Designing a smart nest box for automated biodiversity monitoring

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Abstract

Biodiversity monitoring is important as it provides guidelines for decisions on how to manage biological diversity in terms of production and conservation [1]. Monitoring birds can be challenging as they move quickly and nest in enclosed nest boxes. Monitoring nest boxes are nest boxes that have a camera installed which allows the nest box to be monitored. These systems have been used for many years in research and make biodiversity monitoring in this field accessible. The downside of the current monitoring nest boxes is the way the data is collected and analyzed. The systems capture long videos or many pictures, which currently are analyzed manually by experts. The experts go through hours of footage and annotate the data they are interested in, such as bird species or prey which is brought into the nest. This is a tedious process which takes much time. A proposal is made to use Artificial Intelligence (AI) to analyze the data. The AI requires high-quality data from the nest box. By adding a trigger system and high-quality camera in the nest box, the amount of data is significantly reduced and the image quality is greatly improved. This project determines what the optimal smart nest box is and the design process for a prototype is described. The requirements and necessary components are reviewed. A prototype is made, which consists of a Raspberry Pi, Raspberry Pi High Quality Camera, IR beam sensor and a LED strip. The prototype is designed so that it can easily be installed on standardized nest boxes. These nest boxes are designed for great tit and blue tits to nest in and used for research. From the initial experiment, it can be said that the system can sense incoming objects through the nest box entrance with high precision and recall. A 3D printed bird was inserted in the nest box 50 times and sensed all 50 times by the system resulting in a 100% value for both recall and precision. The quality of the recorded images that get taken is not consistent. The 3D-printed bird was manually inserted in the nest box 50 times with a fast entry, which resulted in 64% of the images being sharp and the other pictures being blurry. Overall a good first prototype of a smart nest box is designed in such a way that it is highly configurable. A wide range of sensors can be connected to the Raspberry Pi and programmed using python. Next to this, the camera angle, brightness of the LED strip and behavior of the IR beam sensor can be changed easily for different setups.

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1. Introduction

Over the last decades, scientific research has shown that there has been a general decline in biodiversity [2], [3]. There are several initiatives that have been set up to address this problem, many of which are international goals and agreements, as this is a global issue [4]–[6]. In order to assess whether the regulations to achieve the goals are functioning and to make potential new decisions regarding biodiversity, biodiversity must first be monitored [7]. The monitoring of biodiversity is a broad area of research. Therefore it is split up into different parts, one of which is bird monitoring.

Bird monitoring can be used to get an indication of the size of bird populations. Next to this, there are numerous avian research topics that require bird monitoring. Well-known examples are the parent-offspring conflict [8], the effect of climate change on birds [9], sibling competition [10] and hybridization in birds [11]. These topics are directly related to birds, but bird monitoring can also give insight into other biodiversity which is related to them. An example is the inter-species relation between birds and their prey, which is the motivation of this report.

In the past years, the amount of oak processionary caterpillars has increased significantly as the springs tend to get warmer and there are not enough natural predators to keep the population in balance [12]. The caterpillars have minuscule stinging hairs which let go and float in the sky. These hairs cause irritations to human skin, lungs and eyes [13]. The city of Amsterdam is trying to combat these caterpillars by attracting great tits and blue tits, which are natural predators of the oak processionary caterpillars [14]. The municipality hung up many nest boxes for these birds. However, they do not know if the birds are nesting here and how many oak processionary caterpillars they are eating. To solve this, nest boxes equipped with cameras can be used, which are nest boxes with a camera inside that records continuous video footage inside the nest box to monitor the birds' behavior.

The monitoring nest boxes produce vast amounts of data which has to be reviewed and analyzed by experts to retrieve useful information. This is labor intensive and tedious task that can only be done by experts, therefore this is an expensive process. This task would be more manageable if the amount of data that is recorded would be drastically reduced to only contain high-quality data that the experts would have to review. This project aims to achieve this. Only high-quality images of birds that enter the nest box should be made. A next step would be to replace the experts that review the data with an AI to annotate the recorded data.

As mentioned previously, there is much avian research covering a wide range of topics. The smart nest box with AI can be used in a wide variety of nest box monitoring, such as observing parent or chick behavior. Since the system is programable, it allows the system to be adapted for different types of data observation. Next to this, the system allows multiple sensors to easily be added when necessary.

In order for the experts and possibly later the AI to distinguish the prey, the quality of the data should be high. Therefore it is important that the smart nest box system works optimally. While there are multiple papers discussing the design of smart nest boxes, as seen in [15]–[19], none have been designed specifically for great tits and blue tits or for the footage to be analyzed by AI.

The goal of this project is to design and make a system that can sense and record great tits and blue tits entering a nest box. Accordingly, the main research question is:

What is the optimal smart nest box design to automatically record high-quality and concise images of provisioning moments and the prey collected by birds?

This research question is a broad question that is difficult to answer at once. In order to understand what makes a smart nest box optimal, the research questions can be split up into sub-questions that cover different topics:

What are the requirements of the optimal smart nest box?

What components are needed to build the optimal nest box?

How can you get high-quality and precise image data that can be used by humans and AI to distinguish species of bird and their prey with good performance?

Experts were interviewed to learn from their experiences with working with monitoring nest boxes, relevant literature and the currently available electronics were reviewed. With the acquired knowledge, the ideation process was used to design multiple prototypes which were based on certain methods and techniques. In Chapter 4, a final concept is made which is discussed in detail in the Specification. Chapter 6 describes the realization of a smart nest box prototype. The smart nest box is evaluated in Chapter 7. Here the product is tested and the results are stated. The results and possible improvements are discussed in Chapter 8. Finally, the research question, sub-questions and general remarks regarding the project are discussed in the Conclusion.

2. Background Research

This chapter will cover background research that is relevant for designing the nest box. Firstly, literature regarding smart nest boxes is reviewed. The components that are used in the state of the art are compared and reviewed. Secondly, the interviews that have been conducted are discussed; this includes a summary of the interview and the lessons learned. Thirdly, the technical research is discussed. Here the selections of different electrical components are presented in decision matrices. Lastly, the challenges of the project will be discussed.

2.1 Literature Review

There are multiple studies that have designed a smart nest box for research purposes. The goals of the different studies will be covered, after which an overview will be given of all components used in the different nest boxes. Part of the literature that is covered was found on Google Scholar using the keywords: smart nest box, nest monitoring and remotely monitor birds. More literature was found as it was mentioned in the previously found literature.

2.1.1 Goals

El Bouanani and Ayoub [15] propose a low-cost nest box that is connected to the internet using Wi-Fi. The nest box is designed to observe nestlings and monitor temperature and humidity. The system can record what is happening inside of the nest box with a camera and weigh the nestlings using a weight sensor. Many bird species are threatened by habitat loss, climate change and impoverishment of food sources. It is necessary to monitor biodiversity in order to conserve it. This is the motivation for El Bouanani and Ayoub [15] to make a low-cost monitoring nest box that also monitors environmental conditions.

McBride and Courter [19] have similar reasoning for making smart nest boxes; it is important to understand and conserve biodiversity as the climate is changing and habitat is lost. In this study, five different nest box systems are deployed and assessed, all using a Raspberry Pi as the microprocessor. The results show that using a Raspberry Pi is a cost-effective manner to build a monitoring nest box. It is stated that 96% of the images that got taken were considered good as the bird was in frame and there was no motion blur. In addition, recommendations are made regarding the different sensors and cameras that were assessed. The five cameras which were used in this study had similar image quality, even though they differed in price (see Table 1).

Camera	Sensor resolution (pixels)	Still resolution (MP)	Highest video mode	Price
ArduCam 5MP Camera Module	2592 x 1944	5	1080p (1920×1080): 30 fps	€ 52,02
Raspberry Pi Camera Module v2	3280 × 2464	8	1080p (1920×1080): 30 fps	€ 29,95
RB-Wav-90	2592 x 1944	5	1080p (1920×1080): 30 fps	€ 27,82
Raspberry Pi NoIR Camera Board V2	3280 x 2464	8	1080p (1920×1080): 30 fps	€ 29,95
Logitech C270 HD WEBCAM	unknown	0.9	720p (1280×720): 30 fps	€ 23,90

Table 1 McBride and Courter camera specifications

Prinz et al. [16] noticed that the reliability and usability of prefabricated video monitoring systems that are designed to monitor biodiversity are often not optimal. The system requirements of researchers are very varied, whilst the prefabricated systems have limited video settings, limited storage possibilities and are not programmable. This study aims to design a system to monitor the behavior of Acorn Woodpeckers in artificial wood cavities. The system that is built is relatively low cost and provides flexibility for field researchers who want to configure the system to their needs. The system is built using a Raspberry Pi Model B, Raspberry Pi NoIR Camera (v1), USB wireless internet adapter, six 940-mm IR LEDs and a 12V 88Ah rechargeable battery to power the system. The system was powered for a week before replacing the battery, but it was estimated that the battery could power the system for 9 or 10 days. The birds were detected using motion-sensing software and the system would record videos when the bird was in the nest box during the daytime. The videos are uploaded to the cloud. There were a total of three woodpecker families, one of the families did not nest in the artificial cavity after the installation of the monitoring system. More than 3500 videos (40 GB) got taken, in which the full range of breeding season activities got captured. The researchers were interested in the color bands on the legs of the birds. The color of the band could be seen about 70% of the time. The times the color band could not be observed were due to the camera positioning (top-down) and due to the muted color of the camera because it is IR. It is mentioned that changing the angle of the camera may improve the visibility of the color bands.

Hereward et al. [17] use a custom-built Raspberry Pi system to monitor the behavior of two types of storm-petrel birds during their breeding season. Many of the monitoring nest boxes are built for a specific species, the aim of this study is to design a system that is fully portable and waterproof. This allows the system to monitor a wide range of species that utilize cavities, burrows and artificial nests as it can be placed in these places. The system is built using a Raspberry Pi Zero WH, 5MP Fisheye camera with IR lighting, PIR sensor, Real Time Clock and powered by a 20 Ah power bank. The battery provides enough power for a 24 to 48-hour deployment. When there is a change in IR levels detected in the nest box, a 30-second video is captured. The system had 138 deployments, of which about 14% had troubleshooting issues. The deployments that were successful or usable resulted in 99% of the videos being useful. Successful was defined as footage being recorded continuously for more than one hour.

According to Kubizňák et al. [20], many applications of wildlife monitoring are limited to off-the-shelf and stand-alone technologies. Kubizňák et al. [20] have made a purpose-designed system that has much functionality. The system is capable of:

- streaming live video and capturing videos
- collecting environmental data such as temperature, light intensity, humidity and air pressure
- automated downloading, storage and dissemination of video and audio data
- automated processing of all streams of data
- remote monitoring and configuring of the system

The system has much functionality, which is possible due to the custom-designed computer unit. This is the third iteration the researchers have made. There are many improvements that have been made compared to the first system that got made. Examples are the possibility of streaming and recording videos simultaneously and adding many environmental monitoring sensors. The goal is to make a system that needs low on-site maintenance and make a design that would potentially allow for commercial production of the monitoring nest box. Generally speaking, the quality of the video that got recorded was sufficient to extract biological data. However, the quality of the data was not consistent. The second iteration produces bright but motion-blurred videos, whilst the third iteration produces smooth but sometimes dark videos. Different cameras were used in the different iterations. Overall the data that the system produces is decent and the system is optimized for its task. But there is much research and development that has been done to achieve a more complex system like this.

It can be seen that many of the studies design a monitoring nest box to allow for the monitoring inside the nest box. The bird's behavior is monitored, which may be affected due to environmental effects, including climate change and habitat loss. Another reason for designing a nest box is because the currently available monitoring boxes are not flexible. Researchers require a specific system for their research which the available monitoring methods are not capable of. A Raspberry Pi is a popular choice as a microprocessor. The studies that use a Raspberry Pi mention that it is relatively easy to add sensors and program the system. Some of the studies use detection methods to detect birds and only record when they enter. This reduces the amount of data that is gathered significantly. The quality of the data and reliability of systems are decent but not optimal.

2.1.2 Design Decisions

Ait abdelouahid et al. [21] observe that many artificial nest boxes are designed for a single or few numbers of avian species. This is done since the researchers are only interested in these species. Ait abdelouahid et al. [21] propose to adapt this feature of a classical nest box by making a modular nest box entrance. For this entrance, a specific diameter can be chosen or part of the front panel can be removed to make a semi-open nest box (Figure 1). Furthermore, Ait abdelouahid et al. [21] mention that the nest box should be large enough to accommodate room for the electronics.

