SMART ENVIRONMENTS PROJECT

DOCUMENTATION REPORT

KAGU

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Chapter 0: Introduction

This report is written by team thirteen. Our team consists of eight team members, all from different backgrounds. Because of this, each team member has its own quality. The problem tackled in this project is how to keep track of endangered tropical bird species. The problem with tropical birds is that they hide in hard-to-reach places that humans cannot easily access. Because of that, humans cannot keep track of these birds and thus cannot help them. To fix this problem, an idea based on wildlife monitoring had to be made.

Tropical birds are mostly endangered because of climate change [1]. Unfortunately, this problem cannot be easily fixed with a smart environment. What can be done is to monitor the birds to understand how their behavior might change due to climate change or deforestation, affecting their habitats.

The proposed solution is to monitor these birds via their singing frequencies. If a system is created that can identify the bird species and location without interfering with the animals, humans will not have to disturb nature as much while still getting data. After collecting some data, it is easier for humans to help these endangered species in the best way possible.

An important part of collecting all this data is also the capability of displaying it, for the team it is very important to display in an entertaining way the data of the birds collected, making people engage and realizing that it's not just numbers on a report, but instead, actual animals endangered than can be helped creating awareness on humans and the will to act.

The team's motivation of solving this problem is to eventually, with all the data collected via wildlife monitoring, to be able to create a bigger impact. The more that is known about a species, the easier it is to help solve its endangerment problem. It is also important to be able to collect significant information without disturbing the species that need help.

Chapter 1: Literature Review

[2] Leveraging BLE and LoRa in IoT network for wildlife monitoring system (WMS)

This article proposes a new way to monitor wildlife using the Internet of Things. It uses two types of radio signals (Bluetooth low energy (BLE) and low power wide area networks (LPWANs)) based on how close the animals are. This allows the energy consumption to be lower than similar monitoring tools.

[3] Precision wildlife monitoring using unmanned aerial vehicles

The unmanned aerial vehicle method was used for data collected in tropical and polar environments. It is manly focused on the count of colony nesting birds. It also presents an analytical model to facilitate the transition of monitoring programs to this precise technique. It is predicted that the UAV technology will be the base in many more wildlife monitoring. So, in this research it is demonstrated that the UAV-derived estimates of colony size results in smaller cumulative variance compared to conventional ground-based approaches. This method is expected, that is can also be used with other animal groups and geographic contexts.

[4] Automatic tracking and alarm system for eradication of wildlife injury and mortality

This article explains a method that tracks wild animals in national parks and wildlife sanctuaries, to make sure they stay within certain boundaries. This is done using GSM and GPS technology, which is attached to the body of the animal. When boundaries are crossed, an alarm goes off, informing people about the danger, so they and the animal can be brought to safety.

[5] Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishment and challenges

This review provided evidence from literature that a wide range of wildlife surveys can be successfully completed with unmanned aircraft systems (UASs). It points out that most surveys other than bird counts showed detection possibilities.

The reason why manly small UASs are used is because of the costs. The UASs has technical limitations and therefore cannot cover wide geographical areas. The use of thermal videos is also promising, and this deserves more investigation. Almost all authors of this review used traditional parallel transects but a completely different protocol may be more efficient.

The development of automatic detection is most important for many targets as every flight would result in hundreds of pictures that require time-consuming analysing. It is one of the most important developments for the future and is requires use of UASs to monitor wildlife. That doesn't count out the human observers. The UASs have too much to bring in terms of development and economy to be held back for too long by legislating.

[6] **Evolution and sustainability of a wildlife monitoring sensor network**

In this paper, details of the first active RFID-WSN (Radio Frequency Identification -Wireless Sensor Network) hybrid system for wildlife tracking was provided. It was found that for wildlife monitoring application, continuous operation is essential. Therefore, maintenance is unavoidable. A pertinent result from the deployments was the realization that no initial deployment will be perfect. The choice made here were influenced by the needs of the application.

The conclusion the authors make is that the results and findings in the paper will provide an important insight into the workings of a long-lived outdoor sensor deployment.

[7] **Benefits of incorporating a scat-detection dog into wildlife monitoring: a case study of Pyrenean brown bear**

In this study a detection dog was used to monitor the Pyrenean brown bear. The dog was used to search for bear scats. The results of the study showed that even when you use a dog, you still can in improve the efficacy of collecting target scats. And because of this you can increase the probability of acquiring genotypes and detecting individuals from the scat samples.

This study observed the bears with the help of dogs since 2014. It turned out that with the help of a dog the improvement in the efficiently came in comparison to the period where only humans were actively searching for scats. The study also confirmed that with the help of the dog more bear scats samples were collected. Also, the scats that were found were fresher than the once found without a dog. Because fresher scats were found it became easier to send the samples to a laboratory for further research. Therefore, a better identification could be done, in addition to that, the dog saves a lot of time, human resources and money.

With this process the study aimed to refine selection of scats sent to the laboratory. This research encourages the integration of a detection dog.

[8] **A cloud computing-based model for wildlife conservation and health care improvement in endangered wildlife animals**

To protect endangered species, different sensors can be used to monitor the health of the animals. This information is sent to the cloud, where it is analysed. If it thinks the animal might be in danger, the information is signalled to a wildlife physician and ranger, so they can help.

[9] **Chytrid fungus effecting frogs**

Shrub frogs are an endangered amphibian species in India's Western Ghats. The main and outmost threat to this species is degradation, habitat loss and the chytrid fungus, which declines the amphibian population worldwide.
A way to help the Shrub Frogs is to control the spread of the chytrid fungus. We can do this by educating people about how to properly clean and disinfect their equipment when they are hiking or camping in areas where the fungus is present.

[10] **Deforestation effecting pandas**
Wild pandas once roamed bamboo forests in China, Vietnam, Laos and Burma. Today, wild pandas are found only in China, and in far fewer numbers than ever before. Scientists estimate that there are only around 1,800 wild pandas alive today.
Habitat loss spells certain doom for pandas. If a bamboo forest is cleared away, then the pandas' food source is gone, because pandas only eat bamboo. Relocating to another forest is often impossible, as forests today have become separated from one another, thanks to human cities and towns.

[11] **Concept for and Implementation of Wildlife Monitoring to Contribute Sustainable Development Goals**
The Article showcases a concept of wildlife monitoring which is used as a case study to further develop their smart city application. This application is developed for use not just in wildlife monitoring but also in other areas focused on the sustainable development goals of the UN.
The study

[12] **Effective Monitoring for Adaptive Wildlife Management: Lessons from the Galápagos Islands**
This article discusses the monitoring of animals in the Galapagos Islands and how that can be used to develop better methods for wildlife monitoring elsewhere. They focus on three specific lessons learned to make an effective program.

[13] **WILDSENSING: Design and deployment of a sustainable sensor network for wildlife monitoring**
This article focuses on the fact that many sensors have been able to gather data with unprecedented sensing capabilities while delivering it to remote users. However, this also comes with many challenges. The article tackles the main difficulties in maintaining a continual operation of an automated wildlife monitoring system over a one-year period. The system focuses on colocation patterns of European badgers residing in dense woodland environments using a hybrid RFID-WSN approach.

[14] **Animal Recognition and Identification with Deep Convolutional Neural Networks for Automated Wildlife Monitoring**

The article focuses on the use of single-labelled dataset from a wildlife spotter project done by citizen scientists, and a deep convolutional neural network architecture that trains a computational system capable of filtering animal images and identifying species automatically. The most important details from this type of monitoring are the efficiency and accuracy of the method, with an experimental result of 96.6% accuracy.

[15] **Integrating Remote Sensing into Wildlife Monitoring for Conservation**

The article focuses on the use of remotely accessible ways to record different types of wildlife. The different options go from satellite-controlled sensors, earth sensors like cameras, acoustic recording devices, and aerial vehicles. The main issue is the development of quality in these devices while keeping a good quality level. These can also help fill data gaps for high biodiversity tropical countries or places difficult to reach.

[16] **Detection errors in wildlife abundance estimates from Unmanned Aerial Systems (UAS) surveys: Synthesis, solutions, and challenges**

Unmanned aerial systems (UAS), also known as drones, are becoming accessible to ecologists to use it as a tool for collecting and distributing data. They have become a reliable tool, but since it's new there are still some errors that need to be corrected.

[17] **Methods for wildlife monitoring in tropical forests: Comparing human observations, camera traps, and passive acoustic sensors**

Tropical forests are a challenging environment for monitoring due to the dense flora and many species of different sizes living there. Most monitoring that is being done in the forest is done by humans, camera traps and passive acoustic sensors.

[18] **Monitoring deer by using their food**

In this study researchers tried to monitor the amount of available deer food by ‘borrowing’ data from several moose ranges. This allowed them to monitor the deer population on a far bigger scale then would be possible without this data. Eventually after the researchers had finished their research it was found that using data from moose ranges was deemed unreliable for deer. No breakthrough in deer monitoring was made after this research.

