UNIVERSITEIT TWENTE.

SMART ENVIRONMENTS PROJECT

DOCUMENTATION REPORT

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Chapter 0: Introduction

Numerous records show that illegal hunting has caused significant decreases in wildlife populations. Research on birds and mammals that included 176 studies indicate that the abundance of such animals decreased by 58% and 83% respectively when comparing hunted and unhunted areas [30]. The project proposed in this paper focuses on tackling such issues by developing a smart environment able to sense, analyze, compare data, and perform actions in response to it. Illegal hunting was chosen as the final issue to be tackled due to its significant impact on society and wildlife: it often causes severe food chain disruptions, which can seriously affect ecological and animal population control [22].

After considering multiple solutions for the selected issue, the group chose to focus on sound anomaly detection based on effectiveness and feasibility criteria. The scope was hence reduced to illegal hunting in protected areas, aiming at detecting gunshots and excluding the use of more sophisticated tools or tranquilizers. Nevertheless, this solution was pertinent enough to be implemented since illegal hunting in reserves is still a relevant and concerning topic as shown in [31], [37].

The group proposes developing a smart system that continuously detects sounds while checking if the obtained data values match gunshots. If this is the case, a message including the location of the source should be sent to the authorities. Such analysis can be done by strategically placing multiple devices in the area to be monitored and comparing the differences in values received. Additionally, research on related studies on sound anomaly detection was done to assess the potential efficiency of the project. After discovering an existing system using a similar kind of gunshot detection [4], the group was convinced of the project’s viability.

This research is conducted by group eleven, composed of seven members: Andreea Goga, Carmen Diez Rodriguez, Ho Tak Fong, Nina Kwaks, Onne Iping, Rémi Astier, and Tim Haarhuis. The final goal is to develop a product that, while following the project’s requirements and guidelines, will positively impact the current scenario by introducing an easier and more efficient way of monitoring while collecting data that can be used for future research. For this reason, the project is referred to as “EyeHear”, referencing that the developed system uses sound sensors to track and localize illegal activities.

The paper is structured as follows: Chapters 1, 2, 3, and 4 present the problem selection process, from research to final choices. Chapters 5 and 6 discuss solutions to the given problem and motivate the project’s direction. Finally, chapters 7, 8, and 9 describe confection and implementation processes.

Chapter 1: Literature Review

1. **“Precision wildlife monitoring using unmanned aerial vehicles” [7]**
   Aerial monitoring using an unmanned drone has a higher accuracy than ground-based observations regarding taking samples and tracking groups of animals. This is because an aerial drone can provide a better vantage and easier means to follow the wildlife that is being observed.

2. **“Innovations in camera trapping technology and approaches: The integration of citizen science and artificial intelligence” [6]**
   The use of AI and citizen science in camera trapping, and the creation of camera trapping technology are exceedingly useful to maximize the amount of data that can be collected and processed. Utilizing camera traps and citizen science combined should yield the best results in camera trapping research.

3. **“Poaching detection technologies—a survey” [8]**
   The paper explains various anti-poaching measures: diplomatic action, law enforcement, demand reduction, negative reinforcement, and substitution. It also presents poaching prevention/detection technologies in current use.

4. **“An assessment of monitoring efforts in endangered species recovery plans. Ecological Applications” [3]**
   The source focuses on species tracking. The method used for monitoring is not presented, but the data collected regarding where and how the species live is given.

5. **“Importance of well-designed monitoring programs for the conservation of endangered species: a case study of the snail kite” [14]**
   The paper presents the steps followed when monitoring snails: an area of action was first defined and surveys involving locals were made. Then, the method used to count the number of snails is explained. The final step was to compare all the data collected during the research and draw conclusions.

6. **“Critical evaluation of a long-term, locally-based wildlife monitoring program in West Africa” [2]**
   The source presents the differences between data collection with cameras and patrol observation. While the former is used to capture solitary and mostly carnivore species, the latter is more efficient when researching big groups of animals such as elephants or giraffes.

7. **“Wireless Sensor Network for Wildlife Tracking and Behavior Classification of Animals in Doñana” [13]**
   The source details how computer vision can be used to track wildlife. It is explained that only a few matches can be done using the method presented (more accurately if the pictures are not taken too far one after the other).

8. **“Optimizing observing strategies for monitoring animals using drone-mounted thermal infrared cameras” [5]**

   Thermal infrared cameras have the benefit of being able to discriminate between different animals based on their body heat and of being able to identify animals at night. However, there are several technical difficulties associated with using thermal infrared cameras installed on drones. If animals, for example, hide under the vegetation, they cannot be well identified.

9. **“Unmanned aircraft systems as a new source of disturbance for wildlife: A systematic review” [15]**

   Unmanned aircraft systems may disturb wildlife while tracking. The paper explains how flight patterns, engine type, and aircraft size can impact the reactions of the animals to the technology.

10. **“Application of temperature measurements for the bee colony monitoring: a review” [19]**

    This paper, it is explained how to monitor a bee colony by measuring temperature. Various implementations of this method are being explained, such as using loggers, wired sensor networks, infrared imaging, and so-called ‘iButtons’. Beekeepers can use the monitored temperature information to detect colony events. This way, resource consumption can be minimized, while productivity can be maximized.

11. **“Are unmanned aircraft systems (UAS s) the future of wildlife monitoring? A review of accomplishments and challenges” [11]**

    This paper explains how unmanned aircraft systems (UASs) can be used soon to protect endangered animals. Some advantages of UASs are low costs and the use of temporal resolution. However, the flight endurance is short, and in most cases, it is hard to get legislation for the use of UASs.

12. **“Internet of Things for wildlife monitoring” [12]**

    This paper looks at the application of the Internet of Things (IoT) on wildlife monitoring. It focuses on three applications: location tracking, habitat environment observation, and behavior recognition. Furthermore, several resource-saving mechanisms have been discussed, like MCU, and effective data transmission and communication area indication.

13. **“The decline of butterflies in Europe: Problems, significance, and possible solutions” [18]**

    The article provides information on the alarming decline rates of butterflies around Europe and urges the need for a change. By presenting the reasons why the insects are going instinct, it shows how this data can indicate pollution rates and climate change. Furthermore, the authors suggest solutions for the problem.

14. **“Emerging technologies revolutionize insect ecology and monitoring” [17]**

    The paper describes how computer vision, acoustic monitoring, radar, and molecular methods are used for insect monitoring. It compares the technologies while presenting their strong and weak points. Additionally, the authors suggest how the combination of approaches can improve research in such a field, explaining why traditional monitoring methods should not be excluded from the process.

15. "Natura 2000: Biodiversity strategy for 2030" [1]

The webpage presents the strategies the Natura 2000 program implemented to restore Europe's biodiversity. The EU's first Nature Restoration Law was proposed by the Commission to solve biodiversity problems on land and seas. Improving knowledge is mentioned as one of the measures to achieve the established goal.

16. "A Wildlife Monitoring System Based on Wireless Image Sensor Networks" [20]

The paper explains how to set up a wireless image sensor network, used for wildlife monitoring. Both the benefits and the disadvantages of a system like this are discussed. The design of the sensor nodes and the software is also explained in the paper.

17. "Bees are dying at an alarming rate. Amsterdam may have the answer" [9]

The article is about the decreasing number of bees and what we can do to stop the numbers from decreasing. The city of Amsterdam is given as an example of a 'bee-friendly' city. The article explains why this is the case, and what other cities can do to increase the number of bees.

18. "A wildlife monitoring network for De Hoge Veluwe National Park: Baseline measurements and design" [10]

This paper is about monitoring deer, boars, and other ungulates in De Hoge Veluwe National Park. The park is enclosed by fences, with two passages to make migration possible for these animals. The paper describes two different plans to monitor the consequences of migration through these passages in the national park, for example by using camera traps.

19. "El ambicioso plan para acabar con la 'isla de basura', la nación de plástico del mar" [16]

The Ocean Cleanup is a project that aims at removing plastic residue from the sea. By deploying floating barriers in the ocean, they expect to control possible new contamination and prevent it from continuing to deploy at sea. The boat has about 600 meters in length, with a U-shaped barrier at the front, whose objective is to get hold of as many plastics as possible. The idea is simple: collect the waste, store it, and every several months, give it to a support ship that takes it to the mainland to be recycled.

20. "El ADN del aire, ¿una nueva manera de medir la biodiversidad animal?" [4]

The source describes how DNA samples collected from the air can be used to detect many animal species. This is a non-invasive method that could change the way animal biodiversity is monitored and measured.

Chapter 2: Identification of General Problems and Challenges

Wildlife monitoring is a broad topic that encompasses several problems and challenges to be addressed. This session summarizes a total of eight initial and general issues identified during the primary research phase.

1. Endangered species tend to be a target for poachers due to their great value in the market. Such a problem needs to be addressed once its impact on biodiversity is rapidly scaling. [8]

2. Most monitoring technologies nowadays disturb wildlife by emitting sounds or intruding on their space and habits [15]. A good direction for the project could be developing a system that aims at monitoring without big impacts.

3. Infrared image cameras cannot properly detect the animals that hide in the vegetation [5]. This technology is not a good choice for monitoring small animals that can easily hide. It could be, therefore, interesting for the group to research and tackle the issue.

4. Insects are decreasing in number, a reflection of the high pollution rates and global warming [18]. Monitoring them could indicate biodiversity problems and be a good direction to be followed during the project.

5. Plastic in the ocean disturbs sea animals: they tend to easily get caught or swallow it. Pollution rates are an important topic in nowadays scenario and could be a good starting point for the project. [26]

6. Enclosed national parks lead animals to feel trapped. In other words, a place that should preserve wildlife can create new problems. [28]

7. Lack of knowledge on wildlife endangerment: the importance of spreading awareness [30]. Monitoring wildlife is the goal of the project; however, a good addition could be using the data collected to provide information to the public.

8. Lack of biodiversity: some species survive while others disappear, which leads to a false impression of variety. Additionally, they must constantly adapt which, sometimes, results in the weakening of the species. [18]

Chapter 3: Identification of Relevant Problems

After further research and debate, five new topics involving wildlife monitoring were analyzed and classified as urgent and interesting issues to be addressed. Such matters are further described in this session.

1. Beavers in the Netherlands are increasing in numbers (especially in the Rivierengebied). The animals dig holes in dikes, weakening the land and increasing the risk of flooding. A common solution is to scare the beavers once they are spotted, which is rather inefficient and time-consuming. [21]

2. Illegal hunting directly affects wildlife and biodiversity: by shooting and killing animals, the hunter is not only impacting the species itself, but also its food chain [22]. The crime can happen for recreational causes, and land and livestock protection against intruding species such as wolves [23].