Zárybnická et al. [18] have made a nest box system consisting of three iterations. The first iteration was designed as a regular nest box designed for boreal owls with additional space for electronics (Figure 2). The control board was stored in a compartment above the nesting compartment, whilst the battery was stored in a compartment below the nesting compartment. Behind the nesting compartment, there was a dedicated area for wiring. Furthermore, this nest box was also covered in aluminum plates to protect it against pine marten. The dimensions of the nest box are 320x250x820 mm. The second and third iterations are covered in a separate paper [20]. The second and third iterations of the nest box were designed for cavity-nesting passerines. The designs of the two newest nest boxes are very similar. Therefore only the design of the newest nest box will be covered. The nest box has two compartments. One nesting area and one compartment for the electronics. The size of the nest box has significantly decreased. This is because the new systems do not accommodate space for a battery as they are powered by an electrical cord. The electronic compartment is situated next to the nest box. The newer nest boxes have a plexiglass window which allows natural light to enter the nest box. The light intensity can be changed by a cover that can be placed in front of the plexiglass (Figure 3). It was mentioned that the nest material often covered the plexiglass window, reducing the amount of daylight that enters the nest.

In contradiction to the previous nest box designs, Hereward et al. [17] made a smart nest system that is completely portable and can be installed in different nest boxes. The system consists of two parts, the camera housing and the power pack housing. The housings are Tupperware boxes, one of which contains the camera, a PIR sensor and a control board. This compartment is installed on the top part of the nest box. The box is camouflaged using a corkboard (Figure 4). The power pack is also stored in a Tupperware box and is located next to the nest. A USB cable connects the two separate boxes and powers the camera system.

Figure 1 Semi open nest box

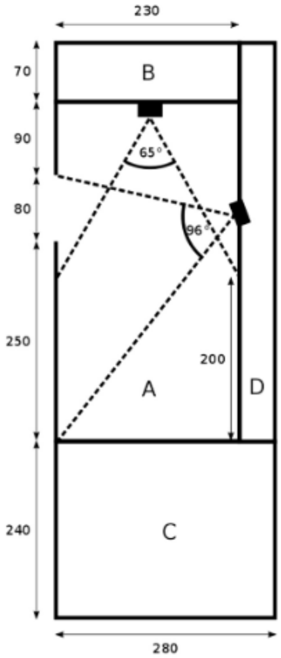


Figure 2 Smart nest box iteration 1

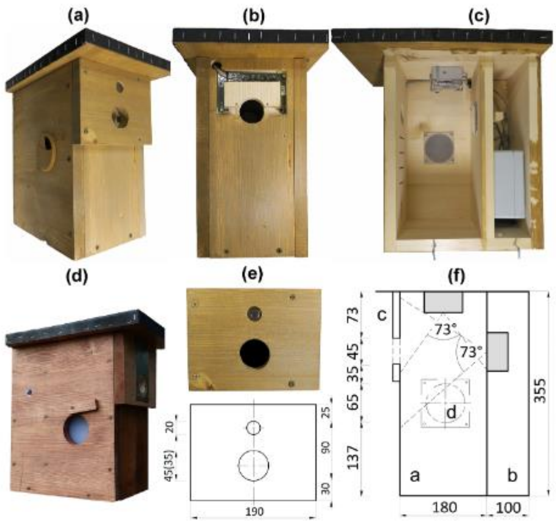


Figure 3 Smart nest box iteration 2 and 3

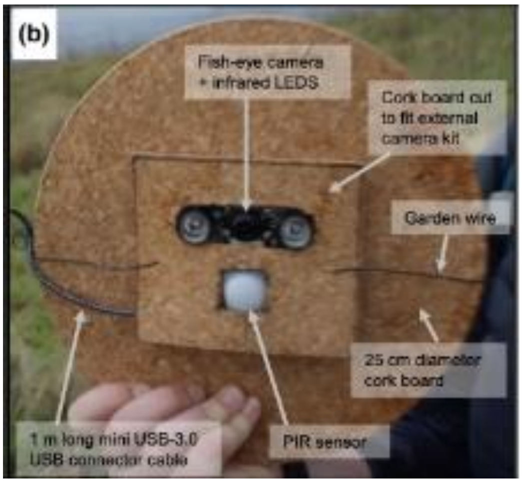


Figure 4 Portable nest box system

2.1.3 Footage Review

Typically there are two types of smart nest box systems; systems that are continuously recording or taking pictures in time intervals and ones that start recording when movement is detected. The systems that don't make use of a sensor to detect birds produce much data. Much of this data is unusable as there are no birds. The smart nest boxes that use sensors or motion detection software to sense birds record significantly less unusable data. Motion detecting software starts recording birds when they are in frame. This reduces the amount of data that is captured as the bird is already in frame. PIR sensors have a relatively slow response time when compared to active IR sensors. This results in less captured data since it takes more time before the bird is sensed and the camera can start recording. Active IR sensors will produce the most amount of valuable data as they have a quick response time.

From the reviewed literature, it has become clear that there are three ways how the data can be reviewed. The most straightforward way is manually analyzing the footage, as seen in the research performed by Zárybnická M. et al. [18]. The advantage of this method is that the analysis is accurate since the data is reviewed by experts. The main disadvantage is that the process of analyzing data is a labor-intensive task. This is because there is a large amount of data from which every photo or video has to be assessed individually.

Using Citizen Science to analyze data requires more preparation before data can be analyzed. The method the data is analyzed is similar to the previously mentioned method since the data is still analyzed by humans. The difference is that the analysis is done by more people who are interested and want to get involved in the project. This method reduces the workload per person, which allows for quicker results. Sometimes citizens are not employed, so they also do not have to be paid. Other times they are paid. The costs of analyzing data can be lower than the previous method, but more preparation is required. [22] have set up a project which combines bird monitoring and citizen science.

Using AI to analyze footage is a method that doesn't require humans to analyze the footage. There are no costs for reviewing the footage. There are only initial costs for making and training an AI. An example of a paper that has used AI to observe behavior in the nest box can be seen in [23].

2.1.4 Components

The covered studies have all designed their own smart nest box system. The individual components of each setup can be found in Table 2.

It can be seen that a Raspberry Pi board is the most popular choice in the reviewed literature. These boards offer a lot of versatility for the use of different cameras. Next to this, the boards are relatively cheap. This combination makes it a popular choice for many smart nest box studies. The ESP32-CAM used by el Bouanani and Ayoub [15] allows for an even cheaper but less powerful setup. The downside of this microprocessor is that the amount of cameras that are compatible is significantly less than with the Raspberry Pi. Next to this, the quality of the compatible cameras is low. Contrary to this, Kubizňák et al. [20] were able to make a setup exactly how they desired since they custom-designed a microprocessor. This allows a system to be built that is compatible with whatever component is desired and is as powerful as required. This gives a lot of freedom and drastically decreases the amount of limitation when compared to ready-made processors. Using a custom-designed processor is by far the best option as it is designed to allow for all desired functionality. However, it is questionable if the costs and amount of work to produce such a board weigh up against this advantage for our project. In multiple studies, it has been shown that a well-functioning, versatile smart nest box can be made using a Raspberry Pi. A Raspberry Pi allows a camera and many sensors to be attached. A program can be made in python, which controls these components, and much information is available regarding different libraries that can be used to control the components. The downside is that the board is not optimized for the specific task therefore it may be less energy efficient than a custom-made PCB.

The cameras that were used in the different setups all seemed to function decently, according to the authors of the reviewed literature. McBride and Courter [19] compared five different cameras that were compatible with Raspberry Pi boards. The authors came to the conclusion that the performance of these cameras is very similar, and therefore there is no reason to buy more expensive cameras from their selection. From the reviewed literature, it is not possible to conclude what the best camera is as the performances are not covered in much detail. The sensor resolutions can be found in Table 2.

All except one study used a type of motion detection system to know when to start recording. Using a motion detection system drastically reduces the amount of data that is recorded. Of the studies that use motion detection in their system, three of the four use an infrared (IR) sensor that is placed near the entrance hole of the nest box. The studies mention that using an IR sensor works well. The study of Prinz et al. [16] uses motion-MMAL software to detect entering birds, which is a reliable and effective method to detect entering birds. The recording starts when there is a certain amount of pixels that have changed color (so when the bird is frame). Since there is no additional hardware required, the chance of a possible hardware failure is lower. This is an advantage when compared to using IR sensors. A downside of this technique is that the camera starts recording when a bird is sensed and consequently, only data is recorded when the bird is in frame. Due to this, footage of the bird entering the nest box is not recorded. When an IR sensor is placed outside of the nest box, the bird can be sensed before entering the nest box. This allows the camera to start recording before the bird enters the nest box. This is a large advantage of the IR monitoring method when compared to software detection, as more valuable data will be recorded.

Authors	Year	Microcontroller	Camera	Sensor resolution (pixels)	Trigger	Trigger location	Light	Environmental sensor	Weight sensor	Time sensor	Battery	Power Chip	Solar panel
El Bouanani and Ayoub	2020	ESP32 CAM	OV24640 2MP	1632 x 1232	Obstacle Avoidance Sensor	Under the entrance hole inside the nest box	10 mm white led	AM2302	1kgLoad Cell and 24-Bit Analog-Digital convertor HX711Module	RTC ds3231	3.7V 3400mAh model 18650 Rechargeable Li-Ion Battery	TP4056	165x165mm (DC12V5W)
McBride and Courter	2019												
setup 1	2019	Raspberry Pi 3 Model B	ArduCam 5 MP Camera Module	2592 x 1944	-	-	-	10 K Precision Epoxy Thermistor and Anemometer Wind Speed Sensor with Analog Voltage Output	-	-	10,000 mAh battery	USB/DC/Solar Lithium Ion/Polymer Charger v2 and High Efficiency 1.2 MHz 2A Step Up Converter	9-Watt solar panel
setup 2	2019	Raspberry Pi 3 Model B	Camera Module v2	3280 × 2464	-	-	-	P9808 High Accuracy I2C Temp. Sensor Board and Anemometer Wind Speed Sensor with Analog Voltage Output	-	-	10,000 mAh battery	USB/DC/Solar Lithium Ion/Polymer Charger v2 and High Efficiency 1.2 MHz 2A Step Up Converter	9-Watt solar panel

setup 3	2019	Raspberry Pi 3 Model B	RB-WAV-90	2592 x 1944	-	-	-	waterproof DS18B20 Digital Temperature Sensor and Anemometer Wind Speed Sensor with Analog Voltage Output	-	-	10,000 mAh battery	USB/DC/Solar Lithium Ion/Polymer Charger v2 and High Efficiency 1.2 MHz 2A Step Up Converter	9-Watt solar panel
setup 4	2019	Raspberry Pi 3 Model B	Pi NoIR Camera v2	3280 x 2464	-	-	-	Platinum RTD Sensor and Anemometer Wind Speed Sensor with Analog Voltage Output	-	-	10,000 mAh battery	USB/DC/Solar Lithium Ion/Polymer Charger v2 and High Efficiency 1.2 MHz 2A Step Up Converter	9-Watt solar panel
setup 5	2019	Raspberry Pi 3 Model B	Logitech C270	unknown	-	-	-	Mesh Protected Weather-Proof Temperature Sensor and Anemometer Wind Speed Sensor with Analog Voltage Output	-	-	10,000 mAh battery	USB/DC/Solar Lithium Ion/Polymer Charger v2 and High Efficiency 1.2 MHz 2A Step Up Converter	9-Watt solar panel
Prinz et al.	2016	Raspberry Pi Model B	Pi NoIR Camera	2592 x 1944	motion-MMAL software	-	6x 940-nm infrared LED	-	-	-	Deka rechargeable gel batteries	-	12V panel

Hereward et al.	2021	Raspberry Pi zero	Fish-eye camera	2592 x 1944	PIR sensor	In the roof of the nest box	IR LEDs	-	-	RTC	(not mentioned)	-	-
Kubizňák et al.	2019	custom built	LP-USB100W04H-RL36	1280 x 800	custom IR light barier	Across the entrance hole, mounted in the wood of the entrance hole	IR LEDs	internal and external temperature sensor, barometer, hygrometer	tensometer	-	Power over Ethernet	-	-

Table 2 Component overview of covered literature

2.2 Interviews

There were weekly meetings with the client and supervisor, which gave much insight into the requirements. Next to this, two interviews were conducted to get a better understanding of smart nest boxes and blue and great tits. In order to get a broad vision on this topic, one interview was held with a commercially oriented expert, whilst the other interview was held with more research-focused experts.