[19] **Long term monitoring of jaguars in Belize**
Little is known about the behaviour of predators; therefore, a group of researchers decided to monitor the survival chances of wild jaguars in the Cockscomb Basin. They set up a camera network which would monitor the behaviour of the jaguars. Since the female jaguars did not trust the cameras within the allotted time, they decided to extend the project and monitoring the jaguars for a whole 14 years. From the footage it has been made clear that the emigration of jaguars is very gradual over the span of those fourteen years and the behaviour of jaguars is now made a bit clearer.

[20] **Remote Sensors Bring Wildlife Tracking to New Level**
Scientists are now combining -animal-tracking and remote-sensing data to create models showing how individuals, animal groups, and species respond to seasonal or climatic changes. Researchers are also building models to forecast how these animals might fare as climate change accelerates.

[21] **The conservation and restoration of wild bees**
Bees are responsible of pollinating the largest amount of wild plant species in the world, bees pollinating makes things cheaper for agriculture because it’s made naturally. One of the major problems is the lack of data of bees and their populations making their conservation status difficult to assess. Bees are underrepresented in conservation planning and protection efforts. 90% of pollination is made by animals, crops and plants rely on these animals that are going extinct.

Chapter 2: Identification of General Problems and Challenges

After some literature research, some problems and challenges for wildlife monitoring where discovered. From the 20 articles found, the selection was reduced to identify eight general problems.

General problems:

1- There is a lot of deforestation and there are a lot of different wildlife species. The problem with this is that you don't know exactly how to fix the problem if there are so many different situations.

2- Endangered animals need protection from humans. Because there are a lot of different possible situations it is difficult to find a solution to protect the endangered species.

3- Parasites may affect the monitored wildlife and cause irregular behavior which can severely mess up measured data.

4- Equipment for remote monitoring tends to need a high level of maintenance, increasing the risk of human disruption on a naturally preserved ecosystem.

5- In some areas the balance of nature is disturbed, because of that the chance of having invasive animal species are high. And this problem can lead to even more disturbed balance and even more problems.

6- Equipment used to monitor wildlife has to blend in in a way that the animals won't avoid the equipment and if it is in an urban area, it must not disturb humans either.

7- There exist a lot of amphibians that having a high change of getting sicknesses or fungi, for example frogs which react to chytrid fungus. To understand how these animals get sick you need to find a way to monitor them so you can reduce the fungus or cure the animals.

8- The accuracy of the monitoring equipment is not always good enough to get reliable data out of it.

Chapter 3: Identification of Relevant Problems

In the previous chapter you have read about different general problems that are existing in the field of monitoring wildlife. The conclusion is that a lot of problems can be traced back to humans. But not all of them, because there are still problems caused by, for example parasites. We were able to identify the researched problems to more specific problems attached to some species in particular.

1- Wolves, for some humans they are harmless, for others they are a threat. Wolves themselves are not a tread for humans, but for their livestock. Farmers are worrying a lot about the wolf. Recently in the Netherlands a pack of wolves has settled. This is a serious problem, because a pack of wolves needs around 129 square kilometers of territory. In the Netherlands this causes even a bigger problem because the nature in the Netherlands simply cannot provide this much nature for the wolf to live in. Because the area the wolf lives in interferes with the living grounds of the humans a lot of sheeps are in danger. This can cause a lot of problems because not only the wolves come too close to humans, but also nature's balance is interfered with. This is why the wolf needs to be supervised. [22]

2- Deers have a lot of different predators, but the top predator in the list are humans. This is a serious problem. The reason why humans are on the list is because they severely disturb the life of the deers severely. Not even in the first place because humans come too close, but simply because we exist. Deers have a "natural clock" that makes them aware of everything that is going around during particular times during the day. Always staying on the lookout can give a deer a lot of stress. But the problem with this is, because of the humans, the deer experiences even more stress. The deer always feels like it needs to stay on the lookout, and because of that they can forget about their killing predators. But humans being around can also work the other way around. Because the deers are always on the lookout they can seem more relaxed. Like nothing is ever going to be a treat to them. So both clockwise and counterclockwise humans are a threat to the balance of nature. [23]

3- Birds in tropical areas are rarely encountered by humans. Their exact location is very difficult to find. This means that humans don't know the exact number of how many birds there are left of one species.
That global warming is a treat to many species is no longer a secret. Unfortunately, tropical birds are threatened by this fact. Because global warming is a serious problem it is even more important to keep track of these animals. But monitoring birds is not that easy. A lot of studies already have tried to monitor birds, but a lot of these monitoring is more research. This is because a lot of tropical birds are examined when they die. This needs to change, because knowing the effect of climate change on birds can be the essential key to a solution.

But finding living birds is not that easy, that is why there needs to be a way for humans to know the exact number of tropical birds still left. [1]

4- Bats are all over the world. They play a very important role in our ecosystem. Because these species are so important for the ecosystem, it is even more reason for us to get to understand these species better. But even though bats are important for the ecosystem, some humans see them as a problem. This is because a bat can be very noisy, and a lot of humans do not like that. Also, a lot of humans know too little about this species to understand their importance. That is the main reason why it is important to locate them. To provide more information about their living area, so the bats do not come too close to human areas and are left alone. And after that to keep track of them because they are very important for the ecosystem. [24]

5- Hedgehogs live all over the world. It is very hard to find them, but if you see one, it will not last long. But when you get the chance to get close to these animals most of the time this is not a very good idea. It is still very unknown, but hedgehogs are a source of treats. The treats are indirectly a problem for humans as well. Animal heath, human health and the environment are closely related. That is the main reason why these animals need to be tracked. Also, because their living area is shrinking, they can come closer to humans. The reason why hedgehogs can be a source of treat for humans is mostly because of their diet. Hedgehogs eat mostly bugs. These bugs can carry a lot of traces that come from our industry. And these traces can live on in the hedgehogs and can be set free after the hedgehogs do their needs. And with this the circle is round. So, in short, because hedgehogs can carry diseases, care must be taken not to let them get too close to people, or habitable areas. [25]

Chapter 4: Problem Selection and Motivation

Now that there are five potential problems it is time to pick one. Every problem has a good way to be solved with the help of different sensors. After some brainstorming and discussion, it is decided that the selected problem is problem three. Problem three is about tropical birds, now everyone knows that tropical birds don’t live in the wild in Europe and not in the Netherlands but the problems they encounter are very important and not talked about enough. But what is the problem with these tropical birds again?

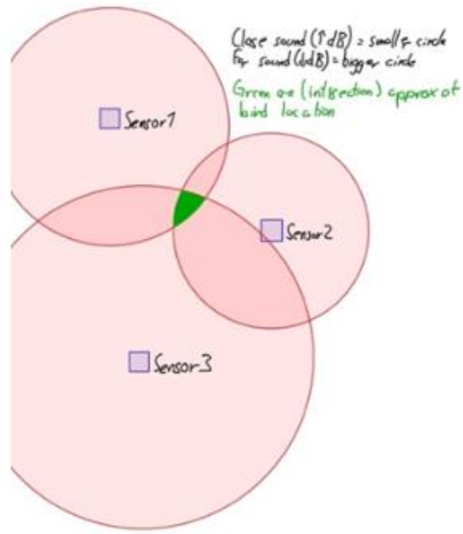
Well, birds are going extinct because of deforestation, hunting for feathers and zoo exhibitions, and being taken as pets. They are trying to hide in hard-to-reach places for their protection which makes it hard for people who want to help and monitor them. The goal is to find a solution where the birds can be monitored without people having to enter their habitat and disturbing them. In that way, it can be identified which species of birds are present and therefore, try to stop deforestation or help the endangered species more efficiently.

When considering if native birds or tropical birds should be studied, it was concluded that tropical birds are way more endangered and need help more than native birds like crows and pigeons. Also, it would be difficult to monitor native birds right now because most of them flew to warm places because of the winter period. But testing tropical birds is not much easier because they cannot be found here, luckily there are other solutions to test the prototype. Namely, audio files of the tropical birds' sounds. These files can be found on the following database: (database of sounds: https://xeno-canto.org/).

Chapter 5: Potential Solutions

In the previous chapter, a problem has been selected. In this chapter, five possible solutions to this problem are addressed and explained.

1- **Detecting the bird sounds within a certain amplitude from different sensors to calculate the location.** Knowing and recording certain amplitudes that a bird emits can help detect the exact location of the bird, using multiple sensors in different trees in the forest can help pinpoint the location of a species. This can help see which trees are more used by what birds, how many birds of that species there are and how these behave in the long run. The risk that could be encountered with this solution is the exact identification of the amplitude because there's more than just the bird sound in the forest/woods. For this solution there would not need to be any humans involved, everything would be monitored with at least 2 to 3 sensors these sensors will be identical in design and construction, a microphone will be needed, Arduinos for sending and receiving the data and a housing good enough to protect from the environment. The impact that this solution could give is helping to understand the movement of certain birds, at what times do these birds come to the trees and if there is any relation with interaction with surroundings (humans). It can help prevent the decline of a species by letting organizations know which are the most valuable trees for endangered species. The testing of our solution can be made in the woods with a speaker, imitating the sounds of specific birds, but ideally it can be used in rainforests or forests where there are endangered species.