3. Some protected reserves are not as efficient as they should be: if nearby lands are being used for agricultural purposes, pesticides will also impact the preserved areas. Such a scenario affects especially insects, which might be one of the causes of the population decrease. [27]

4. Structures such as weirs, dams, and pumping stations led to an increasingly fragmented water system. As a result, natural habitats for fish became smaller and less diverse, making it difficult for various species to reproduce and grow. Fish stocks are becoming progressively more vulnerable to environmental changes, reducing their chances of survival. [24]

5. Nitrogen emissions in the Netherlands worry various groups in the country due to impacts on biodiversity, global warming, and wildlife [25]. Some insects are highly affected by this problem and can be an indicator of habitat deterioration [18]. It is important to spread awareness on the topic and show different sectors of the population the impact their daily actions have on the environment [30].

Chapter 4: Problem Selection and Motivation

Illegal hunting can be described as the act of killing animals in violation of wildlife management laws for recreational [22], property protection [23], or commercial purposes [36]. The felony was chosen as the final problem to be addressed due to its great impact on biodiversity and society: it often leads to extreme disturbances in food chains, which can result in great consequences for ecology and animal population control [22]. Asides from that, the topic is not particularly affected by the climate limitations of the project considering that it doesn't rely on the sleeping, eating, or reproduction habits of animals, a concern that greatly influenced the decision-making process.

This project's scope focuses on illegal hunting in protected areas as research shows that these locations are hotspots for criminals [31], [37]. It was also found that detecting the action in such areas might not always be easy or fast considering various strategies used by illegal hunters [31], which makes it harder for authorities to act. Therefore, the group proposes developing a system to monitor illegal hunts efficiently and relatively cheaply. By doing so, the final product is expected to contribute to the fight against the felony.

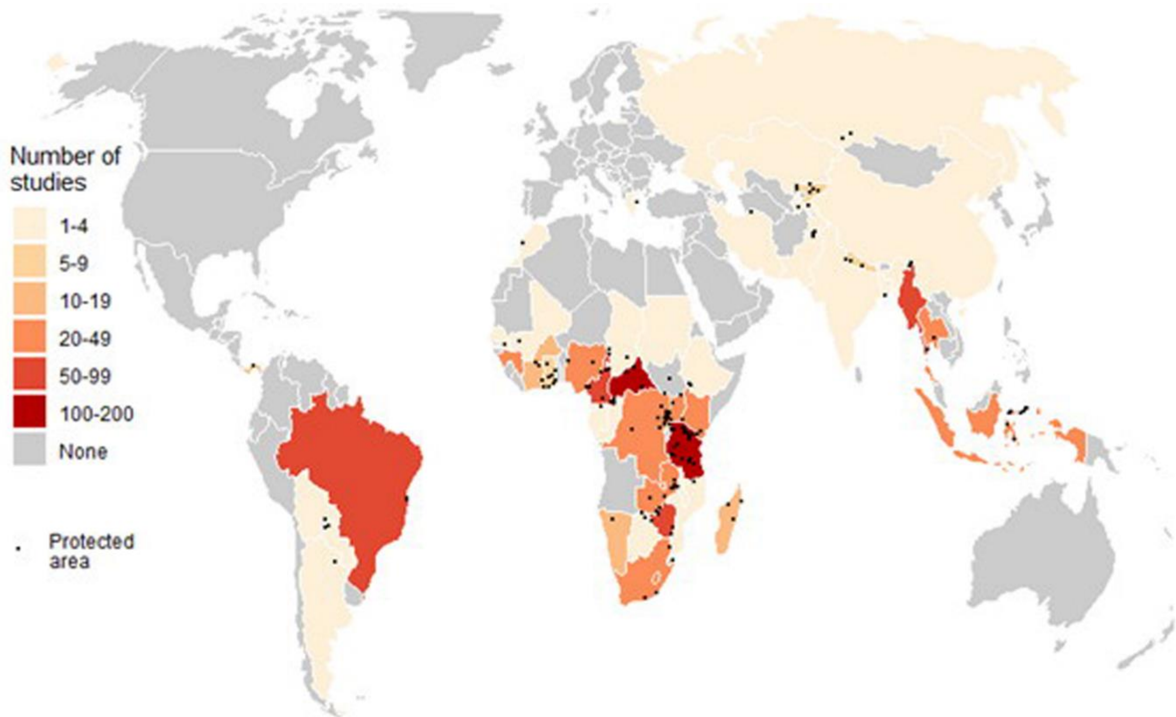


Fig 1. Map retrieved from a research article on the illegal hunting of mammals in protected areas [37]. The colored scale represents the number of studies found regarding the theme, and the black dots indicate the location inside PAs where studies were conducted.

Chapter 5: Potential Solutions

Five potential solutions were identified and elaborated to guide the product development stage. The solutions focus on different steps and consequences of illegal hunting and were later analyzed based on their efficiency to solve the problem selected. In an ideal scenario, with enough knowledge and equipment, the following propositions should somehow change the current scenario:

1. The Netherlands is one of the hotspots for illegal wildlife trafficking. This means that many living animals are still being smuggled into the country without being noticed by authorities [29]. A solution could be creating a smart system to detect life inside closed spaces by measuring gas levels (such as carbon dioxide). The device can be placed in locations such as ports and airports to combat contraband.

2. Hunts are one of the main causes of biodiversity loss as shown in [1]. To prevent it, authorities must be alerted quickly when the criminals are active. This could be done by using smart systems that can detect gunshots through sound sensors: when a loud sound is detected, a signal is sent to the authorities [34]. By doing so, action could be taken faster.

3. Tracking collars for death detection is a method used by researchers when monitoring animals' migration and life cycles [32]. The technology could, however, be implemented to track and collect data on anomalous deaths to predict poaching activities in certain areas. Measurements would then be taken by local authorities.

4. Motion sensors located at strategic points might be a way to reduce the number of illegal hunters. Depending on how their algorithm was developed, the motion sensors can determine whether a mass poses a threat or not. These sensors could, for example, be placed high up in trees [33], [44].

5. Also related to hunting prevention, a solution could be implementing face recognition to identify the human presence in restricted areas [35]. By doing so, preserved territories, as well as their wildlife, could be protected from trespassing and illegal activities by monitoring.

Chapter 6: Solution Selection

The following table presents two different stages involved in illegal hunting, connecting them to the solutions proposed:

STAGE	SOLUTION
The hunt	Sound anomalies detection Tracking collars Face recognition Motion sensors
Wildlife trafficking	Gas level detection

To agree upon a final project, the ideas were compared based on two main aspects:

1. Effectiveness: it was concluded that detecting illegal hunters in action was one of the best scenarios considering that this would give authorities more opportunities to intercept and take the required measures to stop the criminals from further impacting local biodiversity.

2. Feasibility: the solutions were analyzed regarding the group's current knowledge and skills. Due to experience limitations, face recognition was understood to be unattainable. However, a sound analysis should be doable under the budget and time limit.

The group considered implementing tracking collars as the final solution, but research shows that the devices often negatively impact the welfare of the animals. In some cases, illegal hunters were able to gain access to the GPS of the tracking collars, which was used to their advantage [40]. This is one of the reasons why the group decided to pick a different solution.

After much deliberation, gunshot detection was selected as the direction to be followed during the project. Choosing this solution means that the problem's scope was reduced to hunting with loud guns, excluding the usage of tranquilizers or more expensive equipment. However, it was still considered to be relevant enough for the current scenario to be executed.

Chapter 7: Methodology

The project's goal is to develop a smart environment that somehow monitors or affects wildlife. The solution chosen follows the given limitations once it implements sensors to collect and process data to automate a task. This would facilitate the work of forest guards by reducing the necessity for constant patrols. Additionally, the device could improve the security of preserved territories, benefiting wildlife: if it is easier and faster to detect criminal activities, hunters would either be punished more often or be unwilling to hunt at all.

To determine the potential effectiveness of the project, research was made around similar studies on sound anomaly detection. The group came across an existing system used by the police in Minneapolis (among other cities) to detect gunshots in urban areas, also using sound detection technology [41]. This showed that the project was realistic and thus validated the solution choice.

This chapter describes the preparation for prototype development, including the initial materials needed, the action plan, and task division.

7.1 Basic and Ambitious Scenarios

Two goals are being set for this project: a basic product that works and fulfills the given requirements granting a pass, and a more advanced product that will be developed once the initial goal is achieved. Those were defined as follows:

1. Basic scenario: the group creates a system that constantly detects sounds, compares the data acquired, and alerts authorities in case of sensing signals higher than the values given (which match gunshots). Several devices would be placed over the land so different data can be detected and better information can be given. The location would be calculated based on which devices captured the sound. Additionally, the devices will initially communicate via Bluetooth, which has a smaller range but is easier to program.

2. Ambitious scenario: once the system works, the group improves location indication by comparing amplitudes of sounds sensed since it is known that such values decrease with distance from the source as explained by [39]. Furthermore, once data is collected by the system, it can be used to create a map of the local hunting hotspots, information that could be used by local authorities when deciding where patrols should take place. Moreover, communication between devices can be done through Wi-Fi for a bigger range.

7.2 Materials Needed

Three prototypes will be initially built so interaction can be checked, and data compared. For each of them, an Arduino board and a microphone will be acquired. Sources were found on how to connect the materials as needed for the project [42], [43]. Additionally, when it comes to specifications for the microphones, it was concluded that it is not necessary to use a sensor capable of detecting quiet noises. The only requirement is that it captures amplitudes between normal environment noises and gunshots.

For the design, it is important to consider that the prototype will be placed in the wild, and should be able to resist temperature variations, water, humidity, and wind. Furthermore, it shouldn't disturb wildlife or cause visual pollution. The prototypes will be initially 3D printed since it guarantees a solid structure with the possibility to perfectly design slots for the different components.

When generating the local hotspots with the data gathered, Processing will be used. Based on the knowledge accumulated in the Programming and Physical Computing course, it is possible to connect Arduino and a display on a laptop. Therefore, the data gathered from the sensors will be sent to a Processing file and used to create a map disclosing the most common hunting spots. For the demo, a fake database will be used as an example since the prototype will not be tested under real circumstances.

7.2.1 Material List

The specific components initially used for hardware confection are described in the following list:

Component	**Price**	**Specifications**
HC-05 HC-06 Bluetooth Wireless RF Transceiver Module RS232 Serial TTL	€4,67 (x3)	- Range of max. 10 meters - Bluetooth Class 2 - Can be used as sender/receiver - Compatible with Arduino
High Sensitivity Sound Microphone Sensor Detection Module	€1,58 (x3)	- Uses 5V DC power supply - Threshold level output flip - Sensitivity potentiometer adjusters - Operation range of 0-160 dB - Compatible with Arduino
Microcontroller Board ATmega328	€6,66 (x3)	- 14 digital inputs/outputs - 6 analog inputs - Compatible with Arduino IDE
100x M3 x 10mm Countersunk Screws Stainless Steel DIN 7991 Countersunk Head Hexagon A2 V2A VA	€6,75	- NA

7.3 Deployment Method

To detect the location of the sound source in a precise matter, the group studied the most optimal placement for the equipment. It was clear that, to compare data, one prototype would not be sufficient.