2.2.1 Client: Emily Burdfield-Steel

During the graduation project, there were weekly meetings with the client and supervisor. In the first half of the graduation project, the goal was to write a project proposal. During this part, the challenges of the project were discussed in the meetings, which led to requirements. The requirements and the reasonings that emerged from the weekly meetings are stated below.

Requirements

- Waterproof
    - The smart nest box that is designed should be waterproof so that the electrical component stay dry. This also assures that the bird's nest stays dry and provides a dry place for the birds to shelter.
- Modularity
    - The smart nest box will be used for research purposes. The system will be used for nest boxes in research projects that have already begun. In this research, there are standard nest boxes that are being used. These nest boxes have the same dimensions. The nest boxes that are used in the research should remain the same. Therefore the smart nest box should be a modular system that can be installed on the existing nest boxes. This requires the smart nest box to be a system that can be attached or implemented in the preexisting nest boxes. Having a smart nest box system that can be attached to preexisting nest boxes will also reduce the cost and amount of work to produce and install the nest boxes.
- Easy installation
    - In order to minimize the installation time of the smart nest boxes and disturb the nesting birds as little as possible, the smart nest box should be easy and quick to install.

2.2.2 Wildlife Monitoring Solutions: Lennart Suselbeek

The notes of the meeting can be found in Appendix A1. Wildlife Monitoring Solutions (WMS) is a web shop that sells wild cameras, nest cameras and accessories. Much information is provided about their products. The web shop was set up by Lennart Suselbeek in 2011 and is still run by him and an assistant. Lennart is also employed as a Ph.D. Program Coordinator at PE&RC (The Graduate School for Production Ecology & Resource Conservation) from Wageningen University & Research. The meeting with Lennart and his assistant was held at the beginning of the research project. During the meeting, the past, current and new developments in the smart nest box field were discussed.

Lessons learned

- In many wild cameras, passive IR (PIR) sensors are used
    - Advantage: very energy efficient, disadvantage: relatively slow response time
- Smart nest box cameras usually record continuously and add a mark when a change in pixels is detected
- Requirement of detection method: reaction time should be as fast as possible
    - Idea: use a laser detection outside of the box in front of the entrance hole
- The nest box WMS is selling has a hole in the side covered by plexiglass to let in light for the camera (Figure 5)
- WMS has not experienced many problems with water damage
- Ideally, the inside of smart nest boxes should be 30cm high to accommodate room for the camera that is mounted on the ceiling. If the nest box is only 20cm high and a camera is installed on the ceiling, this is very unattractive for the bird.

Figure 5 Window in nest box

Requirements

There should be enough room in the nest box for the bird. If the inside of the nest box is cramped, this will be unattractive for the bird.

2.2.3 Biologists: Marcel Visser & Christiaan Both

The full transcript of the interviews can be found in Appendix A2. On the 8th of march, there was a meeting with biologists and the students, supervisor and client from this project. The meeting was set up to share experiences of working with smart nest boxes and how this can be useful for innovation in this field. Christiaan Both and Marcel Visser were the lead researchers working at the University of Groningen and the Netherlands Institute of Ecology, respectively. Both researchers have been working with smart nest boxes and great and blue tits for many years.
The researchers' methods of monitoring nest boxes are briefly described. They put up a nest box and when this is inhabited by birds, they move the nest to their smart nest box. This nest box has an IR trigger in front of the entrance (called a 'lichtsluis'). When a bird passes the entrance hole, the camera starts taking pictures. The camera is a DSLR camera mounted in a separate wooden box behind the nest box. They use this system for a couple of hours and in order to provide enough light for the camera, they use LED lights inside the nest. Marcel and his team use a similar setup as Christiaan's setup. Next to this setup, they have a second setup that uses a spycam. This is a small camera that is placed on the lid of the nest box for a few days.

It was mentioned that it is acceptable to have light in the nest for a small amount of time (a few hours), but there shouldn't be light permanently in the nest box. The challenges that they face is that the DSLR camera is noisy but is able to make high-quality pictures. The spycam is small, quiet and can easily be installed in existing nest boxes. The downside of this camera is that it is constantly recording, which means it has to be visited often to switch batteries and SD cards. Next to this, the quality of the camera's data is low.

Lessons learned

- The best position for the camera is in front of the entrance
    - The camera should be positioned slightly to one side to avoid lighting problems
- Pictures are preferred over videos as they are easier to analyze
- The nests can be lit by white LEDs for a few hours, but the light should not be on permanently
- The inside dimensions of the nest boxes used in research may differ slightly since different wood thicknesses are used when they are built
- Having a plexiglass window (Figure 5) can cause unstable lighting conditions, which the camera may have difficulty adjusting to

Requirements

It is possible to have lighting in the nest box, but this should not be permanent as this disturbs the bird.

2.2.4 Conclusion

The interviews gave much insight into design choices that should be considered when making the system. It was useful to see the research and a more commercial point of view about nest box requirements.

2.3 Challenges

From the reviewed literature, meetings, and the two interviews that have been held, challenges regarding this project have come forth. It has become clear that a very important aspect is that the bird accepts the smart nest box and wants to nest in it. This means that there should not be too much heat and noise that is dissipated by the electronics. Next to this, there should not be too much light in the nest box. Furthermore, the space in the nest box should not get to occupied by electronics.

There are also challenges that relate to getting high-quality data. The inside of a nest box is very dark. Thus the camera requires a light source inside the nest box to capture usable data. The weather conditions outside may also influence the lighting situation in the nest box. The inside of the nest box will be darker on a cloudy winter day than on a sunny day. Next to this, the bird enters the nest box quickly. This makes it challenging to have pictures or videos which are in focus. Furthermore, the camera must start capturing as soon as a sensor is triggered to make sure the bird is in frame. The amount of data that can be stored on the system is limited; therefore, the amount of captured data must be considered. Recording very long videos may guarantee that there is usable data, but this method will also occupy the storage very quickly.

The system will be powered by a battery. In order to power it for a long time, the system should be energy efficient. The smart nest box should also be weatherproof to assure it won't be damaged or break when it rains or there is a lot of wind. Lastly, there is a time constraint for this project.

2.4 Technical research

In this section, we look at off-the-shelve monitoring nest boxes and individual electrical components that are available in Dutch web shops. If we would only consider components used in literature, the options are limited and some may be outdated. The technical research ensures newer electrical components are also considered. In order to keep the overview of different components clear, a decision matrix has been made for each component. This matrix gives an overview of the different options and if they meet the specific requirements.

2.4.1 Off the Shelve Monitoring Nest Boxes

When searching for off-the-shelve monitoring nest boxes, there are only a few products that can be found. The most complete system is a Kickstarter project called Nest Box Live. The system has a camera that captures data from a top-down view. The data can be captured or streamed live. Next to this, the site claims that the type of bird can be recognized using AI. There is a waiting list for the product. So it cannot be bought yet.

An alternative is buying small camera systems that can be installed in a nest box, also known as spycams. These cameras are sold by WMS, the company which an interview was held with. From their webshop, a spycam and nest box can be bought. The nest box is designed to accommodate enough room for the camera, so the bird is not bothered by it. The spycam can live stream the footage to a smartphone that is connected to its Wi-Fi network. The system can also store data on a SD card. The system senses birds using software detection.

The systems that have been covered are capable of capturing useful data. The downside is that it is not possible to make changes to the system. An example is that it is not possible to change the sensing method to, for example, a PIR sensor. Next to this, the systems seem to be designed for consumers who are interested in the birds staying in their nest box. For example, the systems can send a message to the smartphone of the user when a bird is in the nest box. These functionalities are not useful for research purposes. It is clear that the systems are designed for casual monitoring instead of exact biodiversity monitoring.

2.4.2 Microprocessor

From the literature review, it became clear that a Raspberry Pi board is a great option as it is compatible with many components, powerful and relatively cheap. Next to this, it is a popular microprocessor in many electronic projects, so there is much information available about this board. Other options that came forward in the decision matrix are the Banana Pi Bpi-D1 and the Google Coral DEV Board Mini 2 GB 4 x 1.5 GHz. The Banana Pi is a small microprocessor that has all desired components already installed on the board. This makes it easy to work with all components and the chance that hardware problems occur is small as all components are soldered to the board. The downside is that it is not possible to connect a higher-quality camera to the board. Only a different motion sensor could be connected using the GPIO pins. The last microprocessor is made by Google and specially designed for onboard AI processing. This board is about the same size as the Raspberry Pi 4 but has processing units that are optimized for running AI. This board is a bit more expensive than Raspberry Pi boards. The board is also not as popular as Raspberry Pis; therefore, it may be harder to find solutions for possible software or hardware problems that may occur with the board. These are a few downsides to this board, but it is still a valuable option.

Product	**supports camera**	**Supports sensor**	**Powerful enough**	**Ease of use**	**send data**	**Price**
Raspberry Pi 4B	Yes	Yes, with GPIO pins	Yes	Very common board much information available	Yes	€ 59,95
Banana Pi Bpi-D1	Yes, 1280x720p	Built-in motion detection functionality also has GPIO pins	Powerful enough for hardware that is on the board	Programmable in C, fully open source	Yes, only using Wi-Fi	€ 53,09
Google Coral DEV Board Mini	Yes	Yes, with GPIO pins	Yes	Programmable in Python and C++	Yes	€ 118,86

Table 3 Microprocessor options

2.4.3 Camera

The literature review showed that there are many cameras that can be connected to a Raspberry Pi. There were many cameras available that could be used for this project. In order to keep the table compact, the most interesting and promising lenses have been chosen. The cameras that the literature review covered were all camera modules that have a lens that cannot be switched. Therefore the settings of these cameras cannot easily be changed. Recently a new camera module has been released, which allows different types of lenses to be attached. This allows users to use this camera setup for specific tasks. For example, if a macro shot is desired, there is an appropriate lens for this, but if the user desires a lens that has a big zoom, this is also possible. Compared to the other camera modules, this camera module gives much more freedom to the user. There is an extension board specifically designed to attach up to four IMX477 camera modules. This gives the possibility to use multiple cameras in one nest box, which increases the chance that useful data will be captured. The IMX477 module seems like the most promising camera option. The different lenses that can be attached are reviewed in the next paragraph.

Product	Dimensions (mm)	Resolution	Ability to record with colors	Price	Notes
HQ Camera for Raspberry Pi - 12.3MP IMX477	38x38x20	4056 x 3040	Yes	€ 59,95	Board to which different lenses can be attached
Green Backyard WATERDICHTE IP PoE Nestkastcamera	46x46x43	1920 x 1080	yes,	€ 134,95	Camera sold by WMS. Stand-alone system, may be possible to connect to microprocessor
Arducam 8MP IMX219DS PTZ	24x25x unknown	3296 × 2480	Yes	€33,60	Wide viewing range, compatible with Raspberry Pi CM3/CM3+ (not with the standard boards)
Google Coral Cam 5MP	25x25x6.98	2592 x 1296	Yes	€ 35,99	Compatible with Google Coral DEV Board Mini
e-CAM50_CUCRL	30x30x unknown	1920 x 1080	Yes	$99	Only sold on American websites, compatible with Google Coral DEV Board Mini

Table 4 Camera options

2.4.4 Lens Specifications

The IMX477 is a camera module that can be connected to a raspberry pi. This module offers the possibility to connect multiple lenses to it, similar to a DSLR camera. There are six types of lenses available that can be connected to this module. In Table 5, there is an overview of the different specifications. The focal length and aperture are the factors that change the lens characteristics, these terms are explained below.

Model	Focal length	Aperture	Min. object distance	Dimensions	Price
6mm 3MP Lens	6mm	F1.2 - F16	20cm	ϕ30.00×34.00mm	€ 29,95
16mm 10MP Lens	16mm	F1.4 - F16	20cm	ϕ39.00×50.00mm	€ 59,95
25mm 10MP Telephoto Lens	25mm	F1.4	30cm	34mm x 40mm	€ 46,95
35mm 10MP Telephoto Lens	35mm	F1.7 to F16	20cm	34, 32mm	€ 52,95
50mm 8MP Telephoto Lens	50mm	F1.4 - F16	30cm	39, 52mm	€ 49,95
8-50mm 3MP Lens	8-50mm	F1.4	50cm	40mm, 68.3mm	€ 47,95

Table 5 Lens options

Focal length

The focal length is the distance between where the light converges in the lens and the sensor inside the camera. Adjusting the zoom changes the focal length. A shorter lens has a shorter focal length, this provides a wide view. A longer lens, also called telephoto lens, gives a narrow view. This can also be seen in Figure 7.