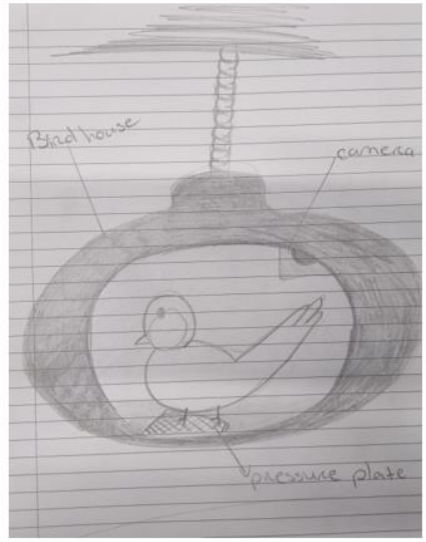


Possible solution one
Figure 0

2- **Detecting the bird based on the color of their feathers.** A possible solution to the problem is by using weight sensors and an image detection system with RGB reading capabilities. This solves the problem as tropical wildlife monitoring is traditionally impractical and very expensive. This way, it can be done in an easier way, which also obtains more data.

To classify birds by their color, a program should be made to recognize the RGB values for each pixel from the picture. This value is now compared to other values stored in a database. This whole process is in charge of determining whether the detected bird matches the species that is relevant for this project or not.

There is also weight data included from the weight sensor to optimize the correlation of the collected data.



Possible solution two

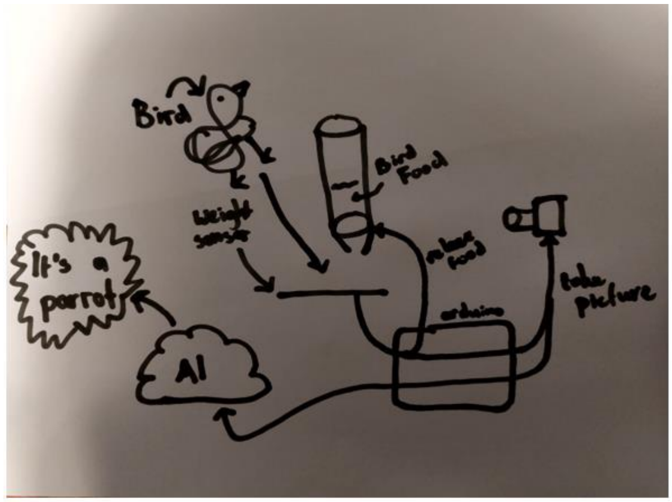
Figure 1

There may need to be different-sized birdhouses, since in tropical areas there is a lot of variation in species and thus in size. This problem could also be solved by focussing on a certain size and species of birds. The idea is also visualized in figure 1.

One of the big risks of this solution is the possibility that there are two species with very similar color distributions and weight, hence the detection systems may classify them incorrectly.

The requirements for this solution are, first of all, a water-sealed birdhouse in which all the electronics and birds can sit safely, a camera (and enough light to expose the sensor correctly), and a weight and pressure plate in the bottom of the house. A microprocessor will also be needed to perform all the classification tasks.

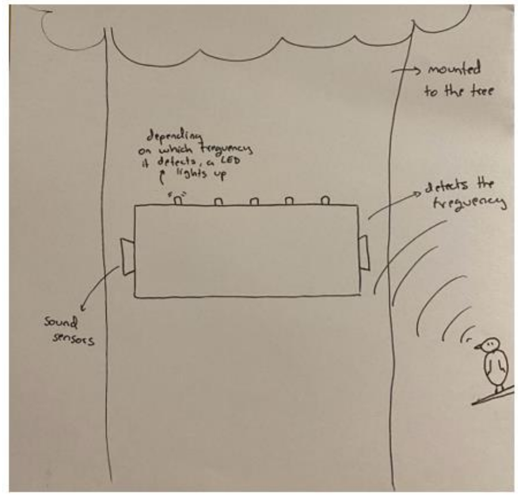
3- **Bird feeder with camera and AI classification.** Create a bird feeder with a weight sensor to detect if there is a bird on it. When there is a bird on it, use an arduino to take a picture. Since it is too difficult for the Arduino to process it by itself, the picture will be uploaded to the cloud, where it can be analyzed using AI, so the type of bird can be detected. This solution would solve the problem partially. It would give an indication of the number of birds of each type, but not an exact number, since it would not be known if the same bird visits multiple times.This problem requires an arduino, with a camera, weight sensor, and internet access. This solution contains a lot of elements, therefore it is visualized in figure 2. That last one might be especially difficult in tropical areas. Also, it needs an artificial intelligence that can distinguish different types of birds in the pictures. Furthermore, it requires the feeder to be refilled regularly, for which humans need to be involved. The risks that come with this, is that it might disturb the natural habitat, either by having the birds get used to being fed, by the presence of the technical equipment, like the camera, or by the humans refilling the bird feeder. This solution can be tested here in the Netherlands by separating it into the two parts. The AI can be tested using pictures on the internet of tropical birds, while the bird feeder with a camera can be tested with birds present here in the Netherlands. It can also be assessed, by checking which percentage of the birds were correctly classified, and checking how many of the birds visiting the feeder got photographed. To assess how well the rest of the model works, a video camera can be ran alongside the model, and manually count the birds and compare that to the amount of pictures taken. It can be presented by showing this video and the pictures that were made, alongside with a demonstration of the AI in class.



Possible solution three
Figure 2

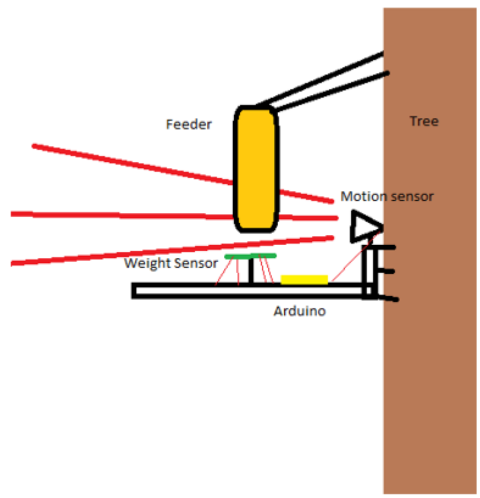
4- **Using the frequency of the bird sounds to detect which species it is.** Different species of birds have different pitches/frequencies of their chirp. The plan is to detect the frequency of the bird's chirp and then correspond it to the species of the bird. By doing that it is possible to detect which species of birds are in hard-to-reach places.

This solves the problem partially because it is only known which species are there, their location or how many birds there are is still unknown. The risk with this solution is that a lot of birds have a similar frequency so the sensor might detect different birds as the same one. Considering the requirements, sound sensors that will detect the frequency and not only the presence of sound are needed. For the software part, a program that will detect the frequency and correspond it to a specific species of bird needs to be made. This type of sensor was chosen so as to have the least amount of human interference possible, as it is undesirable to disturb the birds with human presence.By knowing which birds can be found in which parts of the forest, certain species can be protected and it can be ensured that those parts of the forest won't be cut down. In that way, endangered species can be protected to ensure that they can reproduce and live in peace. In the Netherlands, it is difficult to test the project on tropical birds directly, and also testing on birds usually present in the Netherlands is a bit difficult now because a lot of birds fly to warmer places during the winter period. In figure 3 there is a visualization of this idea. To test the product, different bird sounds can be played and let the sensor determine the frequency and then tell which bird produced the sound.



Possible solution four
Figure 3

5- **Using motion and weight sensors to monitor the activity of the birds.** With a motion sensor and a weight sensor it should be possible to monitor the activity rate of the nearby birds near feeding points. The weight sensor will give an indication of the size and possibly the age of the bird. With enough data and possibly a camera, identification of individual birds will be possible. The program would be able to identify individual birds by pattern recognition for example. This sadly however only partially solves the problem. Because setup is ideal for less populated areas where individual care may sometimes apply instead of just general monitoring. Some human intervention to restock the feeder might be necessary but the system is mostly autonomous. As was stated before, this is a great solution for small areas and would work better in non tropical environments ironically like the Netherlands. The population of tropical birds might be too large for a system like this which can at most detect one bird at a time, and tropical birds are more likely to not trust feeding contraptions. The product would allow for very specific bird monitoring which is great for people who get targeted by bird because of previous actions against them. It would also allow people to gain insight as to when birds feed where. The system would be pretty simple to demonstrate, it should work on all bird types instead of just tropical birds so you could install it in your backyard.



Possible solution five
Figure 4

Chapter 6: Solution Selection

Now that there are five potential problems it is time to choose one. After some discussion, it was decided to combine two potential solutions. The reason why two solutions were picked and merged instead of only picking one is that none of the solutions individually solved the problem. By merging solutions one and four a solution that suits the problem the best will be created.

