IST-Africa 2021 Conference Proceedings
Miriam Cunningham and Paul Cunningham (Eds)
IST-Africa Institute and IIMC, 2021
ISBN: 978-1-905824-66-3

Raspberry Pi Based Recording System for Acoustic Monitoring of Bird Species

Gabriel KIARIE[1], Ciira wa MAINA[2]
[1,2] *Dedan Kimathi University of Technology, Department of Electrical and Electronic Engineering, Centre for Data Science and Artificial Intelligence (DSAIL), Private Bag-10143, Nyeri, Kenya.*
Email: [1]gabriel.kiarie@dkut.ac.ke, [2]ciira.maina@dkut.ac.ke

Abstract: Severe degradation of ecosystems due to human encroachment and climate change call for close monitoring of the ecosystems in order to conserve them. Ecosystems have a lot of acoustic data that can be used to study changes taking place in them remotely. In this paper, we present an acoustic system that is based on the Raspberry Pi and is used to collect audio recordings for use in acoustic monitoring of birds. The system has been designed to work optimally in the field. It has been able to collect good quality acoustic data of several bird species during its pilot deployment. Acoustic data collected over a reasonable amount of time will be used to create datasets that will be used in developing machine learning models for automatic classification of bird species. This will offer a tool to provide continuous monitoring of ecosystems.

Keywords: Ecosystems, acoustics, conservation, spectrograms

1. Introduction

Birds respond quickly to changes in the ecosystems they are found in. This makes them one of the best species to use in studying ecosystems [1] [2]. Increases in human activities and climate change in recent years have resulted in severe degradation of ecosystems [3]. It is projected that by 2100, 600-900 land bird species may become extinct due to global warming. The majority of these, about 89%, are species in the tropics [2]. Therefore, conservation efforts need to be increased especially in the tropics.

Old methods of carrying out surveys to study ecosystems are expensive and limited by other factors like time, weather and inaccessibility of some parts of the ecosystems [4] [5]. However, use of automated systems for data acquisition and classification can help overcome these problems.

Different species of animals, especially birds, vocalize frequently [6]. The sound produced by an animal contains the 'acoustic fingerprint' of its species [7]. Therefore, we can classify organisms by listening to the sound they produce. It is easy to detect many birds from the call they make hence acoustic classification of birds is a good method of studying birds [8].

Using digital signal processing techniques, it is possible to extract the frequency components contained in the sound produced by a bird using digital computers like the Raspberry Pi. A plot of the frequency components of sound against time is called a spectrogram. Spectrograms of birds of the same species are similar but different from those of other species. Therefore, we can identify different bird species by studying the spectrograms of the sound they produce. The spectrograms can be treated as images and fed to machine learning (ML) models for classification. This means we can develop systems that classify birds automatically from their vocalisation and deploy them in ecosystems of interest.

To completely understand the effects of climate change on ecosystems, we need to process data collected over a reasonable amount of time. There is a gap in the research of birds with the aim to conserve ecosystems. In this paper, we present an inexpensive DSAIL Bioacoustics System that will help address this gap. The system will be deployed in ecosystems of interest to collect audio data that will be used to develop ML models to classify birds automatically from their vocalisation.

The system is based on the Raspberry Pi single board computer. The Raspberry Pi was chosen since it provides a platform to record, perform classification and store the timestamped audio recordings for retrieval. It is operated using a Unix-based operating system that is freely distributed and can be powered from DC sources like batteries [9]. The system also comprises a power management board designed at our lab to help power the Raspberry Pi intelligently.

Section 2 outlines the project objectives. Section 3 describes the methodology used in carrying out the project. Section 4 describes in detail the technology used in the project. Section 5 presents and discusses the results obtained from the project. Section 6 gives the business benefit of the project. Section 7 concludes the paper and talks about our future work.

2. Objectives

The objectives of this project are to:

1. Design and develop an acoustic system to help in acoustic monitoring of bird species.
2. Collect acoustic data from ecosystems using the system.
3. Create a labelled acoustic dataset from the collected data
4. Use the data obtained in studying the bird species trends in ecosystems.

3. Methodology

To achieve automatic acoustic classification of birds, we need enough acoustic data to train machine learning models to do the classification. The first step of this project was to design the DSAIL Bioacoustics System to be used in collecting acoustic data of birds in the ecosystems of interest. The system is based on the Raspberry Pi 3 single board computer. The system was designed, developed and tested at our DSAIL lab over a period of five months (from July-November 2020).

The acoustic system comprises of the Raspberry Pi, a USB microphone, a power management board, lithium battery, solar panel and a charging module. Two programs were also developed to run the system. The first program is the power management program that manages power and controls the waking and shutting down of the system. The second program is the audio data collection program that enables the system to collect and save timestamped audio recordings.