Aperture

By changing the aperture, the amount of light that enters the lens is changed. The larger the aperture of the lens, the more light reaches the sensor of the camera. Aperture is expressed in F-numbers. A smaller F-number means a larger aperture, letting in much light. The larger the F-number, the smaller the aperture and lets in less light. A large F-number focuses well on the foreground and background, so the whole picture is focused. A small F-number focuses on one point, making the rest of the picture blurry. Lenses with a lower F-number take pictures faster than lenses with a higher F-number. Figure 6 also explains aperture.

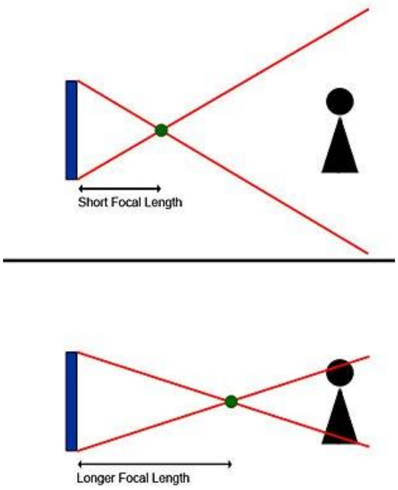


Figure 7 Focal length explained

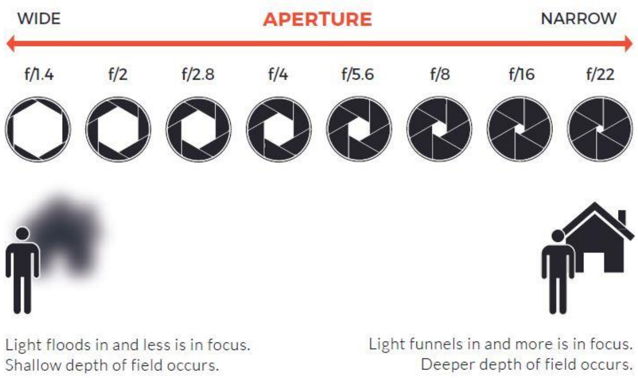


Figure 6 Aperture explained

The camera that is placed in the nest box should focus on the entrance of the nest box. The birds always have to pass through this point, and this point is fixed. When the camera is focused on the nest, this may cause problems with the focus as the height of the nest can vary. In the pictures that our camera takes, having a larger F-number is better than having a smaller F-number. The larger F-number will ensure that everything in the picture is in focus. This removes the potential risk of the camera not being focused on the bird and potential prey. For the focal length, it is important that the entire bird is in the shot. Therefore it is better to use a lens with a smaller focal length. The 6mm 3MP lens and 16mm 10MP lens seem to meet these requirements making them the best potential lenses.

2.4.5 Detection Methods

From the literature review, it became clear that there are multiple ways of detecting birds, but the most popular detection method war using IR sensors. There are many different ways to detect objects (in this case, birds) using different technologies. Object detection methods are used in many different fields, but all serve the same purpose. The methods will be covered. Since different detection methods work in different ways, it is difficult to compare these variables in a table. This is why Table 6 is compact, but the options will be compared later on.

Product	Response time	Price
IR Break Beam Sensor	<2ms	€ 11,95
PIR Motion Sensor	0.3s – 25s (depending on distance)	€ 2,19
Capacitive sensor	<2ms	-
TFmini Plus Lidar senor	1ms – 1s	€ 49,95
SEN0192 microwave sensor	<2ms	€ 9,95

Table 6 Detection options

IR sensors

There are two types of IR sensors. Passive IR sensors have an IR receiver that detects when there is a difference in IR radiation. The detection time of this sensor is relatively large, but the sensor is energy efficient. An active IR sensor has a faster response time as it uses an IR emitter and receiver to detect objects. The downside is that this type of sensor uses more energy than the PIR sensor.

Capacitive sensor

A capacitive sensor senses an object whenever it is touched. Such a sensor can be easily made using two wires and a conductive material such as a piece of copper or aluminum foil. This conductive material can be installed at the entrance of the nest box and whenever a bird touches this, it will be sensed. Since this sensor is very simple to make, it can be made, so it perfectly fits in the nest box entrance. Possible downsides of this sensor are that the bird must touch the capacitive sensor when entering the nest box and that the location of the sensor is in the entering path of the bird. The bird may not accept this and therefore not nest in the nest box.

Lidar

Lidar is a sensing method that can measure the distance to objects, and from this data, it can make a render of the objects. Lidar stands for 'Light Detection and Ranging' and is commonly used to detect the earth's surface by self-driving cars, helicopters and planes [24]. This technology has also been included in the latest iPhones and iPads from Apple. They mainly use this technology with their camera to improve picture quality (especially at night), but the sensor also allows distance to be measured in for example, a room. There are multiple Lidar sensors that can be connected to a Raspberry Pi. This technology has potential as it can detect objects precisely with a low response time. The disadvantage, however, is that many of the available Lidar sensors need a minimal distance of 20 cm. There is a Lidar sensor that needs a minimal distance of 10 cm, but this is still quite large [25].

Microwave sensor

Microwave sensors emit signals with their emitter and wait till they are sensed by the receiver. This technique is very similar to the obstacle avoidance sensor used by El Bouanani and Ayoub [15]. This sensor sends out microwave signals in all directions and waits till they are reflected back. If it takes longer for the signal to return to the sensor, there is an object. There are IR sensors that work in a similar manner, but they can have sensitivity issues with heat and sunlight. This can falsely trigger the IR sensor. Microwave sensors do not have this problem. However, they are able to detect movement through walls. There are a few reasons why this sensor is not ideal in our situation. It senses in all directions, so if movement is detected, it is not certain that this is an entering bird. Movement can also be detected through the walls of the nest box, which makes it even more unreliable in our situation [26].

2.5 Conclusion

The different information sources provided much insight into different components that can be potentially used for the smart nest box. From the literature review, it became clear that the Raspberry Pi can be combined with many different cameras. Next to this, it is a powerful, easy-to-use and relatively cheap microprocessor. From the technical review, it became clear that the Google Coral DEV Board Mini is also a good option. This board is able to run AI, which is a promising function for our project as this could allow for edge computing. For the prototype, however, this is not required. The Google Coral board has not been used in any of the reviewed literature, whilst a Raspberry Pi was a very popular board in the reviewed studies. The newest version of the Raspberry Pi seems like the best option as it allows for many components to be connected, there is much support and information available regarding the software and hardware and it is a relatively cheap board. Overall it is a great board for prototyping which we will be doing.

Many different cameras can be connected to a Raspberry Pi. From the technical review, one camera system stands out because of its customizability. This is the IMX477 camera module that allows different lenses to be attached. The lenses that are expected to function the best regarding the environment are the 6mm 3MP lens and 16mm 10MP lens. Regarding the detection method, it became clear that IR sensors are promising detection methods.

There are many types of detection methods than can be used to sense birds. Lidar is a promising technology as it can measure very precisely. However, it cannot measure close by. This is problematic as the nest box has a compact design, but the sensor cannot properly detect an object within 10 cm. The capacitive sensor requires the object to touch the sensor. This means the bird must touch the entrance hole when entering the nest box. It cannot be guaranteed that this happens every time. Next to this, the material of the entrance hole changes from wood to a capacitive material such as copper. The bird may not accept this and therefore not nest in this box. The microwave sensor is too sensitive as it can detect moving objects through walls. Using this sensor for the nest box would not work well as the sensor would trigger from the chicks in the nest. In the interview with Christiaan, he mentioned that he uses a custom-made IR sensor that works very well called a 'lichtsluis'. This is a custom-made PCB board that has an active IR beam sensor installed. Using a similarly designed sensor seems like the best option for the nest box as it has a precise detection range, fast reaction time and can detect the bird without it noticing it.

3. Methods and Techniques

This chapter will cover the methods and techniques which have been used for the design of the smart nest box. The design process will be presented. After which, the stakeholder identification and analysis method will be discussed. Lastly, it will be discussed how the requirements are set.

3.1 Design Process

A design process is followed in order to keep the process organized. The process used in this design was developed by Mader and Eggink [27]. Their process consists of four phases (Figure 8). The first phase is the Ideation phase which has three starting points: user needs/stakeholder requirements, technology and creative idea. One of these starting points is chosen, after which the other points are explored. The ideas created in this phase are based on the requirements that are set. The second phase is the Specification phase, in which the idea is further specified. The designs of the idea are further specified and story boards can be used to gain more insight. The third phase is the Realization phase, in which the idea will physically be made based on the specifications. The last phase is the evaluation phase. This process is not linear, so when completing a phase, it is possible to return to a previous phase. This can be done because new insights have come forth.

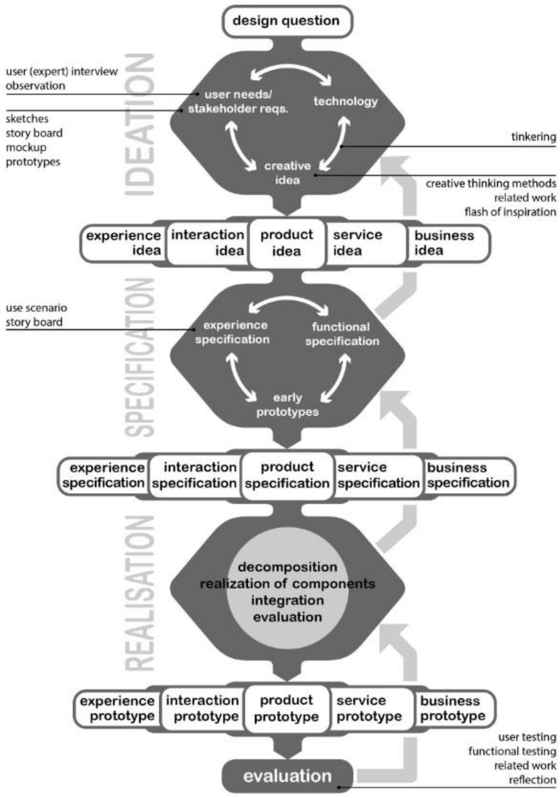


Figure 8: A Creative Technology Design Process

3.2 Stakeholder Identification and Analysis

In order to make a good design, the stakeholders should be kept in mind. Stakeholders are people and, in our case, also animals that have an interest in the project or final product. The stakeholders have their own interests and role. Some stakeholders have more influence/power than others. In order to identify the stakeholders and their values, a table is made that gives this overview. An example is shown in Table 7.

Stakeholder	Power	Interest	Role
…	…	…	…

Table 7 Stakeholder analysis template

The stakeholders can be placed in a grid that sets power against interest [28]. Based on the power and interest level, the stakeholders can be placed in 4 groups: Keep Satisfied, Manage Closely, Monitor and Keep Informed see Figure 9. This grid suggests how the different stakeholders should be treated.

Figure 9 Power versus interest grid template

3.3 Requirement Identification and Categorization

For this project, it is very important that certain requirements are met. If this is not the case, there is a large chance that birds will not nest in the nest box or that the product simply won't be able to fulfill its task. In order to avoid this, requirements need to be stated clearly. This is done using the MoSCoW method [29]. This method categorizes the requirements from most important to least important. The categories are: Must have, Should have, Could have and Won't have.

4. Ideation

This chapter covers the acquired knowledge from the previous chapters and utilizes it to make prototypes. Firstly, the stakeholders will be identified and analyzed. Secondly, the preliminary requirements are established and ranked according to the MoSCoW method. Lastly, the developed concepts will be covered, and the final concept will be presented.

4.1 Stakeholder Identification and Analysis

4.1.1 Stakeholder Identification

The stakeholders in this project all have their own power, interest and role. This information can be found in Table 8.