Solution one is detecting the location of the bird by measuring the amplitude of its sound. Multiple sensors that will measure the amplitude can be used and then the location of the bird can be pinpointed approximately. Solution four is using the frequency of the bird to detect which species it is, every bird has a different frequency chirp and the sensor would detect the frequency and correspond it to a unique species of the bird.

By combining the two solutions both the location of the bird and its species can be found, which helps in resolving the problem of tropical birds being hard to find in deep parts of the forest. If the location and the species of the bird are known this can help finding the best way to help it. Also if the location is measured over some time, it can be found where each species of the bird is usually nesting and which part of the habitat the specific species likes the most.

Also, one of the reasons why this solution was chosen is because it's realistic and doable in our budget plan and time span. A lot of the other solutions needed expensive equipment like cameras, or needed to be connected to the internet which is not very durable in tropical areas. Also, some of the predefined solutions need a lot of time to collect the correct data, and there is simply not enough time for that. Considering all the aspects of the problem and the requirements needed for the project The conclusion is to take solutions one and four, because they're the best on go with and will solve the problem completely.

The part that needs to be done for this product to succeed is building the software. One is to calculate the location of the bird using the amplitude of the sound wave it produces. And the other software will recognize the frequency of the bird's sound and classify it to the correct species of the bird. Also, what needs to be done is building the hardware, using the Arduino and the breadboards to make our idea a product. Further, the casing needs to be designed and made and the whole process needs to be documented.

Chapter 7: Methodology

After it was decided which challenge to take on, it is also necessary to know how to perform this. There is only one requirement for this challenge and that is, that it needs to be a smart environment. A key aspect of a smart environment is that it works with the action-reaction principle. This idea is in this category because the system does a lot without human interference. Also for this system, the action is what the bird does. The reaction is then the data that is collected. Also, the system is supposed to recognize the bird species by the frequency without a human near the system to identify the bird species with its own eyes. If the project goes really well, it should also be able to identify the location of the bird via the data.

Because the system needs to identify the different bird species the sensors need to be calibrated, this to indeed make it a smart system that can do most of the work without human interference. The specific sensors that need to be calibrated are the sound sensors. This is necessary so that the sensors can identify the bird species and put the results directly into the collected data. Because if there is as little as possible human interference the data collected will also be more correct and reliable because the birds will get more comfortable with the device if the humans are not near all the time.

For this system a lot of different components are needed. In figure 5 can be found a list of every needed component for this system.

The collected data also needs to be analyzed. Because the collected data is data of frequency, frequency analysis can be used. Frequency analysis is a descriptive statistical method that shows the number of occurrences of each response chosen by the respondents. When using frequency analysis, SPSS Statistics can also calculate the mean, median and mode to help users analyze the results and draw conclusions. The data will be displayed on some kind of screen or in some kind of interactive way, for the demo day just to show that the prototype can indeed recognize bird species via frequency.

Because our goal is to monitor tropical birds, the system is not in a controlled environment, therefore it needs a housing to protect the equipment from the dirt and rain of the tropical forest. So the casing needs to be water resistant, right now the idea is to 3D-printing the casing. If there are unwanted holes in the case, a kit to fill up these holes can be used.

To show at the demo day that the prototype works, the idea is to make a video of the results, like earlier mentioned attaching a screen that shows a picture of the identified bird species.

Considering our ambitions and realistic approach to the project. The ambition is to make a 100% water resistant product, which can be connected with bluetooth to other units. These units should be able to translate frequencies and amplitudes and communicate these to a remote data collector, and like that identify the species of the bird and its location. The basic idea is that the prototype can recognize birdsong via frequencies.

Before the demo day arrives, the system needs to be tested beforehand. The idea is to test this simply by trial and error. If the code works correctly it should recognize the bird species all by itself. It should do this by itself, to make sure this works, testing via trial and error is the best way. Because the team consists of eight team members a lot of people are able to work on this system and fix any bugs found along the way.

To create this prototype, there are also electrical components needed. A lot of these components can be obtained via a *basic Arduino kit*. The other components can be bought. The list of everything needed can also be seen in Figure 5. is the main resource, unfortunately the *basic Arduino kit* does not contain all the sensors and stuff needed. Therefore, everything that is still needed is listed in figure 5.

To make sure this prototype is going to work out the best way possible a time plan was made. This time plan contains modules that divide the different tasks. Below there is a table with when a task needs to be finished.
Modular time plan:

Module 1: Deciding the topic of the project, planning the structure and deciding the timeline of the rest of the project
Module 2: working on software, ordering the materials for the hardware and the casing
Module 3: Working on casing design and hardware
Module 4: integrating the software and hardware
Module 5: Validation and testing
Module 6: preparing for the final demo

List of materials needed

Equipment needed	Amount	Price
Arduino Uno or Leonardo	3	x
3D print	3	€7,50
wires	10+	x
ZigBee modules	3	x
Sound sensor for Arduino	3	€16,80

		€4,99
Battery Block (9V)	3	€5,88
Battery adapter from 9V to dc 2.1mm plug	3	€17,70
Mini Breadboard	3	€1,41

Birds chosen and their frequency

Bird	Frequency	Image
Kagu	1 kHz	 from: https://pixabay.com/images/search/kagu/ Figure 5 a Kagu
Amazon Kingfisher	3 kHz	 From:https://www.istockphoto.com/en/search/2/image?mediatype=&phrase=amazon+kingfisher&utm_source=pixabay&utm_medium=affiliate&utm_campaign=SRP_image_sponsored&utm_content=https%3A%2F%2Fpixabay.com%2Fimages%2Fsearch%2Famazon%2520kingfisher%2F%3Fmanual_search%3D1&utm_term=amazon+kingfisher Figure 6 An Amazon Kingfish
Toucan Barbet	500 Hz	 from: https://pixabay.com/images/search/toucan/?manual_search=1 Figure 7 a toucan Barbet

Manakin	2kHz	 From: https://ebird.org/species/recman1 Photographed by: Fernando Burgalin Sequaria on the 19th of January 2019. Figure 8: a red-capped manakin
Blue-Chested Hummingbird	5kHz	 From: https://pixabay.com/images/search/hummingbird/?manual_search=1 Figure 9: Blue-chested Hummingbird

To make sure this project is going to work out the best way possible, there is provided a timetable (table 2).

Week	Module/Task	Deadlines
50 Friday 16 dec	Start working on the software and hardware	
51 Tuesday 20 dec	Work on Software and Hardware Work on Design	
51 Friday 23 dec	Casing development, software and hardware combining	
52	BREAK	
1	BRAKE for BREAK	
2 Tuesday 10 jan	Work on ambitious plans	
2 Friday 13 jan	Decision between ambitious and basic idea	**Finish all the modules/get ready to assemble**
3 Tuesday 17 jan	Testing errors/validation	**Finish "background" demo day**
3 Friday 20 jan	Solving errors	
4 Tuesday 24 jan	Prepare Demo Day	
4 Friday 27 jan		**Demoday**

Table 2

The required modules/tasks where also divided over the team members. This had to be an explicit division of our tasks, so this is the division that came to mind:

1- Calculating location using amplitude (software) - Wouter and Niels
2- Classifying birds using frequencies (software) - Nadja and Apurv
3- Modeling/design of the casing - Esmee and Jade
4- Documentation of the process - Jade and Rodrigo
5- Circuits & Arduino/Connecting hardware & software - Carlos and Rodrigo
6- Team leading - Nadja
7- Validation and testing - Carlos, Wouter, Apurv, Esmee

Chapter 8: Validation

Design

Because the Arduino's cannot handle the environmental conditions a casing was needed. At first the idea was just a casing with a roof on it so the rainfall could slide off easily. So the first idea was to make more of a birdhouse-like casing. The casing was modulated in the program *Autodesk fusion 360.* As can be seen in figure 10, the casing is just a rectangular chapped base with a triangle roof and a detachable bottom. The detachable bottom was done so it is easier to put the electronics in there without the casing getting in the way.

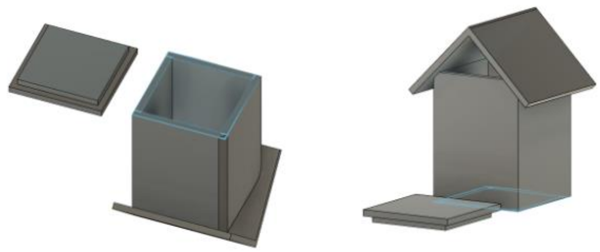


Figure 10: first 3d model of the casing

What also can be seen is that this 3d model was not completely finished because a different idea popped up: it should be more organic. This, so it would fit in the environment and be more hidden.

So, the design had to be organic and still remain rainproof. Those conditions eventually led to a mushroom-like casing. Because most mushrooms are cylinder shaped, the idea popped up to make the casing a cylinder as well. A lot of mushrooms have a circular roof that makes sure that the water falls off and doesn't stay on. This idea is also used in this model. In addition to that, it was tried to make the top as organic as possible. This was done by making some cracks in there as well. This can also be seen in figure 11. The back of the casing is flattened because of the idea to attach it to a tree. And since it is cylinder shaped, doing that would be much harder. The little hole that can be seen in the front is for the sound sensor so the casing does not interfere with the sounds. The idea is to put the sensor as high as possible to reduce the chances of rain getting in the casing. Just like the first 3d model, this one also has a detachable bottom.