Assembling three devices was considered the best option given time and material limitations. The figure below shows a graphic of the operating ranges of the sound sensors to be deployed. The overlapping areas can be used to deduct the location of the source, depending on which device(s) captured the sound.

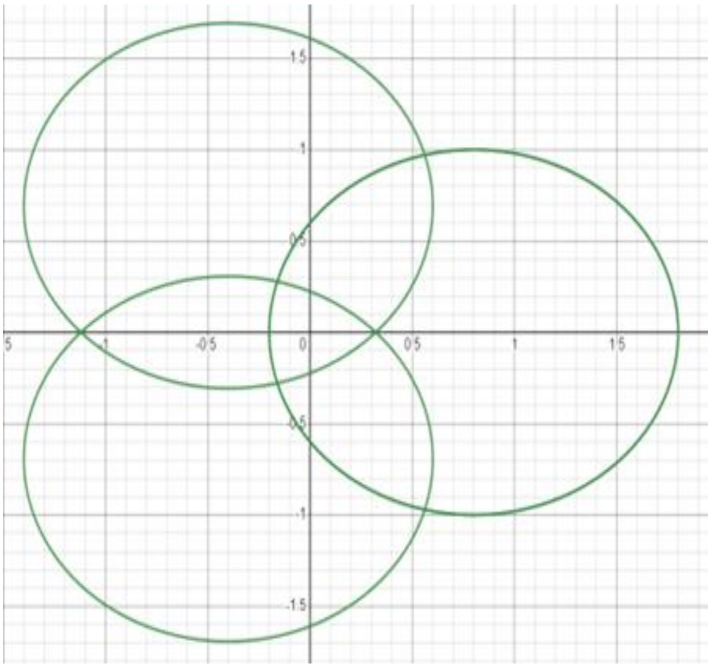


Fig 2. A graph made in Desmos displaying the operating ranges of the microphones when following a triangular setup.

However, when examining placement in the wild, a honeycomb conjecture was assumed to be the most efficient way to cover an arbitrary area [45].

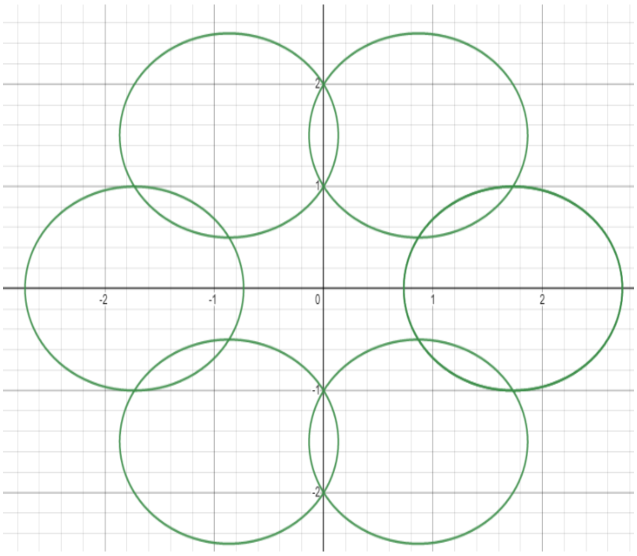


Fig 3. A graph made in Desmos displaying the operating ranges of the microphones when following a honeycomb conjecture.

Nonetheless, as seen in Fig 3, the hexagonal setup presents a sensitive area not covered by the devices. To solve such issue, a seventh device must be added in the middle of the arrangement (Fig 4).

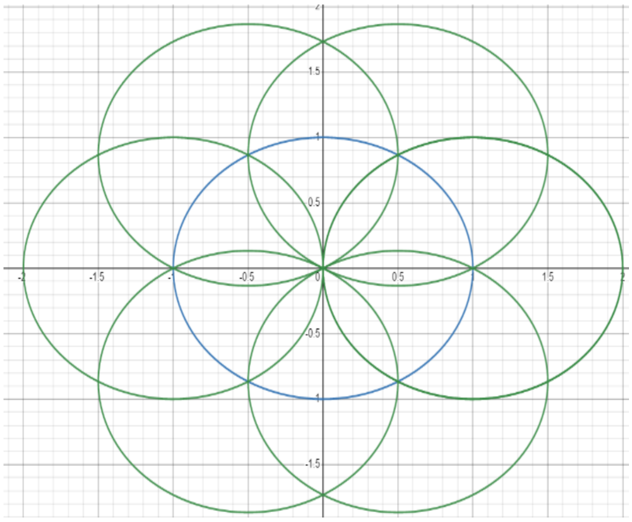


Fig 4. A graph made in Desmos displaying the operating ranges of the microphones in a field of equilateral triangles.

Furthermore, the equipment should be placed r (being r is the radius of the circle) meters apart from each other. By doing so, it is guaranteed that within every area there are at least three overlapping circles.

$$d(M_n, M_{n+1}) = r$$

$r =$ Radius of the circle [m]

7.3.1 Time-based calculation

To calculate the actual location of the sound source, the group studied two potential approaches. The first consideration was a time-based method. Its goal is to identify the location of the sound source by comparing the exact times at which the sensors (in various positions) have detected a possible gunshot. This can be done by using the following formula:

$$d(M,S) = \sqrt{(x_m - x_s)^2 + (y_m - y_s)^2 + (z_m - z_s)^2}$$

$$d(M,S) = v * t$$

$$\sqrt{(x_m - x_s)^2 + (y_m - y_s)^2 + (z_m - z_s)^2} = v * t$$

M= Location of the device's microphone
S = Location of the sound source
v = Velocity of the sound [m/s]

t = The time it takes the sound to reach the microphone [s]

However, the likelihood of this method working is low since the internal clocks might not be perfectly synchronized. For this reason, the group delved into a different approach based on comparing the amplitudes measured by the sensors. This will now be discussed.

7.3.2 Amplitude-based calculation

It is necessary to know the sound pressure at a specific distance to determine the position of the source. This will then be set as a threshold level so amplitudes lower than this limit do not trigger responses. The formula below [38] can be used to determine the sound pressure level.

$$Lp(R_2) = Lp(R_1) - 20\log(\frac{R_2}{R_1})$$

$Lp(R_1)$ = Sound pressure level at location R_1 [dB]
$Lp(R_2)$ = Sound pressure level at location R_2 [dB]
R_1 = Distance from the sound source to location R_1 [m]
R_2 = Distance from the sound source to location R_2 [m]

For this research, the distance from the sound source to the microphone will constantly be equal to one meter. Therefore, we can simplify the equation as follows:

$$Lp(R_M) = Lp(R_S) - 6\log_2(R_{MS})$$

$Lp(R_M)$ = Sound pressure level as measured by the microphone [dB]
$Lp(R_S)$ = Sound pressure level at the location of the sound source [dB]
R_M = Distance from the microphone to the sound source [m]

To calculate the amount of time the devices should store a detected sound, the following equation [46] can be used:

$$t = \frac{R_{MS}}{c_{air}}$$

t = Time [s]
R_{MS} = Distance between the sound source and the microphone [m]
c_{air} = Velocity of sound in the air [m/s]

Defining the value of variable c_{air} is necessary before applying this equation. This can be calculated with the following formula [46]:

$$c_{ideal} = \sqrt{\frac{\gamma RT}{M}}$$

c_{ideal} = Speed of sound in an ideal gas [m/s]
γ = Adiabatic index
R = Molar gas constant [J/(mol*K)]
T = Absolute temperature [K]
M = Molar mass of gas [kg/mol]

As a result, c_{air} in this study can be simplified as follows:

$$c_{air} = \sqrt{\frac{1.4 * 8.314 * T}{0,0289645}} \approx 331.3 + 0,606T$$

The formula is now solely temperature-dependent after using the ideal gas law. Due to the device's lack of a temperature sensor, it was decided to make use of a fixed value for T.

As a further step, it is important to determine the distance between the device and the sound source. For this, the formula shown below can be utilized:

$$d(M,S) = 2^{\frac{1}{6}(Lp(R_S)-Lp(R_M))}$$

$d(M,S)$ = Distance between the microphone and sound source [m]
$Lp(R_S)$ = Sound pressure level of sound source [dB]
$Lp(R_M)$ = Sound pressure level picked up by the microphone [dB]

The precise position of the sound source can be identified once its distance to the device's microphones is known. This can be represented by circles with a radius as large as such distance and centre points at the locations each device will be positioned. These circles will then have one common intersection (Fig 5), representing the location of the sound source.

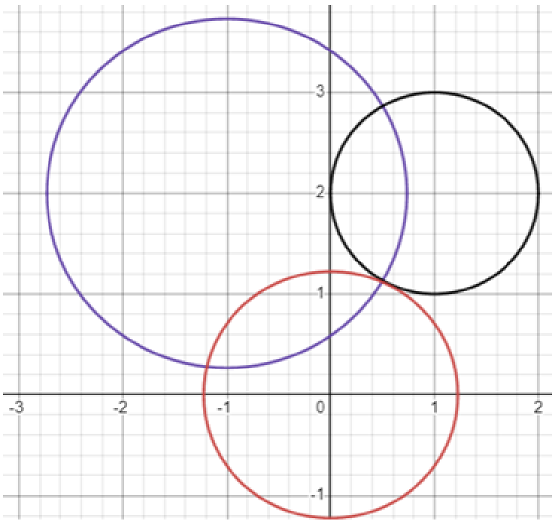


Fig 5. A graph made in Desmos displaying the intersecting circles that represent the distance between the devices and the sound source.

Calculating the coordinates of this junction point, that is the location of the sound source, is the next step. This can be done by making use of the triangular effect [38].

7.3.3 Triangular effect

By applying the previous formulas, the distance between each device and the sound source can be determined. As shown in Fig 6, these values will be implemented as the radius for the circles with centre points A, B, and C (representing master device C, and slave devices A and B). Intersection point E represents the location of the sound source, and thus the objective is to determine this point's coordinates.