Stakeholder	**Power**	**Interest**	**Role**
Bird	Low.	No interest.	Users of the project. Will ideally use the product without actively noticing.
University of Twente	High. The supervisors and assessors want a good product.	Want a successful project for possible further development. Also to keep a good name for the study and university.	Sharing knowledge, giving advice, thinking along, assessing the work.
University of Amsterdam	High. The client wants a good product.	Having a product which functions well and can deliver high quality data.	Sharing knowledge, giving advice, thinking along, decision making.
Interviewees	Medium.	Contributing to this project to increase development in their field of work. The product can possibly be useful for them.	Sharing experience, giving advice.

Table 8 Stakeholder analysis

4.1.2 Stakeholder Analysis

The stakeholders are placed in the Power/Interest grid (see Figure 10). The grid suggests that the client and supervisor should be managed closely. There are weekly meetings with these stakeholders, so this is the case. The interviewees should be kept informed about the progress of the projects. The birds which will be the users of the product will not participate actively in the project. They are only using the product and cannot give direct input as they are animals.

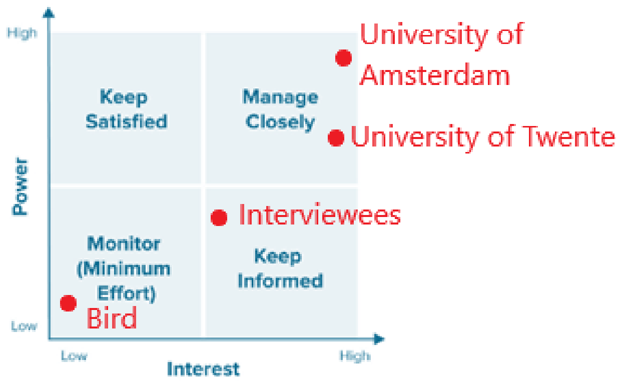


Figure 10 Stakeholders in the power/interest grid

4.2 Preliminary Requirements

Requirements have been made based on information from the interviews, literature review and technical review. Next to this, the client also shared her wishes for the project. This has also been implemented in the requirements. The requirements can be found in Table 9.

Requirement for smart nest box system	Must	Should	Could	Won't
Accepted by birds	■			
Waterproof	■			
Costs within reason	■			
Compatible components	■			
Easy to install on different nest boxes		■		
Requirement for camera				
Minimal HD resolution	■			
Record in color	■			
Adjustable settings		■		
Photo burst functionality			■	
Requirement for motion detection				
Reliable	■			
Fast response time	■			
Constant response time	■			
Sense bird before it enters nest box		■		
Requirement for microcontroller				
Send data	■			
Enough processing power	■			
Requirement for lighting in the nest box				
Constant lighting in the nest box	■			
Light intensity should not bother birds	■			
Enough light for the camera to capture useful data	■			

Table 9 Preliminary requirements in MoSCoW format

4.3 Preliminary Concepts

Concept ideas were developed as soon as the project started. As the project developed, the challenges and requirements became more clear since more background research was done. This can be seen from the different iterations of the concept (see Figure 14). The concept was developed by looping through the Ideation phase and Specification phase.

4.3.1 Concept 1

At the beginning of the project, the idea was to make a nest box that had a small camera attached to the lid of the nest box. There would be a box attached to the nest box where the rest of the electronics were stored, including the microprocessor of the nest box system but also the system that would run the AI program. This compartment would produce heat that is not desired by the bird. To prevent this, the excessive heat of the system could be water-cooled or cooled with computer fans. Again this caused another problem, the system would make noise and perhaps not be waterproof as ventilation would be needed.

4.3.2 Concept 2

From the first concept, it became clear that it was not ideal to store the AI system near the nest box as this produces heat and noise. The solution to this problem was to place the AI system in a separate box further away from the nest box. It would not matter if the AI system produced heat or noise as this was far enough away from the nesting birds that it would not bother them. The camera system stays in a separate compartment attached to the nest box. The two systems are connected by wires that are able to send data and power. A small camera again would be attached to the lid of the nest box. To provide more light for the camera, there would be a hole in the side of the nest box with plexiglass to let in light.

4.3.3 Concept 3

The third concept was developed after the interview with Marcel Visser and Christiaan Both. It became clear that the nest boxes which were used in the study have slightly different inside dimensions. Next to this, it became clear that the nest box was 22cm high from the inside. If a small camera were attached to the top of the lid, this would bother the bird and it would potentially not nest in this box. Next to this, it became clear that a top-down view (camera on the lid of the nest box) is not ideal. Having the camera in front of the entrance hole gives a better view of the bird and its prey.

The idea of using the existing nest boxes that were used for research was abandoned. The idea is to design an entirely new nest box system that would have four cameras installed. Three cameras would be positioned around the entrance hole, and one camera would have the top-down position. Casings would be made around the nest box to protect the cameras. Four cameras were used since a camera adapter was found, which allows four cameras to be attached to a Raspberry Pi. The hole in the side of the nest box to let in light was also removed as this causes inconsistent lighting in the box, which is not ideal for the cameras.

4.3.4 Concept 4

The client indicated that one of the requirements is that the nest box system should be able to be fitted on the ready existing nest boxes. This led to an entirely new concept which can be seen in Figure 11. This concept is a box that can be placed on top of the nest box. The nest box for which it is designed is only 22 cm high on the inside, and the entrance hole is positioned 3cm below the top of the lid. This is why the camera should be positioned above the nest box. The lid can be removed and the box can be placed on top of the nest box. The camera is located at the back of the box and is filming the entrance hole. Prinz et al. [16] mentioned that this camera position might make it easier to identify birds in the nest box when compared to a top-down view. In the previous concepts, the detection system was not mentioned as there was no clear idea yet on what the best system would be. From this concept onwards, the idea is to use an IR beam sensor which is installed on the outside of the nest box across the entrance. The bird will be sensed before it enters the nest box and ideally, the camera will be able to take multiple pictures when the bird enters. The detection method is very similar to the one used by Christiaan Both.

4.3.5 Concept 5

This concept is very similar to concept 4, there are a few changes. First of all, the box is made wider to accommodate two more cameras that can be installed on the side of the box (Figure 13). They are positioned in the same way as the single camera in concept 4. Next to this, there was the idea to add a piece of plexiglass between the nest box and the compartment that houses the components.

4.3.6. Concept 6

Again there are a few improvements made to this concept (Figure 12). Instead of placing the compartment on top of the nest box, it can now be slid over the nest box. This way, it can be more easily be attached to the nest box by screwing it in from the side.

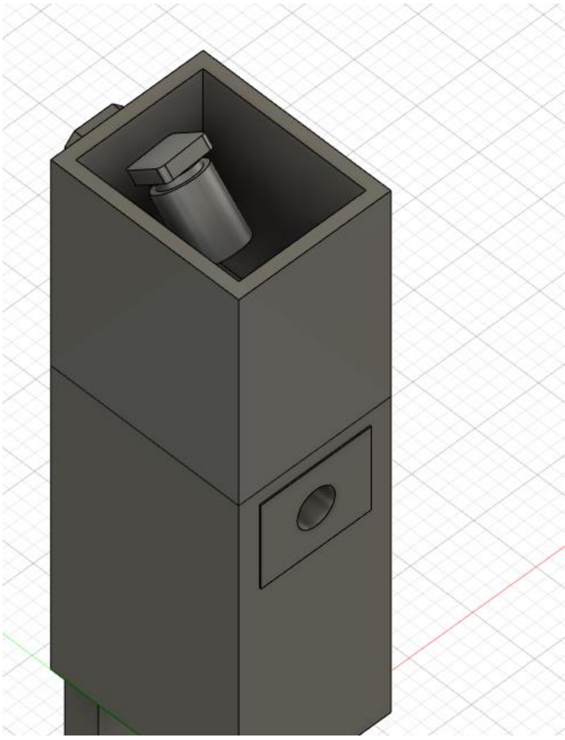


Figure 11 3D model of concept 4

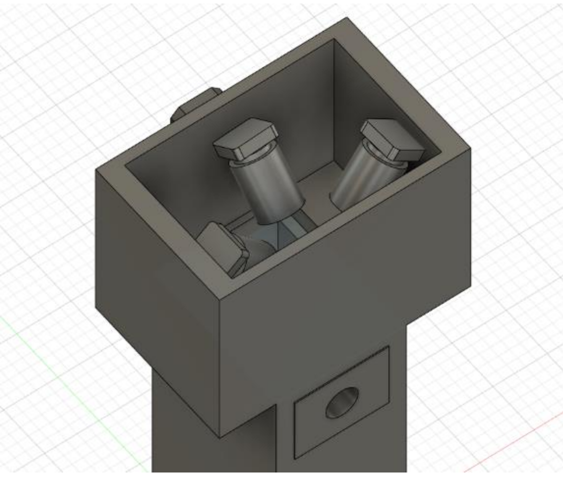


Figure 13 3D model of concept 5

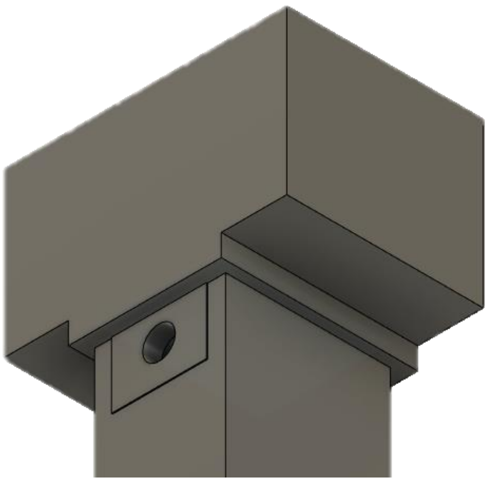


Figure 12 3D model of concept 6

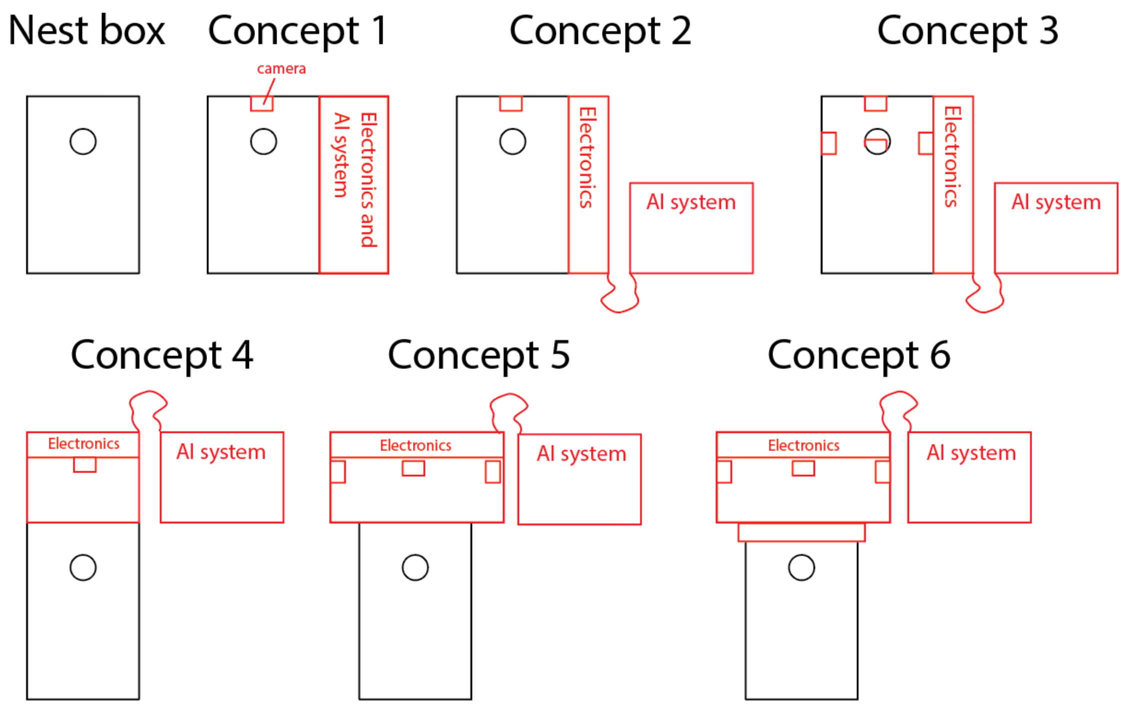


Figure 14 Overview of 2D concept generation

5. Specification

In this chapter, the final concept will be discussed elaborately. This concerns the physical design, the electrical components, the circuit and how the software will operate. In the previous chapter, the idea was discussed that the smart nest box would contain multiple cameras (see 4.3.5 Concept 5 and 4.3.6. Concept 6 of 4. Ideation). In the realization, it became clear that this was not possible due to software limitations. This is why there is only one camera in the design covered in this chapter.