The power management board was one of the most important and the first part of the design. We intended to develop an inexpensive board to power the Raspberry Pi intelligently. The first three months were mostly spent in developing and testing the power management board. The board provides the Raspberry Pi with the ability to monitor power, shutdown intelligently and wake up after sometime.

During development of the system, several deployments were done to test the performance of the system. Early deployments were carried out in October at Dedan Kimathi University of Technology to test the performance of the power management board and program. After several iterations we were able to achieve a system that met our needs. Later in November, the system was deployed with both the audio data collection program and the power management program at Dedan Kimathi University Conservancy and we were able to collect audio data of birds. Figure 1 shows the deployment carried at the university and the conservancy.

Figure 1: DSAIL Bioacoustics System deployment outside the university Resource Centre for power analysis of the system (left) and at the university conservancy to collect acoustic data of birds (right).

Over the next six months, we will be working on developing a hardware on top (HAT) version of the power management board. From there we will proceed to mass production of the system. We are also working on using alternative methods for acoustic activity detection to improve the performance of the system.

4. Project Technology

The project can be divided into hardware and the software. In this section, we will look at the technology used in each of this:

4.1. Hardware

The hardware is the physical parts of the system. The main hardware used in the system are:

4.1.1. The Raspberry Pi

The Raspberry Pi is the central device in the acoustic system. It controls the performance of the setup. It is used to record and store the timestamped birds' sounds in its storage or an external storage. It also monitors the battery voltage and makes an informed decision of shutting down the system whenever the voltage drops to the rated cut-off voltage of the battery.

4.1.2. USB microphone

The acoustic system uses a USB microphone that has its own analog to digital converter (ADC). The USB microphone records sound and samples it at a frequency of 48kHz and then feeds the sampled sound to the Raspberry Pi through a USB port. The USB microphone used is sensitive enough for our setup.

4.1.3. Power source

Power is a crucial consideration when designing any system, particularly those that are meant to be deployed in the field. The Raspberry Pi is considerably a power hungry device.

The acoustic system uses solar power to keep it running. A three lithium cells battery is used to store power from the solar panel during the day for the system to use even when there is no sunlight. Kenya being in the tropics means the system receives sufficient sunshine to keep it running for a long period of time.

4.1.4. Power management board

Care needs to be taken when shutting down the Raspberry Pi. Abrupt cutting of power may result in loss of data due to corruption of its storage. In order to manage power, a lot of attention was directed towards designing a power management board for the system. The board acts as a power supply for the Raspberry Pi and performs intelligent shutdown and wake up of the Raspberry Pi.

The board enables the Raspberry Pi to monitor the state of charge (SOC) of the battery by reading the voltage level of the battery. An ADC and a potential divider have been added on the board to read the voltage and feed it to the Pi in digital form. This enables the Raspberry Pi to make an informed decision of shutting down the whole system whenever the voltage of the battery reaches the cut off voltage, which is 2.8V for the battery we used.

Additionally, the board has a DS3231 real time clock (RTC) that is equipped with an alarm interrupt. The RTC turns the system back on using the alarm interrupt and is also used to set the Raspberry Pi's time and date on boot. Before the Pi shuts down, it normally schedules the time it plans to wake up. This is done by setting the alarm of the RTC whose interrupt is used to trigger the waking of the system.

The correct procedure of shutting down the Raspberry Pi needs to be done before the whole system is disconnected from power. To achieve this, a 555 timer circuit connected in a stable mode and a decade counter have been incorporated in the board. The timer produces pulses with a period of about 4 seconds that are fed to the decade counter, which triggers power disconnection at the tenth pulse. This gives the Raspberry Pi about 40 seconds to safely shutdown which is more than enough time. The Raspberry Pi normally triggers the timer circuit to start counting whenever it has made a decision to shut down. After about 40 seconds, the Raspberry Pi will have completed shutting down and hence power can be safely disconnected from the system. More details are contained in [10].

4.2. Software

The Raspberry Pi has been loaded with the Raspbian Buster operating system (OS). Raspbian is a freely distributed OS that is based on Debian and is optimized to work with the Raspberry Pi hardware [11]. To achieve power management and recording of birds' sounds, two major programs were developed. In the following sections, we will look at each of these programs:

4.2.1. Power management program[1]

The power management program is used to control the shutting down and waking up of the system. The program controls different parts of the power management board to achieve this. Our current setup is designed to work during certain hours of the day due to power constraint. The system operates between 5.00 am and 11.00 am when birds are normally most active.

During this window of operation, the power management program monitors the battery voltage to ensure it is above the cutoff voltage of the battery, 2.8V. The program reads the voltage reading of the ADC after every thirty seconds. The voltage reading corresponding to each five minutes' interval is saved in a CSV file to be used in power analysis of the system. The program, therefore, shuts down the system depending on the time of the day or the voltage of the battery. The program is also responsible for setting the alarm of the RTC to wake the system at 5.00 am the following day and then triggering the timer circuit to disconnect the entire system from power after the Raspberry Pi shuts down.