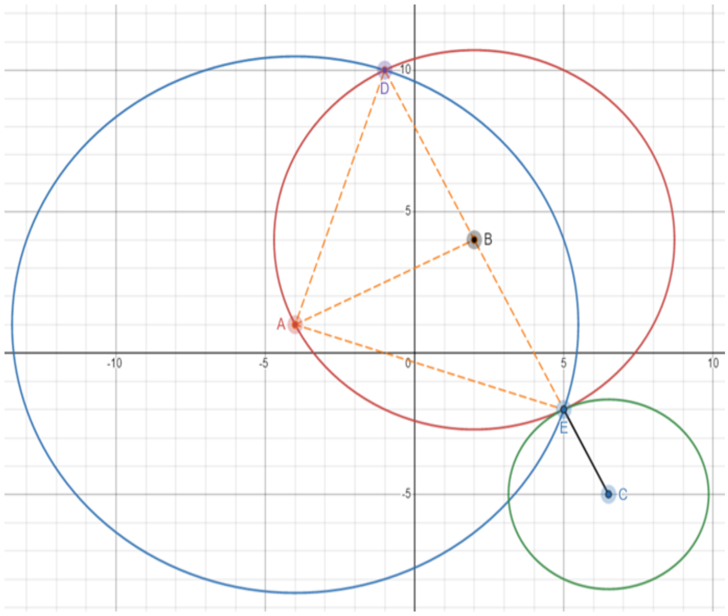


Fig 6. A graph made in Desmos displaying the circles with centre points A, B, and C.

The distance between devices A and B can be calculated using the following equation:

$$d(A,B) = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2}$$

The Pythagorean theorem then gives:

$$r_B^2 - AF^2 = r_A^2 - BF^2$$

For this equation, a new point called F has been used. This is the point where line segment AB and line segment DE intersect. In this case, this point is the same as point B on the graph. Since it's known that the length of line segment AB is equal to the length of line segment AF merged with the length of line segment BF, the following equation can be set up:

$$AB = AF + BF \qquad \rightarrow \qquad BF = AB - AF$$

This equation can then be substituted in the previous formula:

$$r_B^2 - (AB - AF)^2 = r_A^2 - AF^2$$

$$AF = \frac{r_B^2 - r_A^2 + AB^2}{2AB}$$

The coordinates of point F can be found by applying the previous equations' solutions to the formulas below:

$$x_F = x_A + \frac{AF(x_B - x_A)}{AB}$$

$$y_F = y_A + \frac{AF(y_B - y_A)}{AB}$$

In addition, the distance between points F and D is equal to the distance between F and E. This distance can be calculated as follows:

$$DF = EF = \sqrt{(r_B^2 - r_A^2)}$$

The coordinates of points D and E can then be determined:

$$x_D = x_F + \frac{DF(y_B - y_A)}{AB}$$

$$y_D = y_F + \frac{DF(x_B - x_A)}{AB}$$

$$x_E = x_F + \frac{EF(y_B - y_A)}{AB}$$

$$y_E = y_F + \frac{EF(x_B - x_A)}{AB}$$

Finally, the distance between point C and the intersection points D and E can now be calculated using the formulas below:

$$d(C, D) = \sqrt{(x_C - x_D)^2 + (y_C - y_D)^2}$$

$$d(C, E) = \sqrt{(x_C - x_E)^2 + (y_C - y_E)^2}$$

The solution to one of these two equations will be (almost) equal to the radius of the circle with centre point C. The point of intersection in the respective equation represents the location of the sound source.

7.4 Validation

The validation will be divided into two stages: one for the basic scenario (to be conducted during week 8) and one for the ambitious scenario (to be conducted during week 9). For both stages, it is important to decide where and how the system should be tested. An open field was considered the most optimal place since it simulates the preserved areas where the devices would be deployed when sent to the market.

7.4.1 Stage 1 (basic scenario):

Once the devices can detect sound and communicate with each other, the first test will occur. The system will be set up in a triangle, as previously mentioned. Furthermore, every device will be mounted at the same height. It is important to consider during the testing that the equipment used does not have a big communication range, which will affect results: gunshot sounds are loud and travel far so using the Bluetooth module to detect them means that multiple devices would pick the same sound (impairing location specification). Therefore, values such as threshold or sound source's volume must be changed taking into consideration such variables. In real life, components with a greater range would be used to cover a bigger area and guarantee better results.

7.4.2 Stage 2 (ambitious scenario):

This stage will follow the same steps as the previous one, but it will focus on testing the triangulation effect, improving the ranges, and connecting all this data to Processing. The Bluetooth module will be substituted by Wi-Fi and connected to the "eduroam" network since it allows a bigger communication range. In an optimal scenario, the devices would communicate through radio since preserved areas most likely do not have access to a Wi-Fi connection. However, radio communication modules with ranges as large as needed for this project could not be purchased due to budget limitations.

First, it is crucial to check that the sensors' configured noise thresholds are functioning properly. Different noises, including those with an intensity exceeding the thresholds, will be produced to test this: if just the loudest sounds are evaluated, it means this part of the system is working. Since sounds as loud as gunshots are hard to reproduce in legal manners due to sound pollution laws, the thresholds will be adjusted down during validation, to make sure the simulated gunshot sound (with a lower dB level than an actual gunshot) will be detected by the device. If this works, it means the thresholds can be readjusted to match real circumstances. During the validation, the sound of a gunshot will be simulated by making use of a speaker. Finally, the devices will be tested first in an open field with no obstacles and then considering vegetation in between.

In both scenarios, the devices must communicate with each other, and the alert should be triggered once the right data is processed. Furthermore, given the ambitious goal, the test is considered to have been successful when the proper location of the sound source can subsequently be determined using the employed algorithms.

7.5 Internal Organization

7.5.1 Project Planning

WHEN	TASKS
Week 6/7	- Creating a circuit diagram - Researching the most optimal placement of the smart systems - Examining the best options in terms of design, with an emphasis on size, color, and hardware compatibility - Compiling and handing in a list of materials needed for the project
Week 8	- Assembling the electrical circuit by making use of the circuit diagram - Designing a user interface to display all the data to the public - Writing a program that can read the input from the sensors and can therefore also predict the location of the sound source - Writing a program that can send alerts once triggered - Writing a program that can connect the pre-read data to a database. This data should then be displayed, for example in the form of a heatmap - After the first prototype has been created, the product can be tested by following the validation steps
Week 9	- Finishing the last parts of the documentation - Carry out the final tests of the smart system and improve the prototype with these results

7.5.2 Task Division

TEAM LEADING	SOFTWARE	HARDWARE	DESIGN	DOCUMENTATION
Ho Tak Fong Rémi Astier	Andreea Goga Tim Haarhuis Ho Tak Fong Onne Iping	Rémi Astier Ho Tak Fong Andreea Goga	Nina Kwaks Carmen Rodriguez Onne Iping	Nina Kwaks Onne Iping

Ho Tak Fong: As the team leader, Ho Tak leads the communication within the team and with the staff. He also makes sure everything is finished before the deadline, so he can hand everything in on time. Furthermore, he makes sure the project runs smoothly and has a presenting role within the team. In addition, Ho Tak can also assist in the field of software if necessary.

Tim Haarhuis: Tim will assist Andreea with the software.

Onne Iping: Onne will mostly help Nina with the documentation, while also being able to assist the design and software teams.

Nina Kwaks: Nina will ensure that the communication with the other sectors as well as the cooperation within the design and documentation sectors function as smoothly as possible in her capacity as head of design and documentation.

Carmen Diez Rodriguez: Carmen will mostly assist Nina in the design sector.

Andreea Goga: Head of software; working closely with the people working in hardware, as these two things go hand in hand.

Rémi Astier: As the head of hardware, Rémi will make sure the collaboration within the hardware sector and the communication with the software and design sector will run as smoothly as possible.

7.5.3 Task Specification

For the confection to run as smoothly as possible, the defined tasks were also assigned to specific group members based on their roles in the project. The task division is, however, not strict and may suffer changes in case specific tasks need more attention.

1. **Design and usability of user interface:** Onne and Nina
    a. Design a user interface presenting the project
    b. Connect heatmap and website
2. **Logo design and video editing:** Carmen
    a. Improve logo (if necessary)
    b. Creating a video to be displayed during the demo market
3. **Placing the device in the wild:** Rémi and Carmen
    a. Consider climate factors such as rain and wind
    b. Consider where to attach the device
    c. Consider aesthetics
4. **Encapsulation:** Rémi
    a. Make a 3D model and print an initial structure for the prototype
5. **Electric circuit:** Rémi
    a. Creating a circuit diagram
6. **Contacting authorities:** Tim and Onne
    a. Create a code that sends alerts when gunshots are detected.
7. **Circuit assembly:** Andreea and Ho Tak
    a. Assembling the circuit
8. **Location prediction and placement of devices:** Ho Tak
    a. Triangulation for location prediction
    b. Calculate the ideal distance between the devices
9. **General coding:** Andreea and Ho Tak
    a. Properly structure the code
10. **Server/client connection:** Andreea, Ho Tak, and Rémi
    a. Create a wireless connection between the devices and the program
11. **Heatmap and data input:** Tim
    a. Design the heatmap
    b. Pass all the necessary data being received by the sensors to the heatmap
12. **Documentation:** Onne and Nina

Chapter 8: Validation

To verify the accuracy of the calculations and the product's effectiveness, the devices had to be tested in various situations. The initial strategy was to conduct the validation using three fully operational devices that could connect via Bluetooth and communicate with one another. However, despite numerous attempts, Bluetooth connectivity did not function as intended, a factor that delayed the validation process.

At first, the Bluetooth equipment was successfully paired to a laptop. The following step was to pair two modules with each other. For that, the devices were set in AT mode and configured to the same baud rate. It was also specified that the devices would be distinguished between “master” and “slave” and that the slave’s address would be used to connect it to the master. All steps found in the module’s documentation were followed to bind them together. However, the connection was not successfully established.

Tutorials were then studied when trying to connect the devices in AT mode. Nevertheless, even with a clean code, the modules wouldn’t connect to each other. The problem was then pinpointed: after connecting, the devices should switch to communication mode. However, when converting states, the modules would unpair and become unable to communicate. It is believed that such an issue derives from faulty devices unable to maintain a stable connection.

Utilizing Wi-Fi to generate communication between the devices was the second option taken into consideration. This would also allow for testing over a bigger area since Wi-Fi has a wider radius than Bluetooth. However, the group was also unable to conduct the validation in this manner due to a delay in the delivery of Arduino Wi-Fi shields.

Since the communication between devices did not work as predicted, the validation strategy had to be updated. It was concluded that verifying the accuracy of the calculations was crucial for the project: if the system works when inputs are given manually, the only issue to be fixed is connectivity. To confirm such predictions, the tests were conducted in two stages.

8.1 First Stage (Open Field)

The first stage of the validation process aimed at confirming the formulas previously calculated and defining error margins. For that, decibel meters on phone applications and a sound source were placed in three different setups in an open field. Measurements were then compared to the expected values to analyze error margins.

8.1.1 Setup 1

The sound source used for setup 1 was a speaker that could reach 93.1 dB. The devices were positioned as shown in Fig 7.

