisition and data management for small-medium scale research needs.

The objective of this study is to design microcomputer-based bioacoustics monitoring system that is integrated with the cloud. In more detail, the specific objectives are (1) Designing microcomputer-based bioacoustics monitoring system as a supporter of data acquisition systems with cloud integration features, (2) Testing the performance of a bioacoustics monitoring system for field observations compared to existing systems.

2. Materials and Method

2.1. System Design

The architecture design of the bioacoustics monitoring system can be expressed in the schematic as can be seen in Figure 1. The system consists of Local Sub-systems and Global Sub-systems that aim to facilitate data management and control activities using a remote monitoring framework [Nugroho, 2016] supporting continuous long-term monitoring. The local sub-system consists of two main components: (1) Bioacoustics Monitoring Node, and (2) GSM Router to support the data transmission through the Internet. The Global sub-system enables online data storage and flexibility access from remote dashboard from everywhere. The recorded file in the cloud server then can be analyzed for further utilization, especially for bioacoustics detection and identification.

The bioacoustics monitoring node component can be seen in Figure 2(a), composed of power management consisting of Solar Module SP-50-M36 with 50WP, Solar charger controller PWM, and 12V dry batteries Willwood GTZ7s/BS/12V7Aa for storing the electric power; The Microcomputer
units using a Raspberry Pi 3 B+, and as microphone unit, utilizing a Sennheiser MKH 60 with the specifications listed in Table 1. To support the installation in field, the supporting frame design is displayed in Figure 2(b) with a waterproof enclosure and flexible solar panel adjustment following the sun directions for optimum solar energy scavenging. The solar panel system capable of providing long-term continuous unattended monitoring in inhospitable regions.

2.2. Performance Testing
The developed system was tested to evaluate its performance to record the bioacoustics sound at the Smart Agriculture Research, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada in April – October 2019. Two kinds of insects’ sound were tested: Katydid (Cicadidae) and Cricket (Gryllidae) for ensuring the recording quality during the installation in the indoor and outdoor configuration. Quality of sound between two conditions will be analyzed using Software Raven Pro 1.6 to identify the frequency range and its characteristics visualization.

![Figure 1](image1.png)

**Figure 1.** The schematic diagram of cloud-based bioacoustics monitoring system for integrated pest management implementation in agriculture

![Figure 2](image2.png)

**Figure 2.** The schematic diagram of monitoring node hardware design (a), and supporting frame (b).
Table 1. Specification MKH 60 Sennheisser Microphone

| Aspect                                | Information          |
|---------------------------------------|----------------------|
| Pick-up pattern                       | Super-Cardioid/lobar  |
| Frequency response                    | 50 – 20,000 Hz       |
| Sensitivity (free field, no load, 1 kHz) | 40 (12.5) mV/Pa     |
| Nominal impedance                     | 150 Ω                |
| Min. terminating impedance            | 1 kΩ                 |
| A-weighted (DIN IEC 651)              | 8 (15) dB            |
| CCIR-weighted (CCIR 468-3)            | 18 (26) dB           |
| Max. sound pressure level             | 125 (134) dB at 1 kHz |
| Power supply                          | phantom 48 ± 4 V     |
| Supply current                         | 2 mA                 |
| Dimensions                            | Ø 25 x 280 mm        |
| Weight                                | 150 g                |

3. Result and Discussion

3.1. Bioacoustics Monitoring System

![Figure 3](image_url). Bioacoustics monitoring system with frame and solar panel (a), and supporting component arrangement inside the enclosure (b).

The assembled hardware of the bioacoustics monitoring system can be seen in Figure 3. The supporting frame, enclosure, solar panel, and the arrangement of the components is displayed in Figure 3 (b). The completed system could stand by the supporting frame using a squared tube for convenience installation. The components arrangement tries to be optimized by the space and considering the aeration during the system operation. The enclosure designed as waterproof for preventing the damages of
electronics components by the high humidity at the tropical climate. The adjusted design and arrangement consider the functionality and durability against climate challenges.

The performance test was conducted to ensure that the system can operate properly using power from solar panels and manages to record the surrounding sound at the laboratory scale. The recorded bioacoustics files are stored automatically in the Cloud server directory with a file name following the timestamp and WAV format. The system could manage the interval capturing by 10 minutes, and the recording duration about one minute resulting a single WAV file with the size of 10MB. For further analysis, the recorded file in directory can be downloaded from everywhere and every time.