4.2.2. Audio data collection program[2]

This program is used to enable our system to collect audio data. The program records continuously but only saves the sections of the recording that have acoustic activity in them as timestamped audio files. Figure 2 shows the flowchart of the audio data collection program.

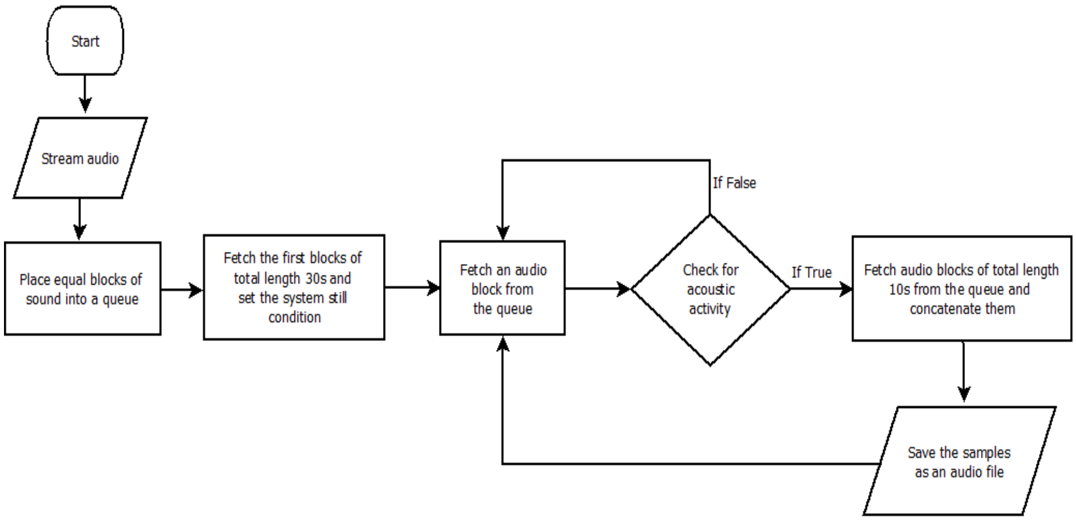

Figure 2: Flowchart of the audio data collection program.

The audio data collection program is written in Python programming language and makes use of some third party libraries like librosa and sounddevice. Librosa is a python module that is used for music and audio analysis [12]. The same principle of detecting activity will be used when the system will be deployed to carry out acoustic classifying birds.

[1,2] The programs discussed above can be found in this repository; https://github.com/DeKUT-DSAIL/bioacoustics.

5. Results

5.1. System's power analysis

One of the challenges encountered when designing sensors is increasing the time of their operation since most of them are battery powered [13]. In our design, we used the available materials to design a solar powered system that will be working during a given time of the day when birds are most active and then shut down for the battery to recharge. Using the measured power consumption of the system and an estimate of the power provided by the solar, we can plan the time the system should operate before shutting down for the battery to be charged.

The DSAIL Bioacoustics System operates for six hours (from $5\ am$ to $11\ am$) every day and then shuts down for the battery to be charged during the rest of the day. When the system operates for six hours in a day, the power source can meet its energy requirement for about two days without recharging the battery. This is called autonomy of the battery, which is two days for our current system design. Figure 3 shows the battery voltage profile when the system is working.

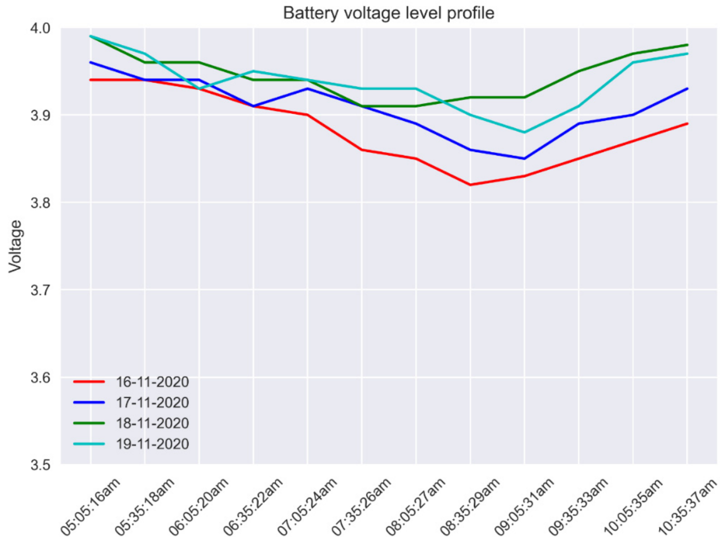

Figure 3: Voltage profiles of the battery for four consecutive days.