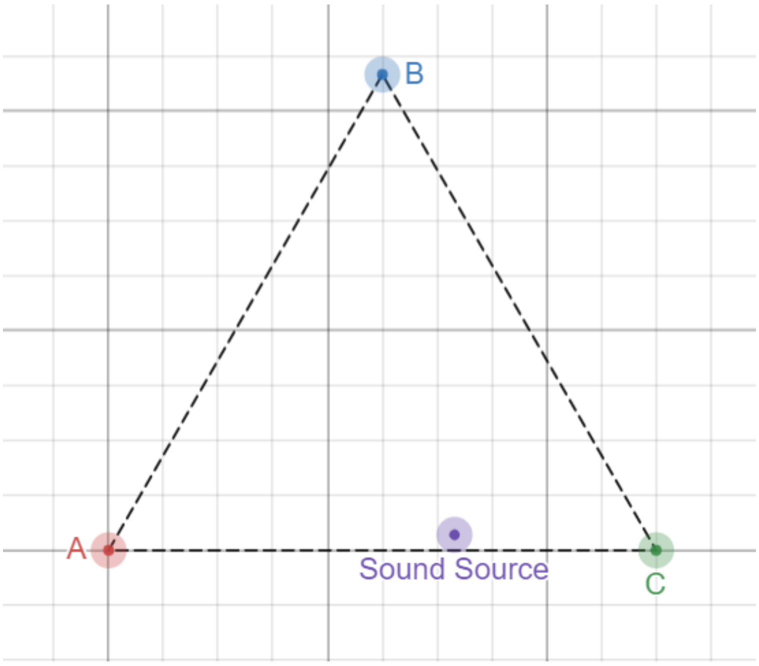
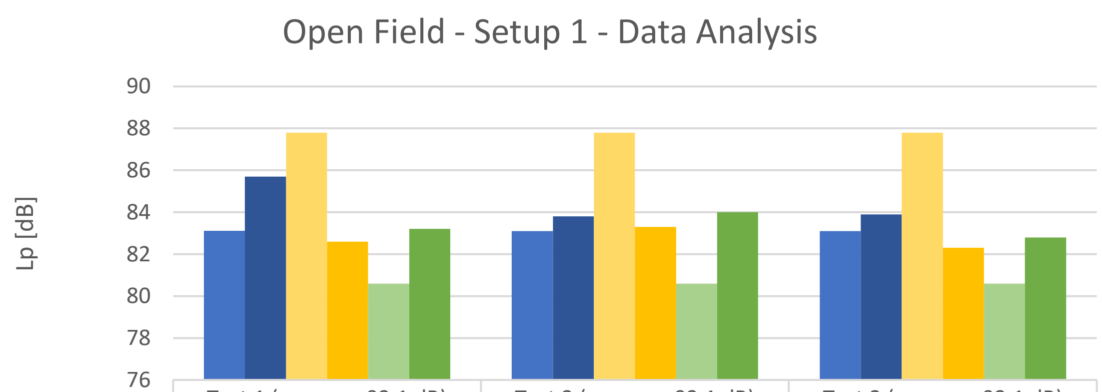


Fig 7. A graph made in Desmos displaying the positions of decibel meters A, B, and C (representing the prototypes) and the sound source for setup 1. The devices are positioned 5 m away from each other.

Measurements were repeatedly taken to test the accuracy of the calculations made. For that, the peak amplitude levels recorded by the decibel meters were compared to the expected results. The graph below can be used to study the initial assumptions and the data gathered (Fig 8).



	Test 1 (source = 93.1 dB)	Test 2 (source = 93.1 dB)	Test 3 (source = 93.1 dB)
Prediction A	83.1	83.1	83.1
Reality A	85.7	83.8	83.9
Prediction B	87.8	87.8	87.8
Reality B	82.6	83.3	82.3
Prediction C	80.6	80.6	80.6
Reality C	83.2	84	82.8

Fig 8. A graph displaying theoretical results and gathered data for setup 1 (open field).

8.1.2 Setup 2

For setup 2, the decibel meters were placed further away from each other (Fig 9). The same sound source was used.

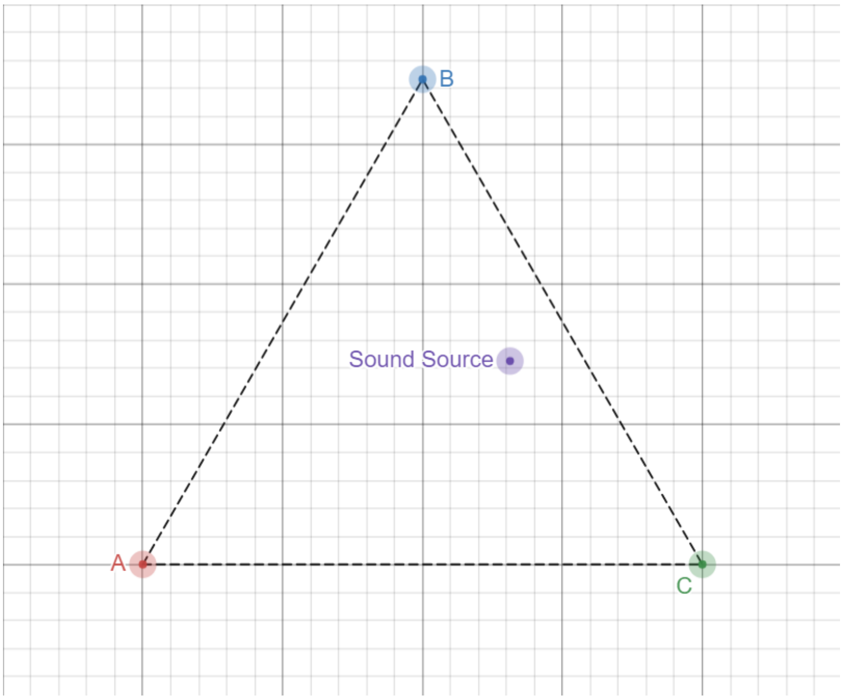
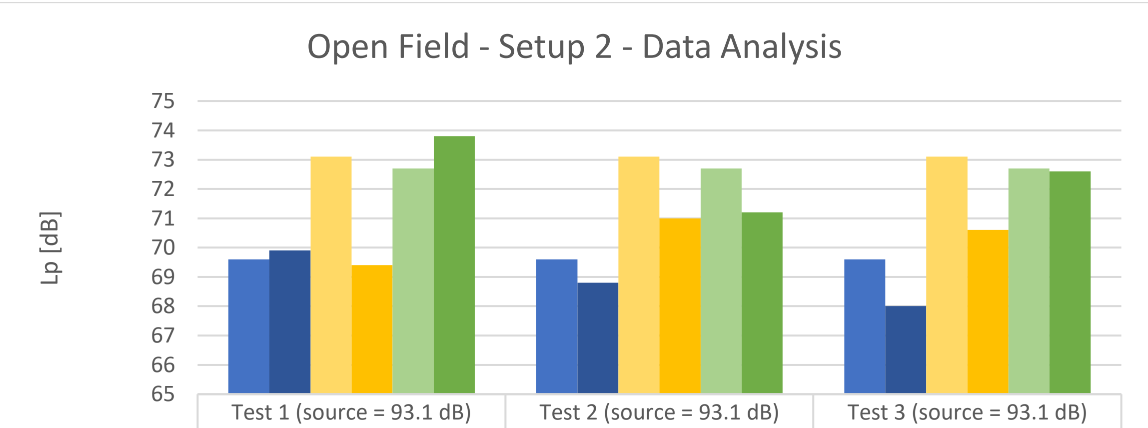


Fig 9. A graph made in Desmos displaying the positions of decibel meters A, B, and C (representing the prototypes) and the sound source for setup 2. The devices are positioned 20 m away from each other.

The same process was followed to register peak amplitudes. The results can be analyzed in Fig 10.



	Test 1 (source = 93.1 dB)	Test 2 (source = 93.1 dB)	Test 3 (source = 93.1 dB)
Prediction A	69.6	69.6	69.6
Reality A	69.9	68.8	68
Prediction B	73.1	73.1	73.1
Reality B	69.4	71	70.6
Prediction C	72.7	72.7	72.7
Reality C	73.8	71.2	72.6

Fig 10. A graph displaying theoretical results and gathered data for setup 2 (open field).

8.1.3 Setup 3

The sound source was changed when testing setup 3: since the speaker could not reach amplitudes as high as desired, one of the group members screamed during testing (achieving levels that varied from 103.9 dB to 107.3 dB). The setup is represented by Fig 11.

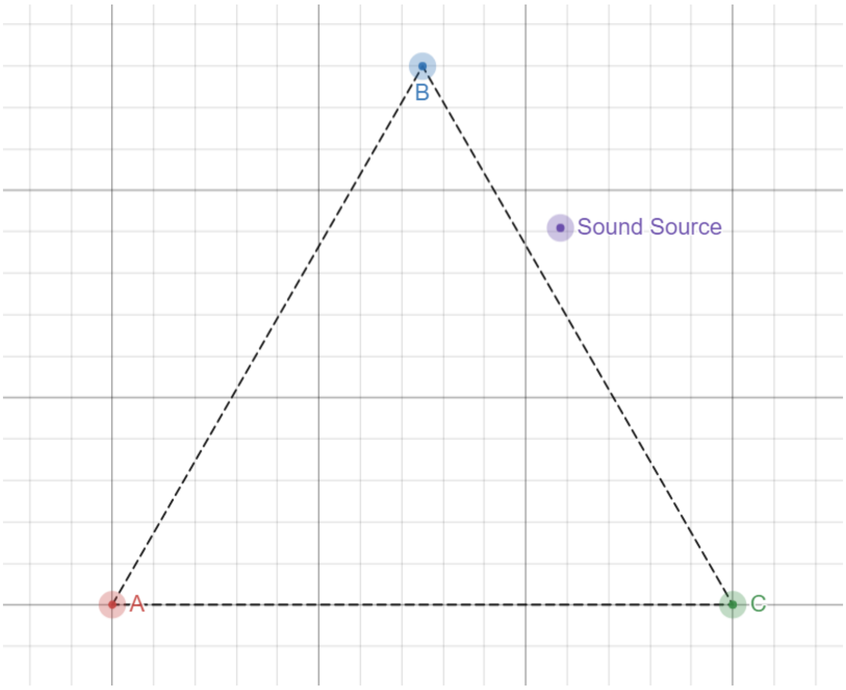
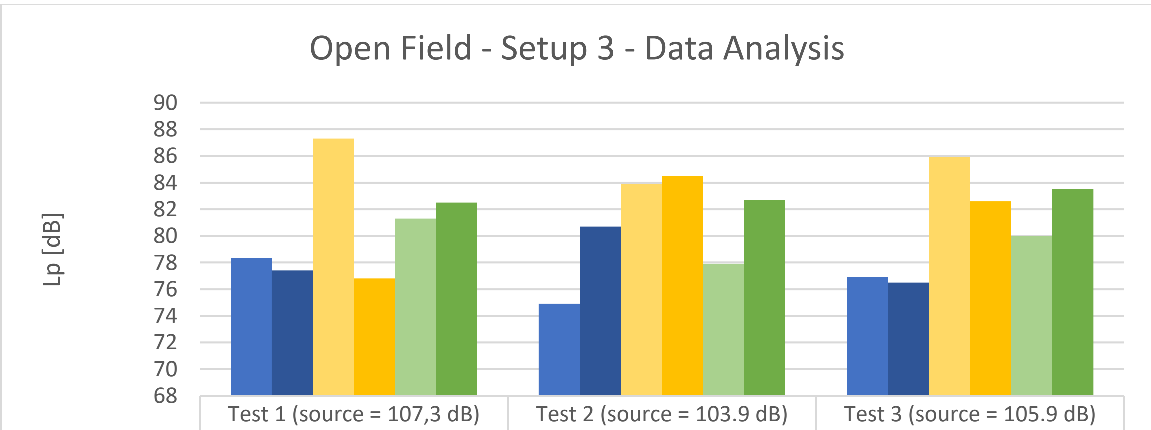


Fig 11. A graph made in Desmos displaying the positions of decibel meters A, B, and C (representing the prototypes) and the sound source for setup 3. The devices are positioned 30 m away from each other.