Figure 11: second model of the casing

Figure 12: third model of the casing

The problem with the second model was that only the top was mushroom like and the trunk not so much. Luckily there is a feature in *Autodesk fusion 360* called revolve. After using that feature the third model came to life. This model can be seen in figure 12.
This was the first model that was also printed. Just like the second model the cracks in the top were a nice detail so that was kept in the model. So it is not a fully cylindrical shape, just like actual mushrooms which don't have that kind of shape. The inside of the casing is cylinder formed, the idea behind that is because a mushroom has also a rounded shape. The idea of making a flat back turned out to be a good idea so this was kept in the model as well as the detachable bottom.

Figure 13: The print of the third model

After the print was done, the following things were concluded; The casing was too big and a cylinder-shaped inside turned out not to be very practical. The print can be seen in figure 13. As seen in figure 13. is that the back of the casing was printer weird. It turned out this happened because the back was not flattened enough. Also, another error became visible. As you can see in figure 13 at the top right is that the circle has become smaller at the bottom. Because of this error the the detachable bottom did no longer fit.

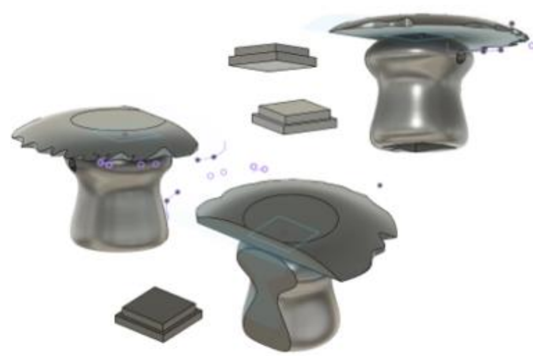


Figure 14: fourth model of the casing

So the 3d model was modified again. The following changes were implemented, as can be seen in figure 14. The inside is made rectangular due to our circuitry being rectangular as well and the whole casing was downsized by approximately 0,6. The top of the casing and the trunk were kept the same. The idea of the detachable bottom turned out to be working really well, so that feature was kept in. Since the inside has become rectangular the detachable bottom had to become that shape as well. The back of the casing was flattened a little bit more into the shape. This was mostly done because then the print would turn out much better. The fourth model was also the model that was the final version and is printed. The print can be seen in Figure 15.

For the print the cover of the first model print was used again. This was because with the first print the lid had to be sized down because it was already too large for the printer. The trunk and the bottom were not sized down because those could still fit in the printer. The decision of not sizing those parts down was because it was not certain if the electronics would still fit inside if their size was reduced as well. It was found only after the first prototype was printed that a cylindrical was not practical.

Figure 15: The print of the fourth model

Location

To determine the exact location of the bird there were some calculations that needed to be done. For the calculations an algorithm for triangulation was needed, this algorithm was not an existing algorithm but was completely created from scratch with processing. During the process of implementing the algorithm it was found that it was called trilateration instead of triangulation. This doesn’t matter for the result, however if this algorithm were to be recreated it would use trilateration as its basis. The idea is that you draw circles from each point, with the distance as it’s radius, and the point where the circles intersect as the location. However, in this project the exact distance is unknown, only the relation to the distances of the different sensors is known.

To start creating the algorithm it was necessary to measure the distance between the mouse and three artificial points instead of using the information of the sound sensors. The reason for that is that the information was unknown at the time. This artificial information was then used to try to calculate the location of the computer mouse. After a few different algorithms were tried out it was time to settle on an iterative algorithm. It draws all the circles, and uses the intersection of those to draw lines. The intersection of these lines is an estimated point.

However, this is not yet an accurate location. Therefore, the circles are scaled so that the biggest circle crosses this point. Then the formula is done again to get a new estimated point. This is repeated 50 times, or till the estimated point doesn’t change anymore. After that the estimation is then taken as the final point. When testing this with the computer mouse, this point was always exactly accurate, except when getting outside of the triangle or very close to any of the sensors.

After this was working, the distances from the mouse could be swapped out with the measurements of the

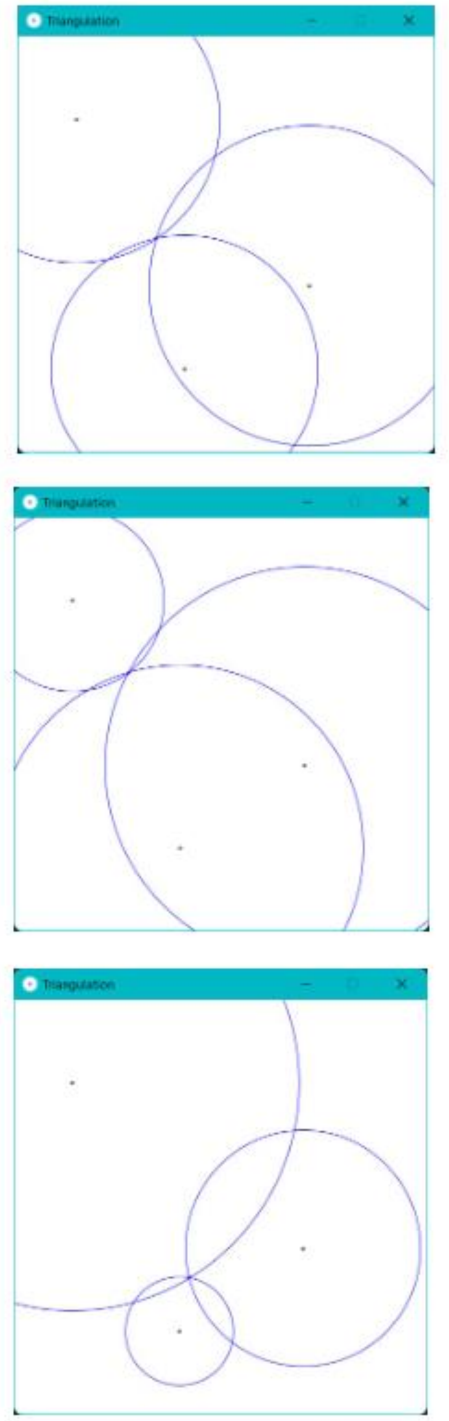


Figure 16: 3 different locations based on the computer mouse

amplitude of the sound. Since here, instead of the distance the amplitude was obtained it needed to be converted to a distance. Therefore, the input is converted using the formula that the amplitude of the sound should be negatively correlated with the square of the distance.

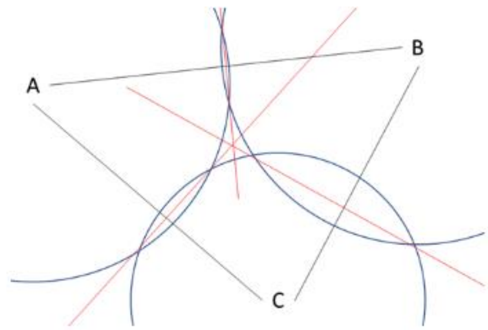


Figure 16a: Point estimation using circle intersections

Sound

The sound section is composed of the program which is used to transform analog input from a sound sensor into a measurable magnitude of frequency and amplitude/volume. Amplitude was the simplest value to calculate. The used sound sensor already had an output for envelope on its transmitted sound wave. This output is directly connected to an analog input in the Arduino and it is just directly printed, this value is later used for the location and trilateration section. However, the frequency was a more diverse calculation. First of all, the used sensor did not have a direct calculated frequency output, but it had a raw audio output. This audio output can be used as an analog input for the Arduino IDE, then this value is used to calculate an average peak frequency on a group of samples. Using an ArduinoFFT or Fast Fourier Transformation library. This library allows the arduino to pick up 128 samples to be used for calculation of a frequency. Then, a sampling frequency is selected, this frequency must be double the expected recorded frequency on the sensor. In this case the sampling frequency is

```
/*Perform FFT on samples*/
  FFT.Windowing(vReal, SAMPLES, FFT_WIN_TYP_HAMMING, FFT_FORWARD);
FFT.Compute(vReal,   vImag, SAMPLES, FFT_FORWARD);
FFT.ComplexToMagnitude(vReal, vImag, SAMPLES);
```

Figure 17: the FFT comments in processing

20480Hz. Moreover, two arrays are made, one array for real censored samples using the raw audio output from the sound sensor and an array for imaginary samples; the imaginary samples are set to zero. Finally, fast fourier transformation is done using the library and just plugging in the commands FFT.Windowing, FFt.Compute, FFT.ComplexToMagnitude, and FFT.MajorPeak (see figure 17).These commands weigh the samples, perform a windowing function, calculate the fast furious transform, and return the frequency of the biggest spike in the analyzed signal consequently. Through further inspection, it was possible to notice that the calculated frequency was off by a multiple of 2.654. After dividing this offset, it was possible to detect the expected frequency values. This process is done in three different locations in three different Arduinos that then send the information to a fourth Arduino that stores the data and communicates with processing in order to start the location section. The data is stored as (Letter corresponding to Arduino)(F)(calculated frequency)(A)(calculated amplitude) see figure 18 and sent to a receiver

Arduino which code only serial writes the incoming information from the other three Arduinos with the sensors.

```
CF1024.34A181.00
AF1396.43A214.00
BF1632.51A178.00
```

Figure 18: values that arduino sends to processing

Arduino connection

In order to connect the Arduinos between them, 4 different ZigBee modules were used. 3 of the Arduinos are programmed to be end devices or routers, these being the sensors, the communication happens via the serial port, the data collected from the sensors is printed in the serial monitor and the collector sensor, and the 4th Arduino receives via serial communication the information. Each of the nodes has a different letter (A, B, C) this is used to distinguish which one is which when selecting the data in processing.