5.1 Physical Design

From the requirements that have been set by the client, it has become clear that the currently used nest boxes should stay in use. Thus a product should be made which is able to fit onto the existing standardized nest boxes. Next to this, the product should be easy to install. This led to the idea of having a complete system that only needs to be placed on the existing nest boxes instead of modifying the existing nest boxes. The top compartment of the product should provide enough space for the camera and other electrical components to be installed. The bottom of this compartment should have a plexiglass plate installed, which allows the camera to see the entrance of the nest box. On the bottom of the compartment, there is a wooden "sleeve" that fits around the outside of the existing nest box. When installed on a nest box, the sides of the sleeve can be screwed to the nest box to allow for a secure connection. The dimensions of the nest box are stated below and the laser cutting file and additional pictures can be found in Appendix A3.

<u>Top compartment:</u>

Inside dimensions (LxWxH in mm): 202x158x150

Outside dimensions (LxWxH in mm): 222x178x170

<u>Plexiglass plate:</u>

Dimension (LxWxH in mm): 145x178x8

<u>Sleeve:</u>

Inside dimensions (LxWxH in mm): 127x160x40

Outside dimensions (LxWxH in mm): 147x180x40

5.2 Electrical System

In the Background Research, different smart nest box systems were discussed. Based on these systems and on the State of the Art in which the currently available components are discussed, an electrical system is designed.

5.2.1 Microprocessor

The microprocessor used is a Raspberry Pi 3B. Initially, the newest version of the Raspberry Pi (Raspberry Pi 4B) was chosen in the technical review. This board was not available due to the chip shortage. This is unfortunate but has no major consequences for the system.

5.2.2 Camera and Lens

The camera module that was paired with the Raspberry Pi is the Raspberry PI HQ Camera. This is a camera board that allows different types of lenses to be connected. Therefore, a specific lens can be chosen for certain situations. The lens that this board was paired with is the 6mm Wide Angle Lens. The lens is located relatively close to the entrance of the nest box where the focus point is. It is, therefore, important that the lens has a short enough minimal focus distance. This is the case and is further discussed in section 7.3.1.

5.2.3 Detection Method

The bird is detected by an IR beam sensor. This sensor consists of two parts; an IR emitter and an IR receiver. These two components are positioned facing each other so that the IR receiver is constantly receiving IR from the emitter. This sensor setup is installed on the inside of the nest box and when a bird enters the nest box, the IR beam is obstructed. The IR receiver does not receive IR and triggers.

5.2.4 Light Source

The last component that is installed in the nest box is a programmable LED strip (ws2812b) that provides light when the camera takes a picture. The LED strip is installed just above the plexiglass facing the entrance of the nest box. The strip consists of 5 LEDs, of which only three are used in the current setup. The data pin requires a 5V signal to operate, whilst the Raspberry Pi GPIO pins only output 3.3V. Therefore the 3.3V signal needs to be level shifted to 5V. This is done using two 10k Ohm resistance and a MOSFET (see Figure 15).

5.2.5 Power Supply

Whilst testing the system, the Raspberry Pi is powered by a 5V 3A AC/DC converter. Next to this, a 14V 1A AC/DC converter is used to power a breadboard power supply (see Figure 16), which outputs 5V to power the LED. The camera, LED strip and sensors are all connected to the Raspberry Pi.

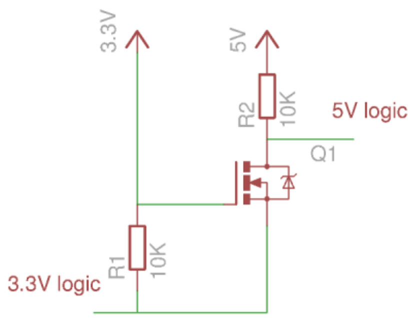


Figure 15 3.3V to 5V level shifter

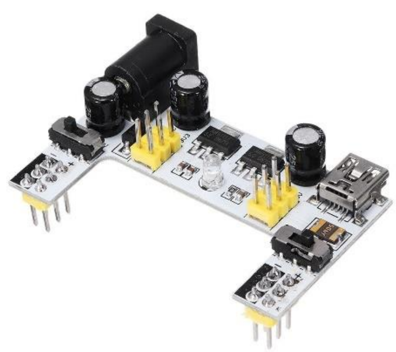


Figure 16 Breadboard power supply

5.3 Software

The Raspberry Pi is running Linux Debian 10 (Buster) and is running a python script. This script controls all the components and is kept as simple as possible. The script can be found in Appendix

A4. A brief description is given of how the script works below. Additionally, Figure 17 can be consulted.

The program is checking whether the IR beam gets obstructed. When this is the case, the LED lights go on, a picture gets taken and the LED lights get turned off. The picture is stored on the Raspberry Pi and the name of the picture is the date and time the picture got taken (for example, "06_23_2022_15_43_33.jpg"). After the picture got taken, the IR beam sensor is checked again. The system only resets and is able to make a picture again if the IR beam is not obstructed anymore. This is done since the bird may stay in the nest box entrance for a while and then photos would constantly be taken. This is unwanted since it would produce much useless data and by doing so, consume more power.

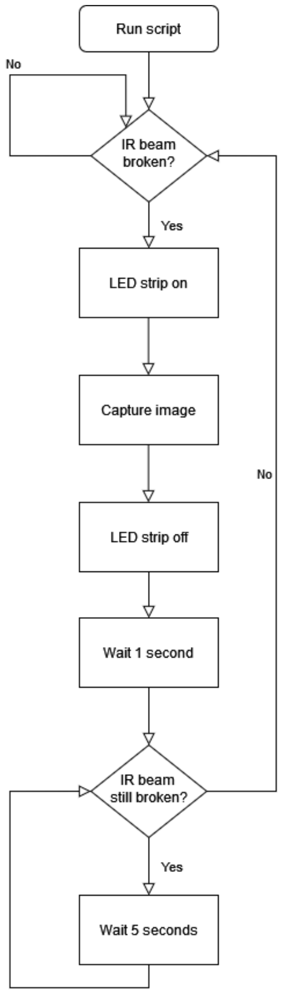


Figure 17 Flowchart of python script

6. Realization

In the Ideation phase, a final concept was made, which included the design of the compartment and the camera positions. During the building phase of the project, there were many more small design details that were not covered in the ideation phase. When actually making the smart nest box, these missing design details became apparent and solutions were usually easily found. Since the smart nest box is made of wood, it was easy to make small adjustments where necessary.

6.1 The Building Process

In this section, the building process of the different parts of the smart nest box will be discussed.

6.1.1 The Compartment

The wooden compartment functions as the foundation of the smart nest box as all the electronics would be mounted against this compartment. The first requirement was that the sleeve of the smart nest box would need to fit over the nest box correctly. The sizes of the pre-existing nest boxes slightly differ. Therefore the sleeve should fit around the largest nest box. This means it may be loosely attached to slightly smaller nest boxes. This can be solved by screwing the sleeve to the nest box using wood screws. The initial idea was to use three cameras in the nest box (see Figure 14, concept 6). To do this, there would have to be enough room on the sides of the compartment for the cameras to fit and have a good shot on the entrance. Since the required locations of the cameras in the nest box were not known, a long compartment was made in which the different camera positions could be tested (see Figure 18). The camera was installed on a separate sheet of wood which could be moved through the entire compartment. This was done whilst the camera was giving a live preview. The desired wideness was found using this technique.

Figure 18 Long compartment for testing camera positions

Since it was now known how wide the compartment should be to have well-positioned cameras, a new compartment was laser cut with these dimensions. Additionally, a plexiglass sheet was added between the sleeve and the top of the compartment. This assures the bird cannot fly up in the compartment and potentially harm itself or damage the electronics. The front plate of the sleeve covers part of the entrance, so the design was adapted. The design of the back plate of the sleeve was also slightly changed to accommodate space for the piece of wood, which is located on the back of the nest box. These changes were first made using woodworking tools but later on also laser cut.

6.1.2 The Camera Mount

From the ideation phase, it was clear where the camera(s) should be placed in the compartment. However, it was not clear how the camera should be mounted. When the camera module and lens were received, it was easier to make a design than making a design from the corresponding datasheets. The camera module has a screw thread that can be used to mount the camera to e.g., a tripod. In the design of the camera mount, this future got used. The location of the camera would be set, but it is useful to still make minor changes to the angle of the camera. Therefore inspiration was taken from a GoPro mount (see Figure 20). A CAD model was made in Fusion 360 and 3D printed (see Figure 19). The model existed of two parts. One part can be attached to the wall using four screws and the other part can connect to the camera module using its screw terminal. The two parts are connected using a nut and bolt to allow for movement between the prints. The camera mount is sturdy and functions as desired.

Figure 20 GoPro mounting system

Figure 19 3D printed camera mount

6.1.3 Light Source

In order to make a high-quality picture, a light source is required in the nest box. LEDs are small, cheap, energy-efficient and the color and brightness are programmable. This seems like the best option for a light source in the smart nest box. The first prototype that was made was a small LED matrix (5x4) that was mounted on the ceiling of the smart nest box compartment. This setup provided much light in the nest box and the camera. The downside was that the light was mainly shining on the bottom of the nest box where the birds and chicks would be. The camera was not focused on this area, so extra light there was not necessary.

A new design was made, which only used 5 LEDs on a LED strip. The small LED strip was mounted just above the plexiglass plate facing the light directly towards the entrance (see Figure 21). There was significantly less light on the bottom of the nest box and the LEDs provided enough light for the camera to function properly. This is further covered in the Evaluation.

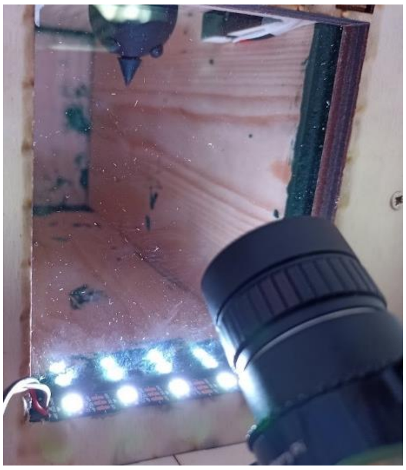


Figure 21 LED strip in the nest box

6.1.4 IR Beam Sensor

There were two types of IR beam sensors that were considered for the detection method. The difference was the size of the LED (3mm and 5mm).

Initially, the idea was to only place the IR sensor beams on the outside of the nest box. This was done to assure the sensors would trigger on time. Many designs were made for the two types of IR beam sensors. The initial idea was to have as many IR beams as possible to cover a large area over the nest box entrance. The designs can be seen in Figure 22. This design did not work well since there were many IR emitters that spread the beams of IR light. When one emitter beam was broken, this should cause a trigger at the IR receiver. However, often it did not happen because that IR receiver still received IR from another emitter. An example is given in Figure 23. After this became clear, a new design was made.

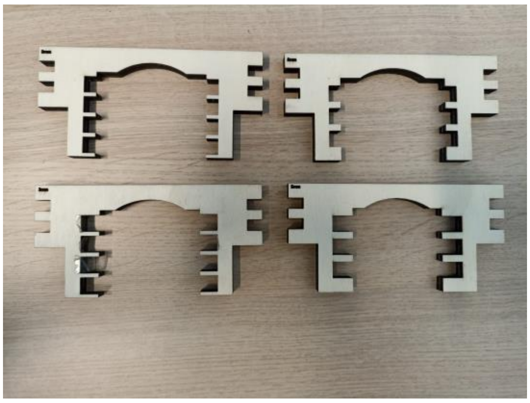


Figure 22 IR sensor holder 1st concept

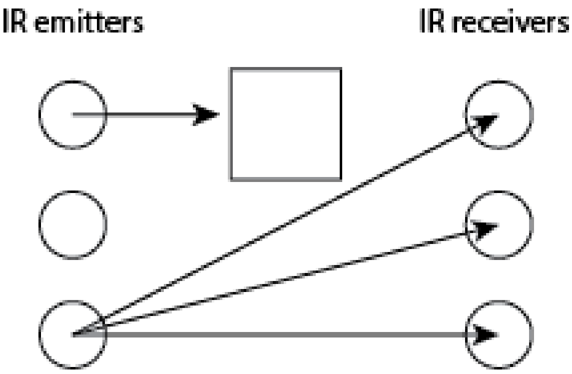


Figure 23 IR emitter problem

Figure 24 IR sensor holder 1st concept with sensors

With this design, an attempt was made to stop the spread of the IR emitter by making longer walls that would stop the spreading of the IR (see Figure 25). This, however, did not work.