The process was once more followed as previously done. The results can be analyzed in Fig 12.



	Test 1 (source = 107,3 dB)	Test 2 (source = 103.9 dB)	Test 3 (source = 105.9 dB)
Prediction A	78.3	74.9	76.9
Reality A	77.4	80.7	76.5
Prediction B	87.3	83.9	85.9
Reality B	76.8	84.5	82.6
Prediction C	81.3	77.9	80
Reality C	82.5	82.7	83.5

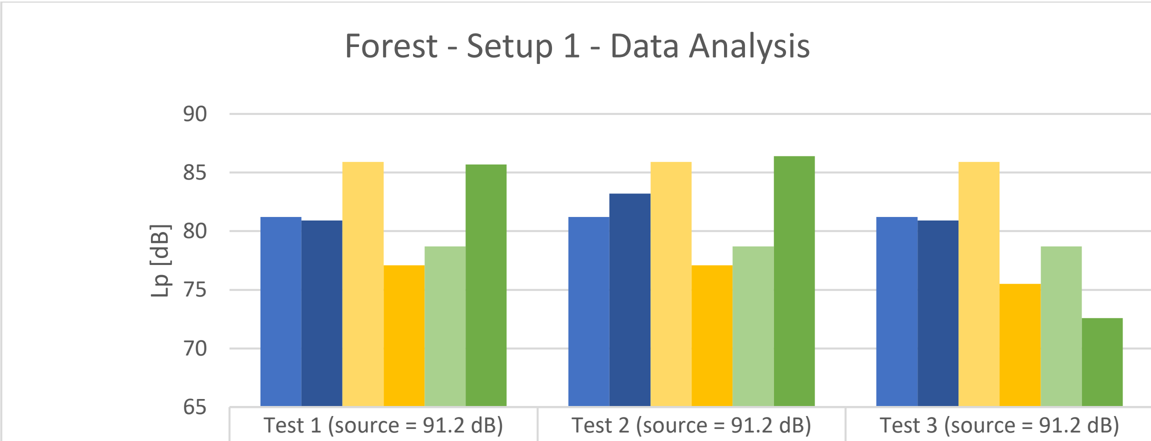
Fig 12. A graph displaying theoretical results and gathered data for setup 3 (open field).

8.2 Second Stage (Forest)

The second stage of the validation process focused on testing the influence of obstacles such as trees on the expected results. For that, the devices were deployed in a forest following the same setups as in the first stage of the validation.

8.2.1 Setup 1

The sound source used for setup 1 was a speaker that could reach 91.2 dB. The devices were positioned as shown in Fig 7. The measurements were then taken following the previously established steps. Results can be seen in the graph below (Fig 13).

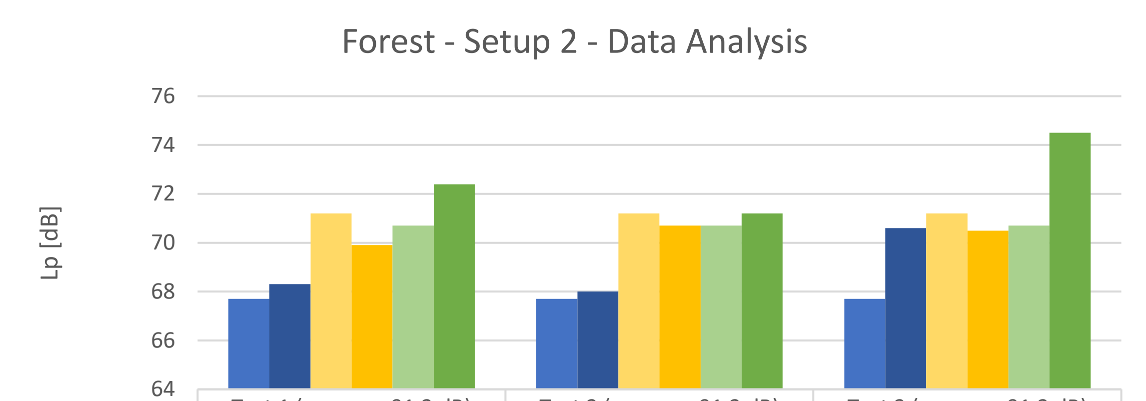


	Test 1 (source = 91.2 dB)	Test 2 (source = 91.2 dB)	Test 3 (source = 91.2 dB)
Prediction A	81.2	81.2	81.2
Reality A	80.9	83.2	80.9
Prediction B	85.9	85.9	85.9
Reality B	77.1	77.1	75.5
Prediction C	78.7	78.7	78.7
Reality C	85.7	86.4	72.6

Fig 13. A graph displaying theoretical results and gathered data for setup 1 (forest).

8.2.2 Setup 2

The same speaker was used for setup 2, emitting 91.2 dB. The devices were positioned as shown in Fig 9 and data was recorded as specified in the graph below (Fig 14).

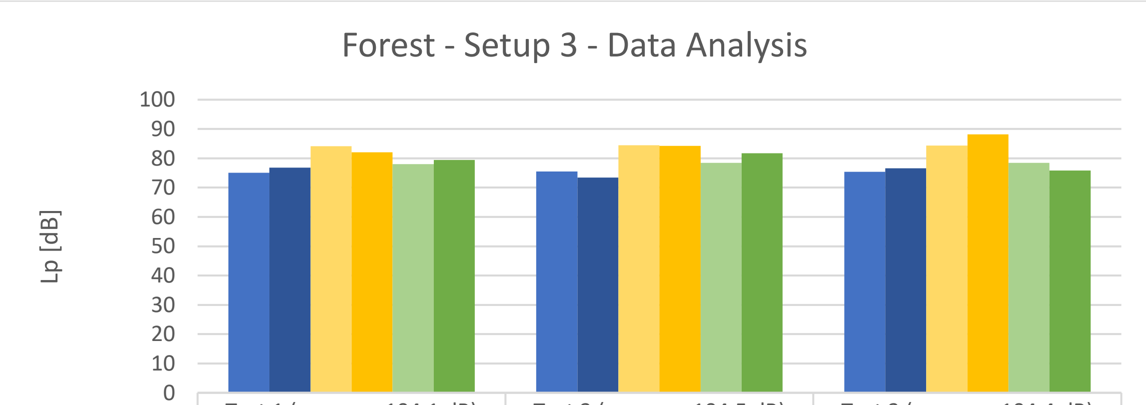


	Test 1 (source = 91.2 dB)	Test 2 (source = 91.2 dB)	Test 3 (source = 91.2 dB)
Prediction A	67.7	67.7	67.7
Reality A	68.3	68	70.6
Prediction B	71.2	71.2	71.2
Reality B	69.9	70.7	70.5
Prediction C	70.7	70.7	70.7
Reality C	72.4	71.2	74.5

Fig 14. A graph displaying theoretical results and gathered data for setup 2 (forest).

8.2.3 Setup 3

Finally, the last setup followed Fig 11. The sound source was once more changed to one of the group members screaming, achieving constant levels of around 104 dB. The graph below displays the data gathered (Fig 15).



	Test 1 (source = 104.1 dB)	Test 2 (source = 104.5 dB)	Test 3 (source = 104.4 dB)
Prediction A	75.1	75.5	75.4
Reality A	76.8	73.4	76.6
Prediction B	84.1	84.5	84.4
Reality B	82.1	84.2	88.2
Prediction C	78	78.5	78.4
Reality C	79.4	81.7	75.8

Fig 15. A graph displaying theoretical results and gathered data for setup 3 (forest).

8.3 Testing with Manual Input

Since the devices could not communicate with each other, the data gathered during the validation process was manually inputted to test the code. The program then predicted the location of the sound source, sent a message to the authorities, and updated the heatmap[1]. The threshold levels calculated were also added to the code for documentation purposes. However, this could not be implemented during testing since the devices were not connected to each other.

Finally, to prove that the system should work once communication problems are fixed, the microphones were tested and mapped to properly analyze the decibels being received. Additionally, their sensitivity can be manually changed according to needs, allowing the user to calibrate it according to ambient noise.

8.4 Error Margin

The error margins calculated with the gathered data can be analyzed in Fig 16 and Fig 17. Each line corresponds to a different setup. It is assumed that such inaccuracies happened mostly due to wind and imprecise measurement equipment. However, the results were, overall, close to the values calculated with the theory.

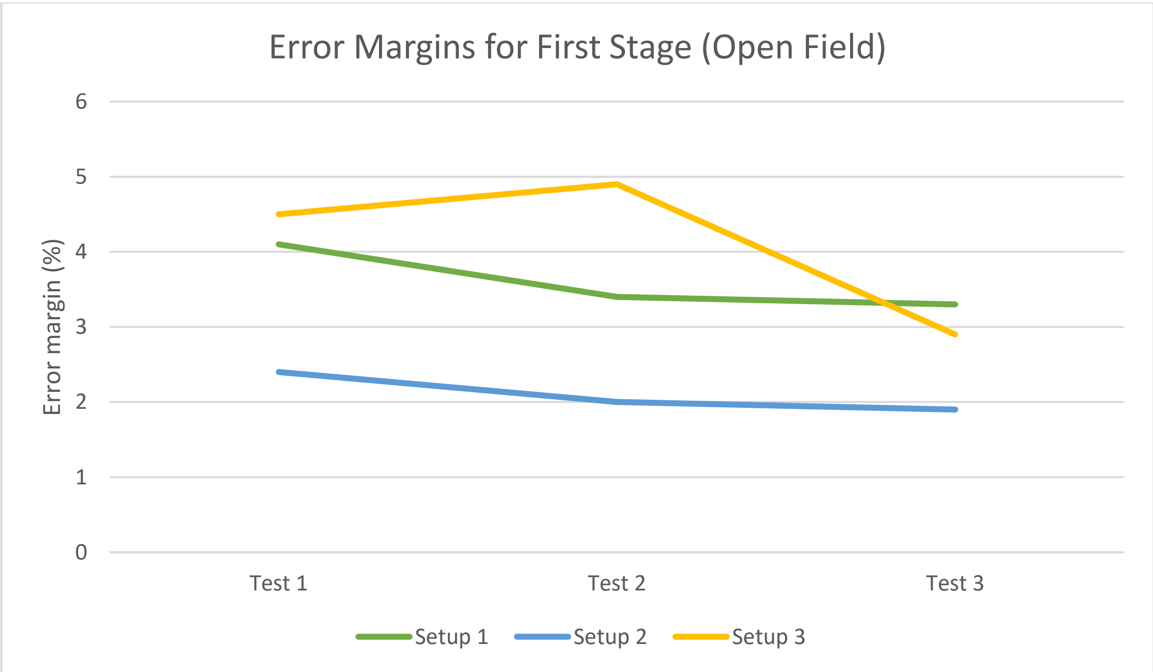


Fig 16. A graph displaying error margins from the data gathered during the first stage of the validation.