Chapter 9: results and conclusion

Testing

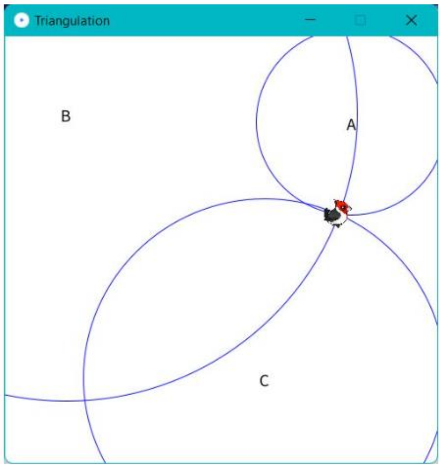


Figure 19: The location of the bird with the indicated species

First thing that we started to test is the sound sensor. The main thing that the sensor needed to do was measure the frequency, so we tested what frequencies the sensor can pick up. Out of the test came that it could only do up to 4k hz. Because of this finding, we couldn't test all the birds that we originally planned to test. One of the birds, the blue-chested hummingbird, had too high frequency for the Arduino sound sensor, 5k Hz, which is why we had to exclude that bird from further testing.

The next thing we tested was the Arduino connection via the ZigBee module. Firstly, we started with LEDs to test the connection between the three Arduinos that are going to send the data and the one that is going to receive the data. All that testing went as planned so the next thing we connected instead of the LEDs was the sound sensors. After that we connected the receiver to processing and tried out the trilateration.

We tested the sound sensors firstly with clapping since that gave us a very high amplitude sound that all the sensors picked up on. The sensors pick up the signal properly and send the amplitudes to processing. These values are then translated to allow the algorithm to detect the origin of the sound. The trilateration was working so the next thing was to implement frequency detection. By corresponding the frequency to a certain bird, we managed to detect the species of the bird. It was decided in between a few tests to add a picture in the processing so that the type of sound that belonged to a bird species could be recognized. The pictures were added to the processing and assigned to the frequency the sounds belong to. In figure 19 you can see the bird species and the location it is at.

After testing everything inside it was time for an outside test. We separated the sensor in a triangle about five meters apart from each other and played the bird sounds from a speaker. We moved the speaker around the triangle to test if we can pinpoint the bird.

Findings

The main problem that we found is that the sensor is more designed to test quick, loud and short-lasting sounds, like a clap, that's why the trilateration worked as planned when we clapped around the sensors. But when we used the bird sounds the trilateration worked some of the times because it was picking up a lot of different amplitudes form the bird's chirp. Which confused the program and gave us incorrect results.

Concerning the frequency, the sensor can easily pick up frequencies, but it also picks up a lot of random frequencies in the environment. We managed to get the sensor to recognize a certain frequency and to give us a corresponding bird to it. But we cannot account for the random sounds in the background.

Conclusion

After tests were run and the final prototype was finished the following things were concluded: The project was finished in time, which meant that it could both recognize each bird by sound and detect its location. The only problem with this was, that the sensor that was used is not strong enough to detect the frequency when there is a lot of background noise. This resulted in only loud sounds like a handclap could do the trick of sending data.

So this means in short, that basically everything works. That concludes the algorithm of the trilateration, the casing which is not interfering with results and the Arduino's are communicating with each other but only with a specific sound. So, if this project were to be continued, the following changes should be taken into consideration. There should be a higher quality sound sensor provided to receive the sounds. The sensor currently used is simply not powerful enough, but the tests show the system still operating. So that suggests that the problem does not lie with the algorithm or the casing.

Also, the testing was done without rainfall or other hazards. If this project was to be taken forward or in another time of year the testing could also be done with rainfall and all the other complications which arise because of the jungle location. Because the casing was not tested on waterproof, there is no conclusion if the material for the casing works. The shape is made for allowing water to flow down the casing. This was not specifically tested but the top does not contain holes and it is not flat so there should be no way that the rainfall could drop in the casing from the top.

At the start of the project the basic plan was that the prototype could detect the bird species via frequencies. The final result is the ambitious plan that it can detect both the bird species via frequency and the location of the birds. Unfortunately because of the weak sound sensor these functions work both really well separately. But when tried together there are some difficulties like stated before. So, our algorithm is working but because of the lacking sensors it is difficult to have both the location and the frequency working simultaneously.

So to answer the question: "How can location and species detection save tropical birds from extinction?" Both factors are needed because they are necessary to determine what the living area of the bird is and what kind of bird species it is. And the more you know about a species the better you can help it. By keeping their living area as unharmed as possible to ensure biodiversity the birds will also indirectly prosper or by knowing which type of food they might need. This prototype is not strong enough to be set out in its actual nature but like stated before a few times, with more budget and a little bit more time and research this idea can be scaled up and be very useful for preservation.

Appendix A: Processing code

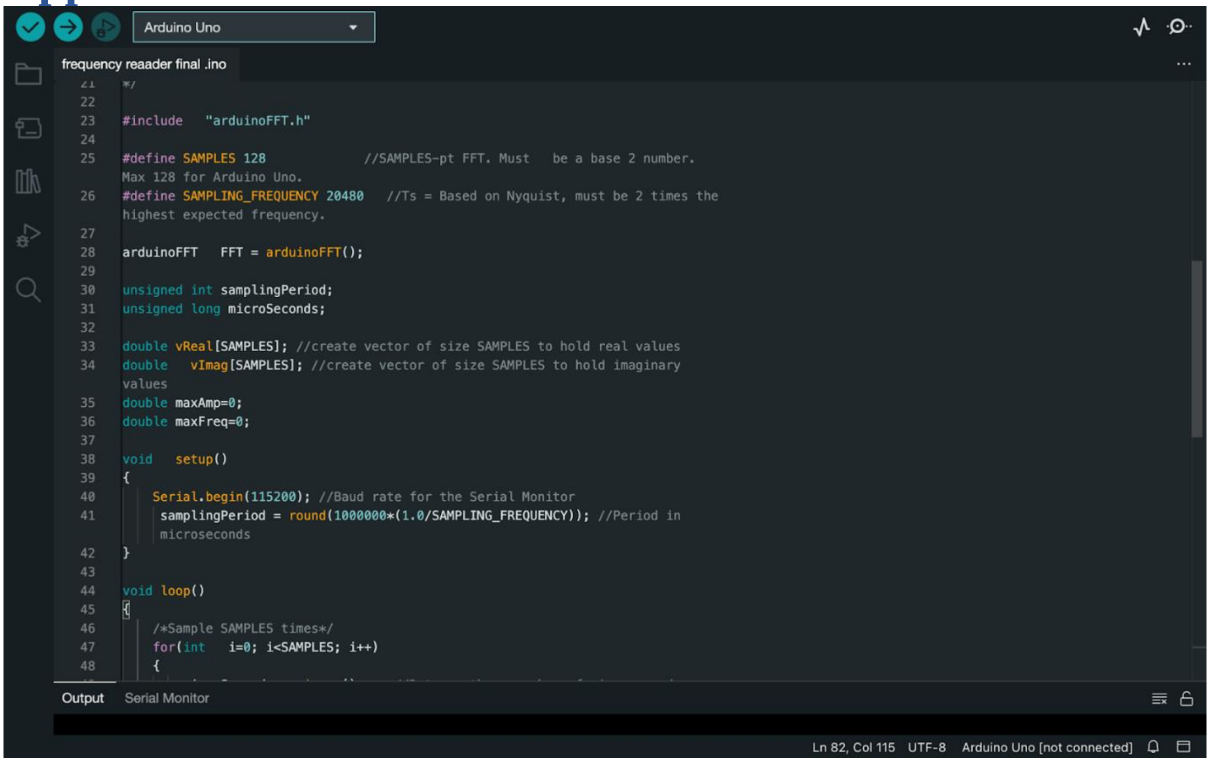
```
PVector[] p = {new PVector(400, 100), new PVector(70, 90), new
PVector(300, 400)}; //Locations of the stations
//STATIONS SHOULD NOT HAVE THE SAME X OR THE SAME Y COORDINATE
int t = 0;
PVector res;

import processing.serial.*;

String buff = "";
int NEWLINE = 10;
char stations[] = {'A','B','C'};
float freqs[] = new float[3];
float amps[] = new float[3];
int n;
Serial port;

PImage img_kagu;
PImage img_toucan;
PImage img_manakin;
PImage img_kingfisher;

void setup() {
  size(500,500);
  //Get the serial port of the arduino for communication
  println("Available serial ports:");
  println(Serial.list());
  port = new Serial(this, Serial.list()[1], 115200);
  img_kagu = loadImage("KAGU.PNG");
  img_toucan = loadImage("TOUCAN.PNG");
  img_manakin = loadImage("MANAKIN.PNG");
  img_kingfisher = loadImage("KINGFISHER.PNG");
}
void draw() {
  while (port.available() > 0) {
    serialEvent(port.read()); // read data
  }

  background(#FFFFFF);
  //noFill();
  //stroke(#000000);

  fill(#000000);
  textAlign(CENTER);
  textSize(20);
  for (int i = 0; i < p.length; ++i) {
    //circle(p[i].x,p[i].y,3); //draw a location for each station
    text(stations[i],p[i].x,p[i].y + 10);
  }
  noFill();

  if (max(amps) > 0) { //Check if we have an amplitude from every station,
because otherwise we cannot calculate a location
```