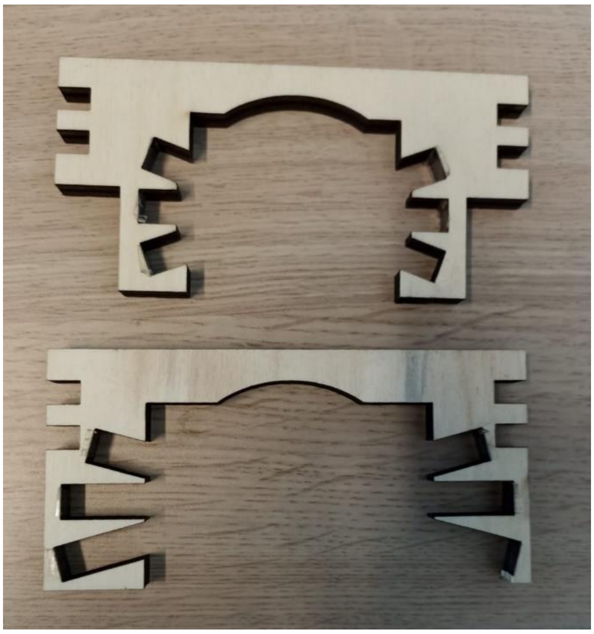


Figure 25 IR sensor holder 2nd concept

Instead of having multiple IR emitters, there was only one installed whose IR light would still reach all the IR receivers. This setup worked well and correctly triggered when an object entered the nest box. The design of the plate can be seen in Figure 26.

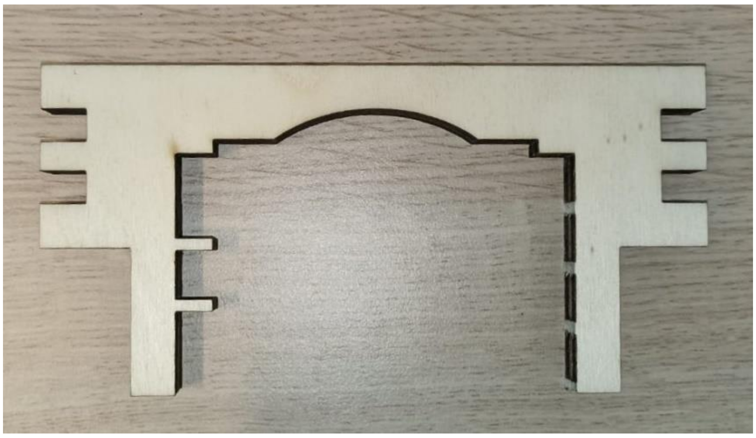


Figure 26 IR sensor holder 3rd concept

After a meeting with the client discussing the IR setup, we came to the conclusion that we could make the assumption that the bird would fill the entire nest box entrance hole when entering. This led to the conclusion that only one IR beam had to cover the entrance hole, reducing the amount of IR receivers needed. Next to this, the idea arose of installing the IR beam sensors on the inside of the nest box. With this setup, you would know for sure that the bird is in frame when the sensor triggers. There were some concerns about the birds picking at the sensors inside the nest box. However, the client mentioned it was okay to use this setup. The inside sensor holder can be seen in Figure 27.

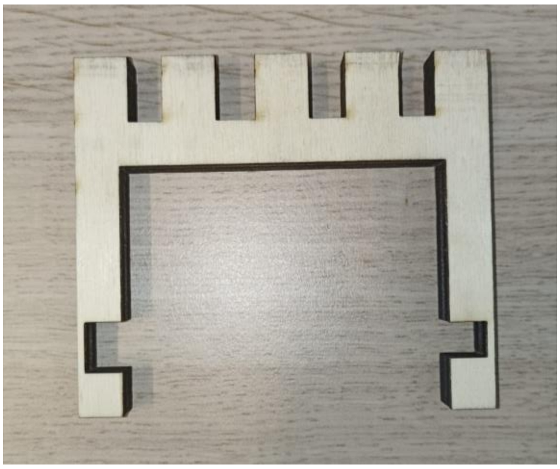


Figure 27 Inside IR sensor holder

The design that is shown in Figure 27 would have exposed wires from the IR beam sensors when they are installed. To solve this, a new design was made (see Figure 28). This design was made to accommodate the new IR sensor casings and to protect the wires. The sensor holder is built up of 3 different plates, which allows the middle of the sensor holder to be hollow. The wires can now go through the plate into the top compartment.

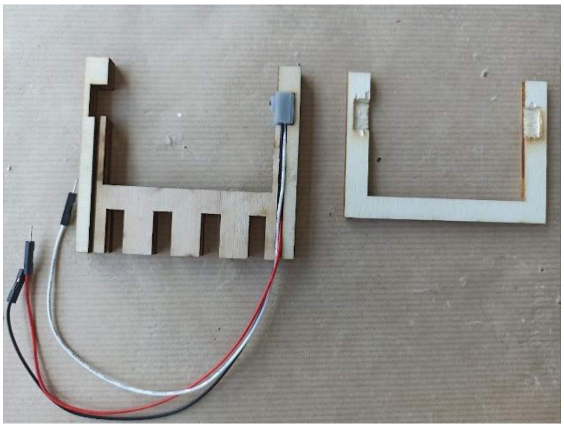


Figure 28 Final IR sensor holder

6.1.5 IR Sensor Casing

The IR emitter and receiver sensors are in relatively large casings compared to the size of the PCB. Since we want to keep the space, we use inside the nest box, as small as possible. A 3D print is made for the PCBs. A CAD model and 3D print were first made for multiple IR sensor and receivers. Later a design was made for a single IR receiver and emitter. The design of the single IR sensor holder was also changed in order to allow the wires to go through the wooden IR sensor holder (see Figure 29).

Figure 29 3D printer IR sensor casing

6.1.6 Bird Model

In order to test the system, a replica of a bird was needed. This replica does not have to be very detailed, but the dimensions should mainly resemble a great or blue tit. The bird was designed in Fusion 360 and 3D printed. The diameter of the body is 3 cm and the bird has eyes and a beak. See Figure 30.

Figure 30 3D printed bird replica

7. Evaluation

In this chapter, different aspects of the prototype will be evaluated by doing experiments and calculations. In section 4.2, requirements have been set according to the MoSCoW-method. The experiments that are covered in this chapter will assess whether the prototype meets the set requirements. Not all of the requirements are tested due to time limitations. For each experiment, the method, metric and result will be discussed. In the next chapter, the results of the experiments will be discussed.

7.1 Acceptance Rate of Birds

7.1.1 Time to Enter the Nest Box

A nest box with a prototype installed has a different appearance than a standard nest box. This may affect the willingness of birds to enter the boxes once the camera has been installed. This experiment examines if the bird enters the nest box and, if so, how long it takes when the prototype is installed.

Method

A nest box in Buitenveldert, Amsterdam, with large great tit chicks (approximately 14 days old) inside was observed during this experiment. There was a control observation period (prior to installing the prototype) and a setup with the prototype installed. In the control setup, the lid of the nest box was opened and closed. In the setup with the prototype, the lid of the nest box was opened and the prototype was placed on the nest box. The prototype did not properly fit on the nest box see Figure 31. For both setups, the time it took for the bird to successfully enter the nest box after the changes were made was observed and recorded.

Figure 31 Prototype on nest box

Metric

The time to enter the nest after changing the lid for a smart nest box module is observed and expressed in minutes and seconds.

Results

In the control setup, the bird had the first successful entry after 30 seconds.
In the setup with the prototype installed, the bird attempted to enter the nest box after 12 minutes

and 54 seconds. This was an unsuccessful entrance as the bird did not enter the nest box. The bird entered the nest box successfully after 21 minutes and 54 seconds.

7.1.2 Visitation rate

This experiment observes the influence of the installed prototype on the visitation rate (how many times it entered the box) of the bird.

Method

The same nest box with large chicks inside was observed in this experiment. The same setup was used as described above. The control setup was observed for 20 minutes, and the setup with the prototype installed was observed for 45 minutes. The difference in observed time is due to the different initial entrance times of the nest box, which is covered in the experiment above.

Metric

The visitation rate of the bird got observed, which includes the number of entries and exits at the corresponding time.

Results

The results of the experiments can be found in Table 10 and Table 10. The number of entries after the prototype was installed was lower than during the control period.

Control setup	
Event	Time (min, sec)
Entry1	0,30
Exit1	1,02
Entry2	1,35
Exit2	1,45
Entry3	3,57
Exit3	6,30
Entry4	18,43
Exit4	19,26

Table 10 Visitation rate control setup

Setup with prototype	
Event	Time (min, sec)
Attempt, no entry	12,54
Entry1	21,54
Exit1	26,5
Entry2	35,04
Exit2	35,23
Entry3	39,2
Exit3	40,24

Table 11 Visitation rate setup with prototype

7.2 Energy Efficiency

7.2.1 Power Usage

The system will eventually be powered by a battery. In order to calculate how large the battery should be, measurements should be done, which can be used to calculate this. In this experiment, the voltage and current are measured and the power is calculated.

Method

Whilst testing the system, it was powered by 2 AC/DC converters which are plugged into power outlets. The first cable plugs directly into the Raspberry Pi using a micro-USB cable, the second cable plugs into a breadboard power supply (see Figure 16) with a 5.5mm x 2.1mm plug (the breadboard power supply powers the LED strip at 5V). In order to calculate the power usage, the voltage and current need to be known. Since the system uses two power sources whilst running, it is necessary to measure the voltage and current for both these sources. The measurements are done using a multimeter whilst the entire system is running and powered.

The current is measured by connecting the multimeter directly to either the “+” or “-” wire of the power supply (see Figure 32). In this experiment, the multimeter was connected to the “-” wire. The multimeter displays the current used in the system. The voltage that is used in the system can be measured by connecting the wires of the multimeter to the “+” and “-” wires of the power supply (see Figure 33).

When the measurements are done, the power usage can be calculated using Ohm’s Law:

$$P = I * V$$

Equation 1 Ohm's law

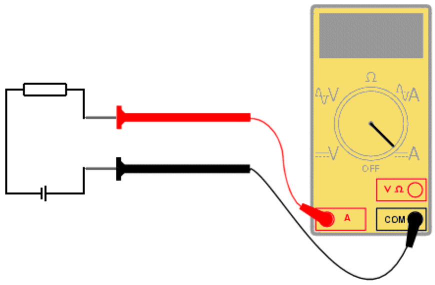


Figure 32 Setup to measure current

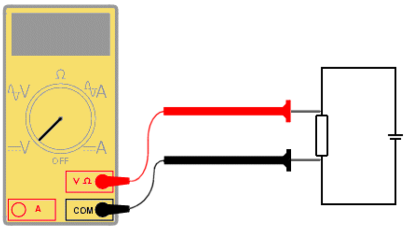


Figure 33 Setup to measure voltage

Metric

For the measurements, we are interested in the current (Amps) and Voltage (Volts). For the calculation, we are interested in power in Watts.

Results

For the cable that was connected to the Raspberry Pi, the measured voltage was 5.44V and the measured current varied between 0.35A and 0.45A. The measurements were done in two different situations; when the system was taking a picture and when the system was not taking a picture. The measurements were the same for both situations.

For the calculation, we use the highest current measurement to make sure we do not underestimate the power usage. The power can now be calculated:

$$P_{Raspberry\ Pi\ cable} = I * V = 0.45A * 5.44V = 2.448W$$

For the cable that was connected to the breadboard power supply, the measured voltage was 14.44V, and the measured current was 12mA when no picture was taken and 35mA when the system was taking a picture.

Since the current differed, which depended on if a photo got taken, the power can be calculated for these two situations.

The power can now be calculated when no picture was taken:

$$P_{breadboard\ power\ supply\ cable\ idle} = I * V = 0.012A * 14.44V = 0.17328W$$

The power can now be calculated when a picture was taken:

$$P_{breadboard\ power\ supply\ cable\ picture\ taken} = I * V = 0.035A * 14.44V = 0.5054W$$

7.2.2 Battery Usage

When the system is in use, it will have to be powered by a battery since, in most cases, there won't be a power outlet within reach. The size of the battery will be calculated in this experiment.