From figure 3, we can see the discharge and charging profile of the battery. More details are contained here [10].

5.2. Audio data collection

From the acoustic system's deployment at the conservancy, we have managed to collect audio recordings of birds. Several birds can be identified from listening to the saved recordings. Some of the identified birds are the Hartlaub's Turaco and the Grey-backed Camaroptera. A comparison between the spectrograms of the recordings of these birds and sample recordings from Xeno-canto show a lot of similarity. Xeno-canto is a website that offers a platform for sharing birds' sound recording from all over the world [14].

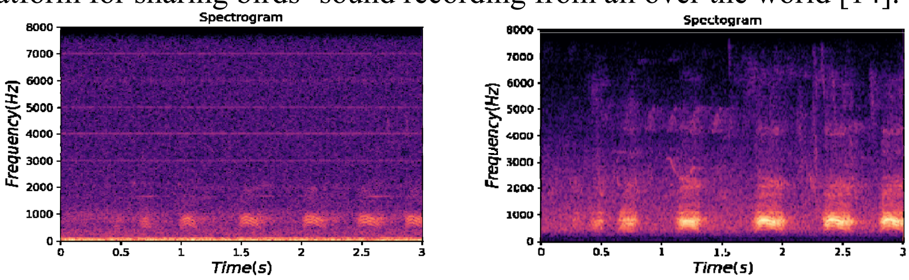

Figure 4: Spectrograms of Hartlaub's Turacos recordings from the conservancy (left) and from Xeno-canto (right).

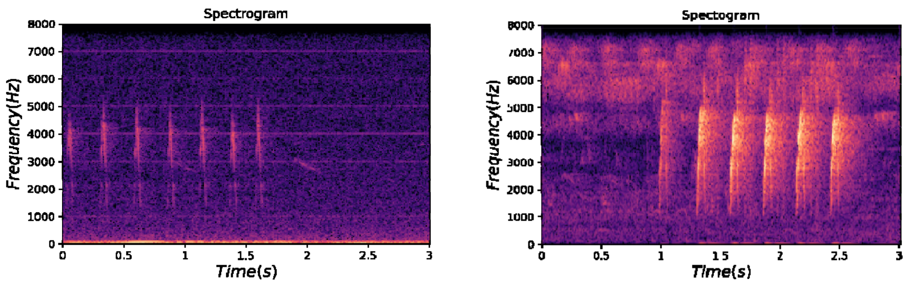

Figure 5: Spectrograms of Grey-backed Camaroptera recordings from the conservancy (left) and the spectrogram from Xeno-canto (right).

From the spectrograms above, we can see some similarity between the recordings made by our system and those from Xeno-canto. Also, the spectrogram of each species of bird is unique. Therefore, we can classify birds by recording them, perform spectral analysis of the recordings and then treat the spectrograms as images that are fed to ML models for classification.

6. Business Benefits

The most used alternative to acoustic monitoring of ecosystems are the camera traps. Many camera traps would be required in dense parts of the ecosystems since cameras record what is in the line of sight. However, acoustic sensors can record sound even in dense parts of the ecosystem since sound is not obstructed by vegetation. This makes the use of acoustic monitoring of ecosystems to be a cheap alternative compared to camera traps.

The other benefit is that the system will help reduce the cost required for taking surveys. Surveys are expensive and do not provide live data like is expected with our system. This means our system will be reliable and inexpensive compared to carrying out surveys.

7. Conclusion

Acoustic monitoring of birds offers a tool to efficiently study ecosystems remotely. More research efforts should be directed towards developing acoustic monitoring of bird species from proof of concept to actual implementation.

The DSAIL Bioacoustics System is a robust system based on the Raspberry Pi for collecting birds' acoustic data for monitoring ecosystems. Development of the power management board that intelligently powers the Raspberry Pi and the power management program makes the system to work efficiently in the field. From this research, we have learned that power is one of the most crucial factors to consider during design of sensors to be deployed in the field. We have also learned that we will need to develop acoustic systems that are robust enough to work in the ever changing acoustic environment of ecosystems.

We intend to collect audio data of birds from various ecosystems in Kenya and then have it labelled to create our own dataset. We will then develop machine learning models to perform acoustic classification of birds using the data. From there, we will deploy the acoustic systems with the automatic acoustic classification of birds ML models in various ecosystems for the purpose of studying trends in them.

Acknowledgment

We would like to thank the National Research Fund Kenya (NRF) for funding through the Multidisciplinary Research Award. We would also like to thank Google for funding through the Artists + Machine Intelligence (AMI) Focused Research Award. We also express our sincere gratitude to DSAIL research interns Jason Kabi and Jared Makario for their support in developing the DSAIL Bioacoustics System. We would also like to thank the wardens at the Dedan Kimathi University Conservancy for their willingness to let us set up the acoustic system at the conservancy.

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