[1] All code files are available at https://github.com/goga4/module_2_create.git

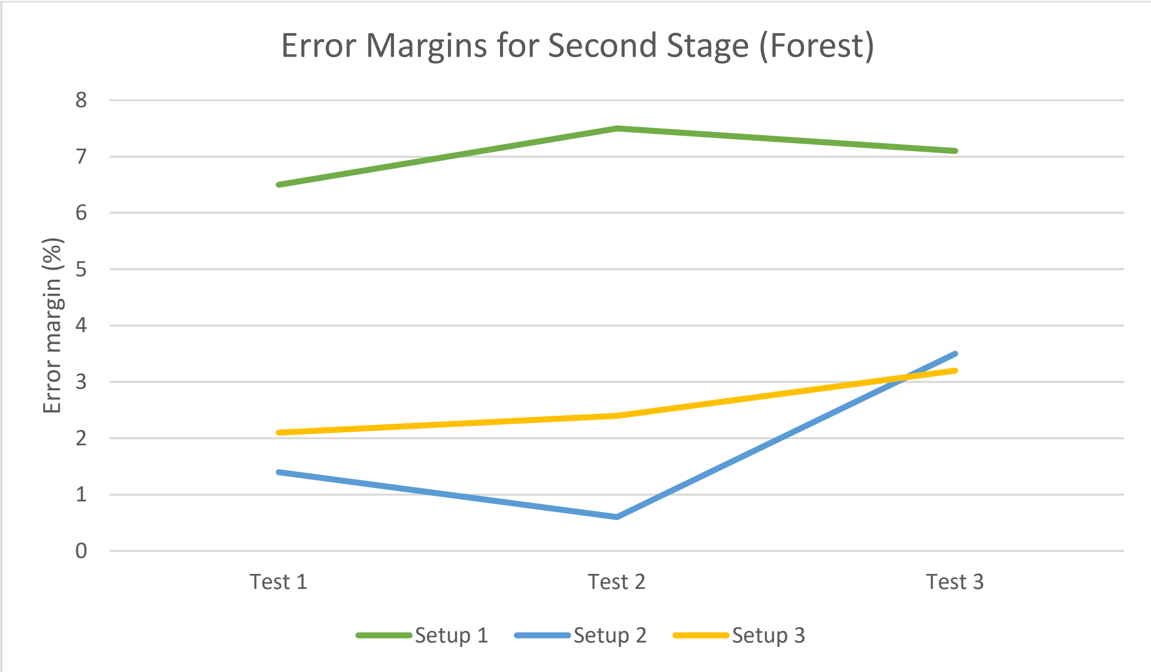


Fig 17. A graph displaying error margins from the data gathered during the second stage of the validation.

As seen in Fig 17, the mean absolute error of the data collected for setup one during the second stage of validation drastically differs from setups 2 and 3. It is assumed that such a discrepancy happened due to a big tree located between point B and the sound source (Fig 18), acting as a direct obstacle. Logically, this has a major effect on the way sound travels.

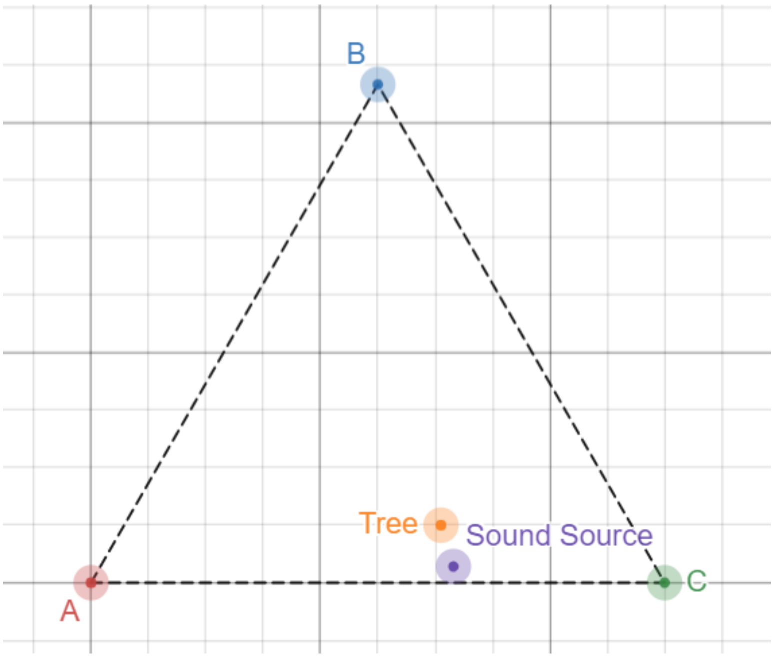


Fig 18. A graph made in Desmos displaying the positions of decibel meters A, B, and C (representing the prototypes) and the sound source for setup 1 during the second stage of the validation process. The orange point represents a tree.

8.5 The Final Project

The final project consists of prototypes capable of detecting gunshots and calculating the expected location of the source by triangulation. Each prototype consists of a circuit (Appendix 1) encased with a 3D-printed model (Appendix 2 and 3) that can be attached to trees or poles (Appendix 4). Additionally, a locally hosted website was created with the purpose of displaying the project and sharing information about illegal hunting as a problem to be tackled.

Since the communication between devices was not completed on time due to equipment limitations, all the data gathered during the validation stages were inputted manually into the code to prove that the program can interpret and properly estimate the location with a triangulation effect (Appendix 5). By doing so, the outputs could be used as follows:

1. Alerting authorities: once a gunshot is detected, a message will be sent to authorities via email, displaying the predicted location of the source and when it happened (Appendix 6 and 7).

2. Creating a heatmap: The location calculated by the device is sent to a Processing file and converted into a heatmap (Appendix 8). The code is then programmed to take screenshots once new data is received and save them inside a specified folder to constantly substitute the image displayed on the website created. By doing so, the page is updated in real-time to display the most recent data gathered.

Chapter 9: Results and Conclusion

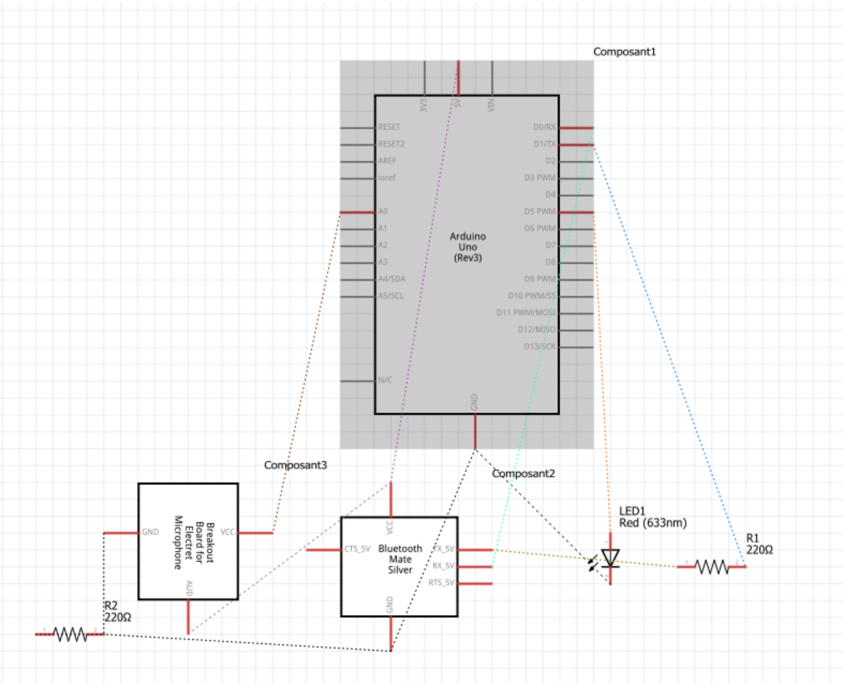
The group's goal was to contribute to the fight against illegal hunting in preserved areas and to draw attention to the impacts of the felony on the environment by developing a smart system. The results were considered successful once basic and ambitious scenarios previously set were mostly achieved: despite the lack of communication between devices, the final prototype is based on a circuit that can detect gunshots, predict the location of the sound source, and alert authorities. Furthermore, a code to generate a map of hunting hotspots was written in Processing for better visualization of results. This feature can be used by park managers for security strategy purposes or to share information and raise awareness among the public.

Undoubtedly, measurement errors were encountered throughout the validation process. An error margin has been used to account for these mistakes. However, most margins presented values under 5%. The first setup for stage two, however, did not fall within this category. With a value of around 8%, it stands out from the other results. This deviation has a logical explanation: the sound source was positioned next to a tree throughout this test, which inevitably led to measurement data that did not match the expectations. Despite that, the results were sufficient to predict a location relatively accurately when compared to the exact placement of the sound source. It is believed that, with better equipment, the predictions could be far more precise.

The biggest obstacle encountered when working on the project was creating a functional transmission channel between the devices. After several attempts, Bluetooth communication did not work as expected, and it was deemed that it was no longer viable to fix the problem within the allotted timeframe. Despite this, Bluetooth remains an option for further research (assuming a connection can be established in this manner) and for evaluating prototypes. Its small range, however, is a limiting factor. For this reason, due to the wider radius and hence larger operating range, communication across radio frequency appears to be a preferable option for projects focused on gun detection over a larger area.

To conclude, considering the limitations encountered, the impact of the study conducted by team 11 (EyeHear) is expected to contribute to future research on the matter. As a recommendation, the group highlights investing in radio communication as it guarantees a wider operational range. By doing so, the system becomes far more scalable, which is advantageous in large nature reserves. Furthermore, the use of communication via radio frequency is independent of the internet or a Wi-Fi network. This is another major benefit when covering areas with poor internet access and a lack of Wi-Fi networks. Furthermore, future tests should be conducted with more precise microphones, realistic sound sources, and wider communication ranges.