3.2. Bioacoustics Analysis

Figure 4 shows the data visualization of recorded bioacoustics sound in indoor setup, for both Katydid (a) and Cricket (b). From the visualization chart appearance, it can be quantified that Katydid produces a frequency value of around 16000 Hz with a duration of 0.947 seconds to produce the sound "ngik-ngik". The cricket sound resulted in 13000 Hz with a duration of 0.511 seconds to produce the sound of "cricket". For the comparison, the second performance test was conducted in outdoor conditions, assuming uncontrollable noises and wind will also disturb the activity of bioacoustics monitoring.

The result of outdoor monitoring is displayed in Figure 5 (a) for Katydid, and Figure 5(b) for Cricket. The frequency distribution for Katydid also shows the value around 16000 Hz and duration about 0.947 second, but the appearance is not as clear as in indoor condition. The Cricket sound shows an identical pattern, range of frequency, and duration, although the visualization is also quite lighter than in indoor condition. Noise presents a particular challenge in that the majority of approaches to speech recognition rely in part on short-time spectral estimates from Cepstral coefficients which are particularly sensitive to noise [9]. As a means to improve bioacoustics signal detection in the presence of noise, techniques that look for spectral peaks have been explored. To date, these have consisted of measurements of the peak frequencies directly [10] or trying to estimate their shape throughout the frequency versus time display of the signal [11].

According to the performance test for recording the insects sound in indoor and outdoor conditions, the developed system could manage the monitoring process, by automatic recording with specified duration and interval. The system also managed the sound file to be synchronized to the cloud server for flexibility access for further analysis. As the result of bioacoustics analysis for the recording of Katydid and Cricket, shows that the recorded file could be used for identifying the different range of frequency and duration, also the indoor and outdoor condition affects the monitoring performance by the reduction of the detailed by the natural disturbance (Geophony). Further utilization for integrated pest management, the bioacoustics monitoring system will be implemented to monitor the insect sound and its surrounding environment for pest monitoring and identification in the future works.

![Figure 4](image-url)  
**Figure 4.** Visualization result of bioacoustics monitoring for Katydid (a), and Cricket (b) in Indoor
4. Current conclusion and future works

Bioacoustics monitoring system based on a microcomputer with cloud integration has been developed to support the implementation of integrated pest management. The developed system uses a raspberry pi as a central processing unit in local for data acquisition systems that are connected to the cloud using the Internet connection and powered by solar energy for flexible implementation in the agricultural field. As a result of the laboratory-scale test in indoor and outdoor setup, the system could record sample insect sound (Katydid and Cricket) clearly for both conditions, although noise from the environment also appears in data analysis affecting the insect identification in future utilization. Further utilization for integrated pest management, the bioacoustics monitoring system will be implemented to monitor the insect sound and its surrounding environment for pest monitoring and identification in the future works.

References

[1] Nugroho A P, Sutiarso L and Okayasu T 2019 Appropriate adaptation of precision agriculture technology in open field cultivation in tropics IOP Conf. Ser. Earth Environ. Sci. 355 12028
[2] Okayasu T, Nugroho A P, Arita D, Yoshinaga T, Hashimoto Y and Tachiguchi R ichiro 2017 Sensing and visualization in agriculture with affordable smart devices Smart Sensors at the IoT Frontier
[3] Okayasu T, Nugroho A P, Sakai A, Arita D, Yoshinaga T, Taniguchi R I, Horimoto M, Inoue E, Hirai Y and Mitsuoka M 2018 Affordable field environmental monitoring and plant growth measurement system for smart agriculture Proceedings of the International Conference on Sensing Technology, ICST
[4] Mankin R W 2011 Recent Developments in the use of Acoustic Sensors and Signal Processing Tools to Target Early Infestations of Red Palm Weevil in Agricultural Environments 1 Florida Entomol.
[5] Aflitto N C and Hofstetter R W 2014 Use of acoustics to deter bark beetles from entering tree material Pest Manag. Sci.
[6] Parker III T A 1991 On the use of tape recorders in avifaunal surveys Auk 108 443–4
[7] Al-Manie M A and Alkanhal M I 2005 Acoustic Detection of the Red Date Palm Weevil Proc. World Acad. Sci. Eng. Technol. Vol 2
[8] Bardeli R, Wolff D, Kurth F, Koch M, Tauchert K H and Frommolt K H 2010 Detecting bird sounds in a complex acoustic environment and application to bioacoustic monitoring Pattern Recognit. Lett.
[9] Openshaw J P and Masan J S 2002 On the limitations of cepstral features in noise
[10] Taylor A, Watson G, Grigg G and McCallum H 1996 Monitoring frog communities: An application of machine learning Innovative Applications of Artificial Intelligence - Conference Proceedings
[11] Chen Z and Maher R C 2006 Semi-automatic classification of bird vocalizations using spectral
peak tracks *J. Acoust. Soc. Am.*

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