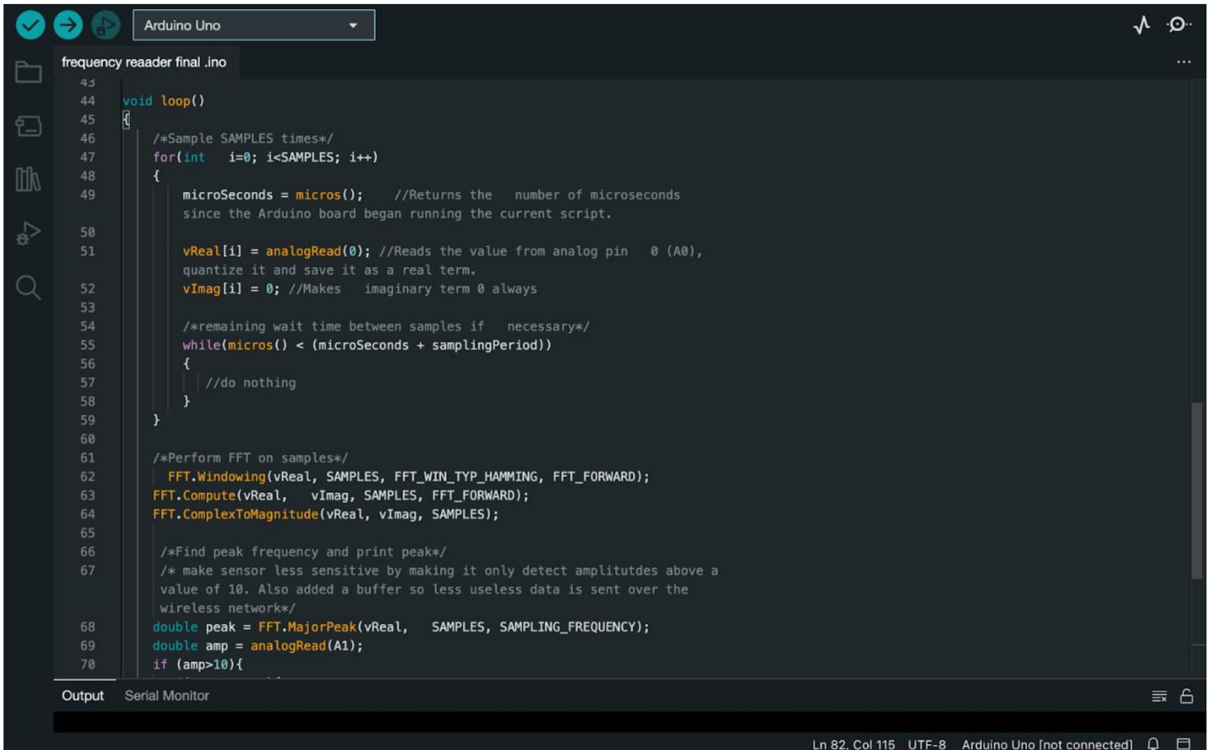
```
    float v[] = new float[3];
    for (int i = 0; i < p.length; ++i) {
      v[i] = pow(amps[i], -2); //Take the amplitude and do it to the power
of -2, because that should be an indication of the distance
    }

    //Find the station with the highest distance (biggest circle) and
store it in mi
    //Change the distance values to a multiplier of the maximum distance
    float m = max(v);
    int mi = 0;
    for (int i = 0; i < p.length; ++i) {
      if (v[i] == m) mi = i;
      v[i] = v[i]/m;
      //println(stations[i] + ":" + v[i]*200);
    }
    m = 200; //Set the radius of the biggest circle to 200

    //Create variables for the x and y coordinate of the location
    float x = 0;
    float y = 0;
    for (int i = 0; i < 50; ++i) { // Do maximum 50 itarations in
approaching the right location of the sound
      float a1 = 0;
      float b1 = 0;
      float a2 = 0;
      float b2 = 0;
      //Go through every possible pair of stations, calculate a line
between the stations, and calculate a line perpendiculat to this line
going through the the intersection of the circles of both stations
      for (int i1 = 0; i1 < p.length; ++i1) {
        int i2 = (i1 + 1) % 3;
        float x1 = p[i1].x;
        float y1 = p[i1].y;
        float v1 = v[i1]*m;//Multiply the relative distance to the radius
of the biggest circle that was set (this gets updated every cycle)
        float x2 = p[i2].x;
        float y2 = p[i2].y;
        float v2 = v[i2]*m;//Multiply the relative distance to the radius
of the biggest circle that was set (this gets updated every cycle)

        float d = p[i1].dist(p[i2]);
        if (d == 0 || !Float.isFinite(d)) println("d:"+d);
        float a = (sq(v1) - sq(v2) + sq(d)) / (2*d);
        if (d == 0 || !Float.isFinite(d)) println("a:"+d);
        float xc = x1 + (x2 - x1)/d*a;
        float yc = y1 + (y2 - y1)/d*a;

        //Store the previously found line as line 2 instead of 1
        a2 = a1;
        b2 = b1;
        //Calculate a line through the intersections of the circle in the
format y = ax+b
        a1 = (x2 - x1)/(y1 - y2);
```

```
        b1 = yc - (a1*xc);
      }
      // Calculate the intersection of the lines with the following
formula
      x = (b2 - b1)/(a1 - a2);
      y = a1 * x + b1;
      res = new PVector(x,y); //Create a vector with the estimated
location
      float mnew = p[mi].dist(res); //Calculate the new size of the
biggest circle
      if (abs(m - mnew) < 1) break; //If the difference between the new
estimation and the previous estimation is less than 1 pixel, stop with
making more estimations
      m = mnew; //Set the size of the biggest circle to the new size.
    }
    circle(x,y,3); //Draw a circl on the final estimated location




    //Draw circles from the stations to this point.
    stroke(#0000FF);
    for (int i = 0; i < p.length; ++i) {
      circle(p[i].x,p[i].y,p[i].dist(res)*2);
    }

    //Get frequency and compare to birds, show pic of relevant bird
    float avgfreq = (freqs[0] + freqs[1] + freqs[2])/3;
    if (avgfreq > 900 && avgfreq < 1200) {
      image(img_kagu,x-20,y-20,40,40);
    } else if (avgfreq < 400 && avgfreq > 600) {
      image(img_toucan,x-20,y-20,40,40);
    } else if (avgfreq > 1900 && avgfreq < 2200) {
      image(img_manakin,x-20,y-20,40,40);
    } else if (avgfreq > 2700 && avgfreq < 3500) {
      image(img_kingfisher,x-20,y-20,40,40);
    }
  }
}

/*
Transmission protocol:

AF10A20
BF43A21
CF98A12

-> Sensor A has a frequency of 10 and an amplitude of 20, Sensor B has a
Frequncy of 43 and an amplitude of 21, etc.
*/
String valid = "ABCF0123456789.\r\n";
void serialEvent(int serial)
{
```