Appendix



Appendix 1. Diagram of the circuit used to create each prototype.

Appendix 2. 3D model of the encasings printed (view 1).

Appendix 3. 3D model of the encasings printed (view 2).

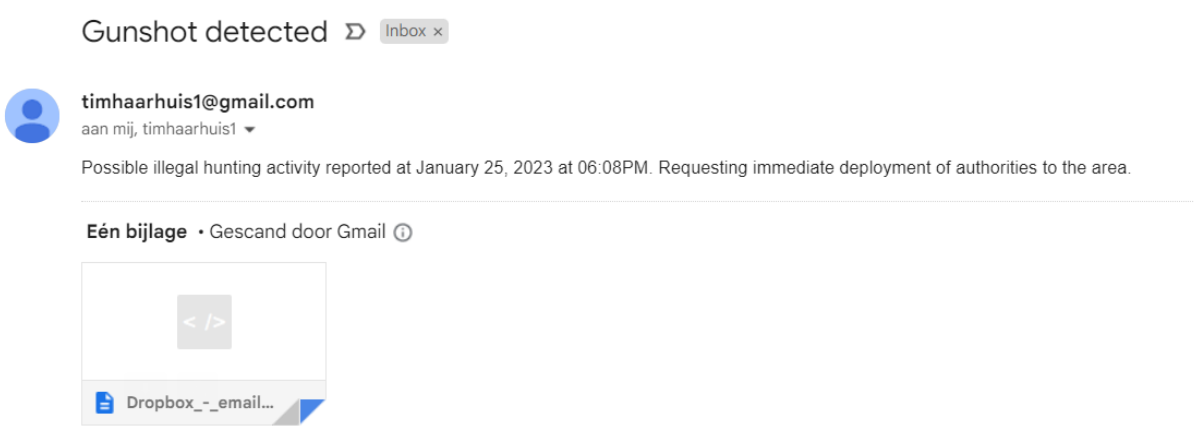
Appendix 4. Picture of the device placed in the wild. The prototypes were initially attached to objects with Velcro stripes.

Setup 1 Speaker	Observed Lp(R2) [dB]	Lp(R1) [dB]	R2 [m]	R1 [m]	Lp(R2) [dB]	Error %	Calculated R2 [m]	Calculated X	Calculated Y	D/E		Actual X	Actual Y
A (0, 0)	85.7	93.1	3.162	1.00	83.100	3.129	2.3442288					3.1591	0.1408
B (2.5, 4.33)	82.6	93.1	4.241	1.00	87.774	5.895	3.3496544	2.1192681	1.0020533	D			
C (5, 0)	83.2	93.1	1.846	1.00	80.551	3.289	3.1260794					ΔX	ΔY
												0.6565	-0.8980
A (0, 0)	83.8	93.1	3.162	1.00	83.100	0.842	2.9174270						
B (2.5, 4.33)	83.3	93.1	4.241	1.00	87.774	5.097	3.0902954	2.6394503	1.2428524	D			
C (5, 0)	84.0	93.1	1.846	1.00	80.551	4.282	2.8510183						
A (0, 0)	83.9	93.1	3.162	1.00	83.100	0.963	2.8840315						
B (2.5, 4.33)	82.3	93.1	4.241	1.00	87.774	6.237	3.4673685	2.7491741	0.8715961	D			
C (5, 0)	82.8	93.1	1.846	1.00	80.551	2.792	3.2734069						
					AVG	**3.61**		**2.50**	**1.04**				

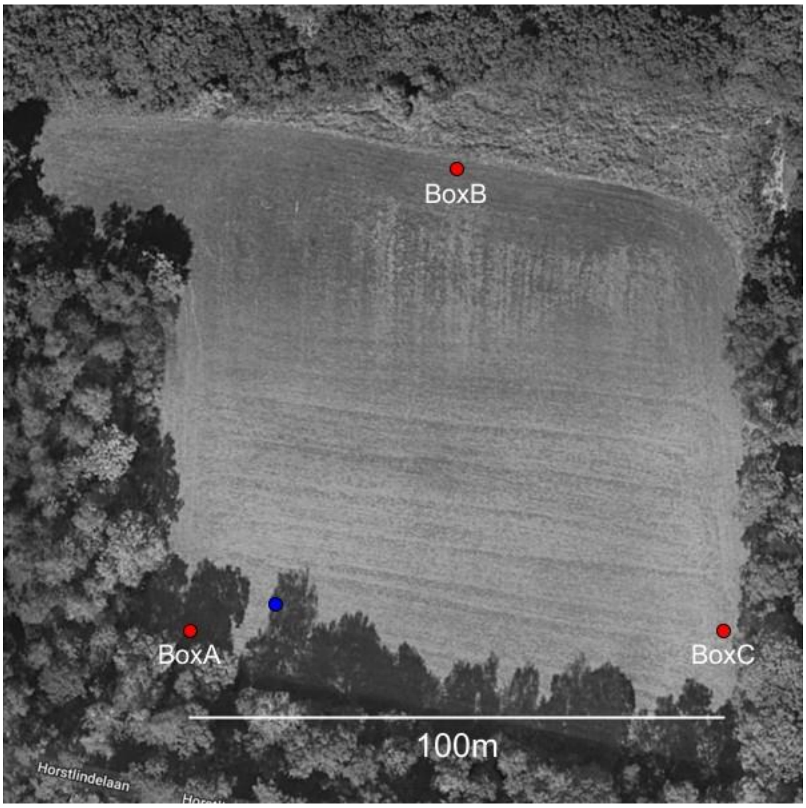
Setup 2 Speaker	Observed Lp(R2) [dB]	Lp(R-1...) [dB]	R2 [m]	R1 [m]	Lp(R2) [dB]	Error %	Calculated R2 [m]	Calculated X	Calculated Y	D/E		Actual X	Actual Y
A (0, 0)	69.9	93.1	15.000	1.00	69.578	0.463	14.4543977					13.125	7.262
B (10, 17.32)	69.4	93.1	10.000	1.00	73.100	5.061	15.3108746	14.2183275	2.6016912	D			
C (20, 0)	73.8	93.1	10.533	1.00	72.649	1.584	9.2257143					ΔX	ΔY
												-2.3923	2.4876
A (0, 0)	68.8	93.1	15.000	1.00	69.578	1.118	16.4058977						
B (10, 17.32)	71.0	93.1	10.000	1.00	73.100	2.873	12.7350308	15.3587627	5.7673096	D			
C (20, 0)	71.2	93.1	10.533	1.00	72.649	1.995	12.4451461						
A (0, 0)	68.0	93.1	15.000	1.00	69.578	2.268	17.9887092						
B (10, 17.32)	70.6	93.1	10.000	1.00	73.100	3.420	13.3352143	16.97472	5.9542064	D			
C (20, 0)	72.6	93.1	10.533	1.00	72.649	0.068	10.5925373						
					AVG	**2.09**		**15.52**	**4.77**				

Setup 3 Group Member	Observed Lp(R2) [dB]	Lp(R-1...) [dB]	R2 [m]	R1 [m]	Lp(R2) [dB]	Error %	Calculated R2 [m]	Calculated X	Calculated Y	D/E		Actual X	Actual Y
A (0, 0)	77.4	107.3	28.284	1.00	78.269	1.110	31.2607937					21.66667	18.181
B (15, 25.98)	76.8	107.3	10.047	1.00	87.259	11.986	33.4965439	31.0745201	-3.4075536	D			
C (30, 0)	82.5	107.3	20.000	1.00	81.279	1.502	17.3780083					ΔX	ΔY
												-2.5112	10.7516
A (0, 0)	80.7	103.9	28.284	1.00	74.869	7.788	14.4543977						
B (15, 25.98)	84.5	103.9	10.047	1.00	83.859	0.764	9.3325430	16.3143215	10.2456493	D			
C (30, 0)	82.7	103.9	20.000	1.00	77.879	6.190	11.4815362						
A (0, 0)	76.5	105.9	28.284	1.00	76.869	0.480	29.5120923						
B (15, 25.98)	82.6	105.9	10.047	1.00	85.859	3.796	14.6217717	25.1447696	15.4500503	D			
C (30, 0)	83.5	105.9	20.000	1.00	79.879	4.533	13.1825674						
					AVG	**4.24**		**24.18**	**7.43**				

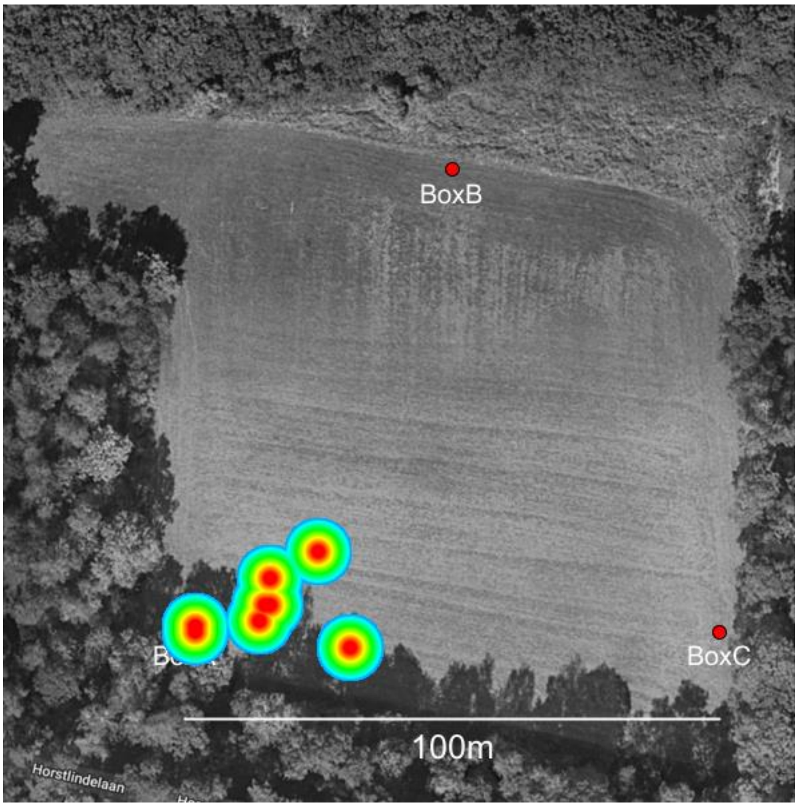
Appendix 5. Table made in Excel displaying how the results can be used to predict the location of the sound source. Data gathered from the first stage of the validation process was used as input. ΔX and ΔY show the difference between expected values and real-life measurements for each setup.



Appendix 6. Screenshot of an example of the email sent to the authorities.



Appendix 7. Screenshot of an example of the picture sent via email to the authorities. The blue dot represents the predicted location of the sound source.



Appendix 8. Screenshot of an example of the heatmap generated in Processing.

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