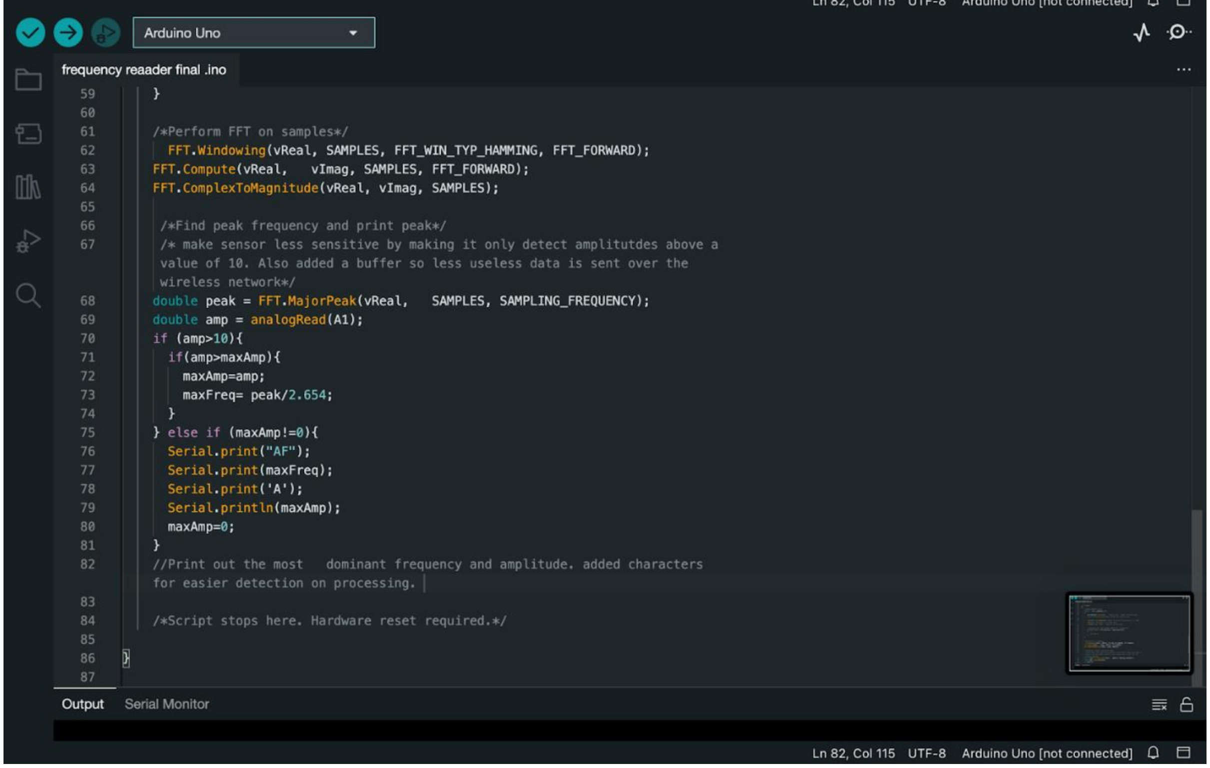
```
  try  {    // try-catch because of transmission errors
    if(serial != NEWLINE) {
      buff += char(serial);
      //println(valid.indexOf(char(serial)));
      if (valid.indexOf(char(serial)) == -1) buff = ""; //Empty buffer
when encountering an invalid character
    } else {
      println(buff);
      buff = buff.substring(0, buff.length()-1);// Discard the carriage
return at the end of the buffer
      char station = buff.charAt(0); // The first character tells us which
station the value is from
      buff = buff.substring(1); // Remove it from the string
      if (buff.charAt(0) != 'F') throw new Exception("Second character is
not F");
      buff = buff.substring(1); // Remove it from the string
      String[] buff_split = split(buff,"A"); //Get the number before A
(Frequency) and after (Amplitude)

      // Parse the String into two floats
      for(int z=0;z<3;z++) {
        if(station == stations[z]) {
          freqs[z] = Float.parseFloat(buff_split[0]); //Use the first
number as frequency
          amps[z] = Float.parseFloat(buff_split[1]); //Use the second
number as amplitude
        }
      }
      buff = ""; // Clear the value of "buff"
    }
  }
  catch(Exception e) {
    println("no valid data:" + e);
    buff = ""; // Clear the value of "buff"
  }
}
```

Appendix B: Arduino Code for sensors



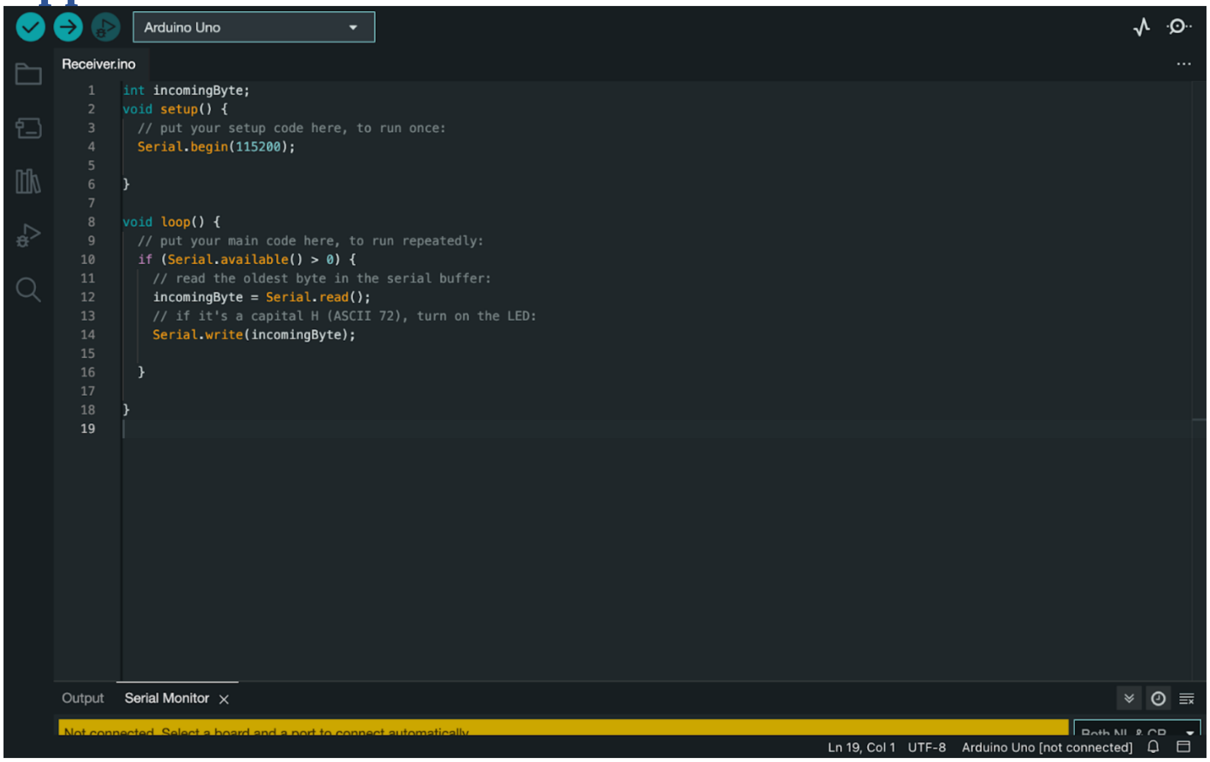



```
void loop()
{
  /*Sample SAMPLES times*/
  for(int   i=0; i<SAMPLES; i++)
  {
    microSeconds = micros();    //Returns the   number of microseconds
    since the Arduino board began running the current script.

    vReal[i] = analogRead(0); //Reads the value from analog pin   0 (A0),
    quantize it and save it as a real term.
    vImag[i] = 0; //Makes   imaginary term 0 always

    /*remaining wait time between samples if   necessary*/
    while(micros() < (microSeconds + samplingPeriod))
    {
      //do nothing
    }
  }

  /*Perform FFT on samples*/
    FFT.Windowing(vReal, SAMPLES, FFT_WIN_TYP_HAMMING, FFT_FORWARD);
  FFT.Compute(vReal,   vImag, SAMPLES, FFT_FORWARD);
  FFT.ComplexToMagnitude(vReal, vImag, SAMPLES);

   /*Find peak frequency and print peak*/
   /* make sensor less sensitive by making it only detect amplitutdes above a
   value of 10. Also added a buffer so less useless data is sent over the
   wireless network*/
  double peak = FFT.MajorPeak(vReal,   SAMPLES, SAMPLING_FREQUENCY);
  double amp = analogRead(A1);
  if (amp>10){
```




```
  }

  /*Perform FFT on samples*/
    FFT.Windowing(vReal, SAMPLES, FFT_WIN_TYP_HAMMING, FFT_FORWARD);
  FFT.Compute(vReal,   vImag, SAMPLES, FFT_FORWARD);
  FFT.ComplexToMagnitude(vReal, vImag, SAMPLES);

   /*Find peak frequency and print peak*/
   /* make sensor less sensitive by making it only detect amplitutdes above a
   value of 10. Also added a buffer so less useless data is sent over the
   wireless network*/
  double peak = FFT.MajorPeak(vReal,   SAMPLES, SAMPLING_FREQUENCY);
  double amp = analogRead(A1);
  if (amp>10){
    if(amp>maxAmp){
      maxAmp=amp;
      maxFreq= peak/2.654;
    }
  } else if (maxAmp!=0){
    Serial.print("AF");
    Serial.print(maxFreq);
    Serial.print('A');
    Serial.println(maxAmp);
    maxAmp=0;
  }
  //Print out the most   dominant frequency and amplitude. added characters
  for easier detection on processing.

  /*Script stops here. Hardware reset required.*/

}
```

Appendix C: Receiver Arduino code



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