Method

The size of a battery can be calculated using the following formula:

$$Battery\ Capacity = \frac{Energy\ Demand\ \times Time}{DoD\ \times DC\ Voltage}$$

Equation 2 Battery capacity

There are many elements in this function for which estimations need to be made. The estimations that are made should be larger than the expected values to ensure that the battery is large enough. The estimations which are calculated are covered in the results.

Metric

The metric which is calculated in this experiment is Ah, which represents the Battery Capacity.

Result

When a photo is taken, the power consumption increases slightly and this spike in the power usage clearly takes less than a second. It is estimated that the bird enters two times every minute [30]. Therefore there is a slight peak in the energy consumption twice every minute (see Figure 34). With this information, an estimate can be made of the Watts per hour when the system is running and making two pictures per minute. This is shown below:

$P_{Raspberry\ Pi}$ = 2.448W

$P_{Power\ Supply\ Idle}$ = 0.17328W

$P_{Power\ Supply\ Taking\ Picture}$ = 0.5054W

The energy consumption per second can be calculated for two situations; when the system is idle and when the system is making a photo. The power usage is converted to the energy consumption per second by dividing the power usage by 3600. After this, the two situations can be calculated by adding the values:

$$J_{Raspberry\ Pi} = 2.448W\ /3600 = 6{,}8 * 10^{-4}\ J$$

$$J_{Power\ Supply\ Idle} = 0.17328W\ /3600 = 4{,}81 * 10^{-5}J$$

$$J_{Power\ Supply\ Taking\ Picture} = 0.5054W\ /3600 = 1{,}40 * 10^{-4}J$$

$$J_{Total\ System\ Idle} = 6{,}8 * 10^{-4}J + 4{,}81 * 10 - 5J = 7{,}28 * 10^{-4}J$$

$$J_{Total\ System\ Taking\ Picture} = 6{,}8 * 10^{-4}W \cdot s + 4{,}81 * 10^{-5}W \cdot s = 8{,}20 * 10^{-4}J$$

The energy consumption can be calculated per minute by using the values that are calculated above:

$$(58 * 7{,}28 * 10^{-4}J) + (2 * 8{,}20 * 10^{-4}J) = 4{,}39 * 10^{-2}W \cdot m$$

From this value the energy consumption per hour can be calculated:

$$60 * 4{,}39 * 10^{-2}W \cdot m = 2{,}63\ Wh$$

Time: This variable represents the time the system will run on the (to be calculated) capacity of one battery. The client mentioned that, ideally, the system would run for two weeks. Since this may differ and to account for a buffer, we set the expectation to 3 weeks which is equal to 21 days. Next to this, it is expected that the system only runs during day time. The day with the most daylight is the 21st of June (in the Netherlands), with about 16 hours of light. The hours can be calculated by multiplying the number of days by the number of hours the system is used per day:

$$Time \;=\; 21 * 16 = \; 336h$$

DoD: The depth of discharge is the percentage of the battery that can discharge without causing damage to it. This differs based on the type of battery. If a portable charger is used, the DoD should be 100% since there is a control board in this system. This is the value we will use as we expect to be using a portable charger.

DC Voltage: The voltage that the Raspberry Pi and LED strip require is 5V. Most portable chargers that are designed to charge smartphones output 5V. Therefore the value chosen here is 5V.

All the values required by the formula are known. Thus the battery capacity can be calculated:

$$Battery\ Capacity = \frac{Energy\ Demand\ \times Time}{DoD\ \times DC\ Voltage} = \frac{2{,}63\ Wh\ \times (21 * 16)}{1{,}00\ \times 5} = \ 884{,}46\ \text{Ah}$$

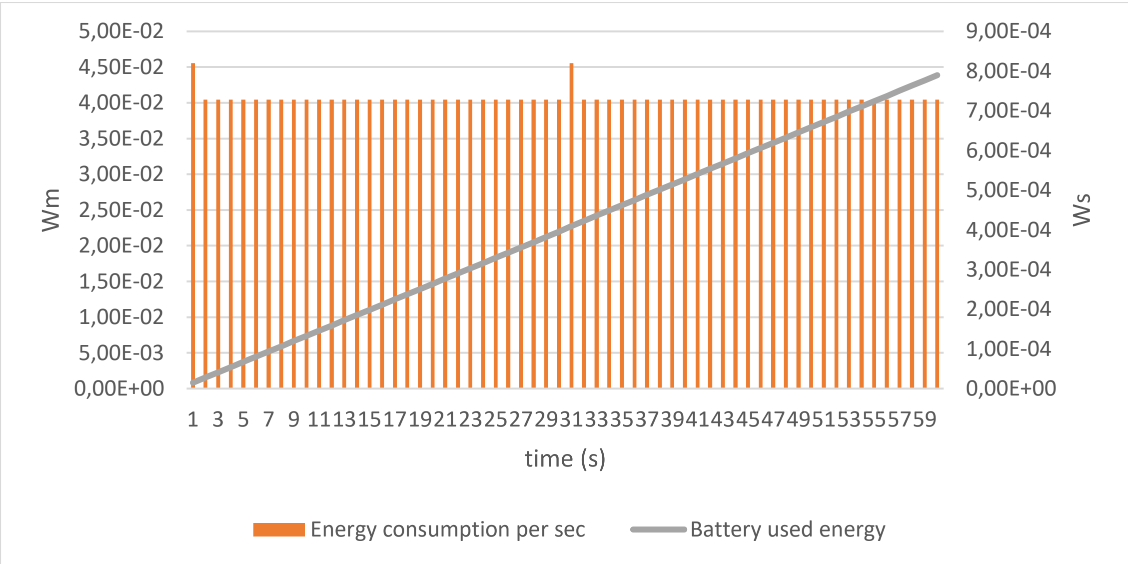


Figure 34 Power consumption during 1 minute

7.3 Lens

7.3.1 Camera Minimal Focus Distance

From the background research, it became clear that the Raspberry Pi HQ Camera Module was a valuable option. This board allows different types of lenses to be connected to it. Two lenses have been investigated since they both seemed to be suitable lenses to use in a smart nest box. The lenses were a 6mm lens and a 16mm lens. The minimal distance of these lenses is compared in this experiment

Method

The camera module was set up with a lens in a normal daylight situation, to which the aperture was set. The camera was placed at a set location on a tripod and an object was placed in front of the camera with plenty of space in-between for the camera to focus (about half a meter). The object was moved closer to the camera bit by bit and the focus of the lens was manually adjusted. This was done until the lens was not able to focus anymore. This experiment was done with both lenses.

Metric

This experiment tests the minimal focus distance, which was measured in cm.

Result

The 6mm lens had a short minimal focus distance of 5 cm, whilst the focus distance of the 16mm lens was 32 cm. The results can be seen in Figure 35 and Figure 36, respectively.

Figure 35 Picture from 6mm lens (5 cm distance)

Figure 36 Picture from 16mm lens (32 cm distance)

7.4 Data Quality

7.4.1 Sharpness Estimation for Document and Scene Images

In order to review the images that are made by the smart nest box system, they should be quantified. In this experiment, a range of images will be quantified based on sharpness.

Method

J. Kumar et al. [31] have developed a method that can predict sharpness based on camera motion, defocus or inherent properties of the imaging system. The method performs well on document images and natural scenes. In this experiment, the method is tested on eight images that were taken in the nest box when the 3D-printed bird was inserted. The images are ordered on sharpness, with picture one being the sharpest and picture eight being the blurriest. We expect that the metric score will reflect the ordering. To get a better understanding of the results, the scores are also normalized using feature scaling. The images that are used have been manually ordered and chosen from the 7.5.1 IR Beam Sensor Reliability experiment, which is covered below. The images can be found in Appendix A5.

The images are imported in a python program (see Appendix A6), and the program is run. The program prints the results of the accompanying images.

Metric

The method quantifies the images by "deriving a measure that captures whether the slope changes quickly, a characteristic of sharp edges. We propose to use difference of differences in grayscale values of a median-filtered image (ΔDoM) as an indicator of edge sharpness"[30, p. 2].

Results

The results of the method are shown below, with the first row representing the number of the image the second row representing the corresponding score and the third row being the normalized data of the second row (see Table 12). The score ranges from 0, representing the blurriest image, to 1, representing the sharpest image.

Image	Score	Min-Max
1	0,889231	0.5766
2	0,892857	0.7035
3	0,893587	0.7290
4	0,886076	0.4662
5	0,901332	1.0000
6	0,891446	0.6541
7	0,87275	0.0000
8	0,887772	0.5256

Table 12 Score of sharpness estimation for document and scene images

The data can also be found in the graph below (see Figure 37):

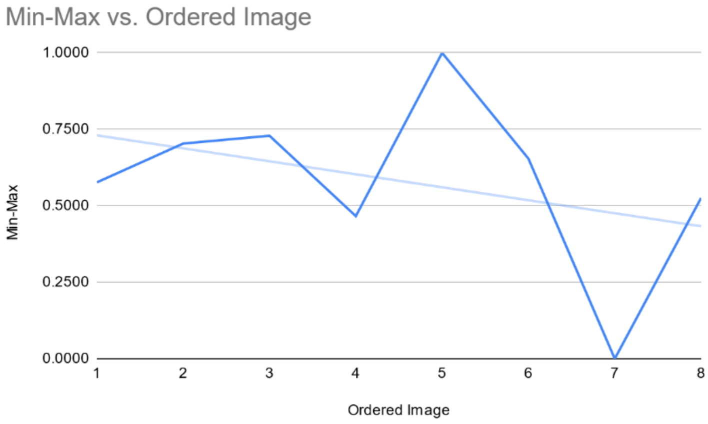


Figure 37 Graph of sharpness estimation for document and scene images

7.4.2 Estimate Strength of Blur

Similar to the previous experiment, this experiment quantifies the blur. F. Crete et al. [32] have developed a method to quantify the blurriness of an image without the need for a reference image. Moreover, F. Crete et al. have noted that “tests show the robustness and the ability of the metric to evaluate not only the blur introduced by a restoration processing but also focal blur or motion blur” [31, p. 2].

Method

This experiment is similar to the previous experiment, which is covered above. There are eight images that are ordered from sharp to blurry. Image 1 is the sharpest and image 8 is the most blurry (see Appendix A6). The images are imported in the python program (see Appendix A7) and the python program is started. The program prints the results and also produces a graph. The results are normalized using feature scaling and can be found in Table 13

Metric

F. Crete et al. obtain “a no-reference perceptual blur estimation blur_$_F$ ranging from 0 to 1 which are respectively the best and the worst quality in term of blur perception” [31, p. 6].

Results

The normalized scores of this experiment can be seen in Table 13 and Figure 38.

Image	Score	Min-Max
1	0,43641	0.5140
2	0,42645	0.0000
3	0,429206	0.1422
4	0,439903	0.6943
5	0,43508	0.4454
6	0,430025	0.1845
7	0,445827	1.0000
8	0,432798	0.3276

Table 13 Score of estimate strength of blur

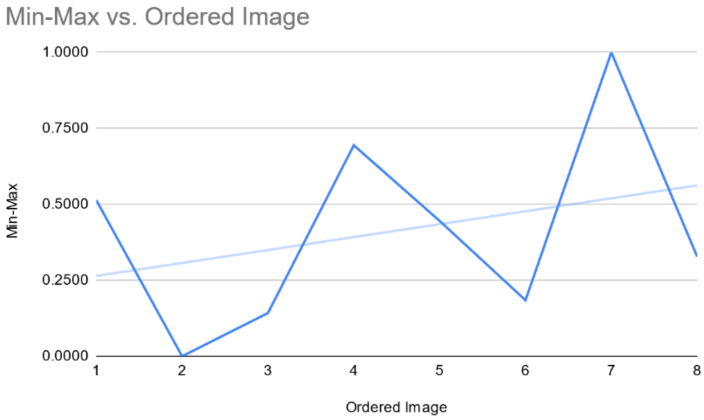


Figure 38 Graph of estimate strength of blur

7.4.3 Data Quality Tests with Cropped Images

Method

The test that have been run in section 7.4.1 and 7.4.2 have been done again with the same images that have been cropped. The sides of the images have been cropped, which removes much of the background which is not interesting for this test. The cropped images can be found in Appendix A6.

Metric

The same metrics are used as in the previous two experiments:

The method quantifies the images by "deriving a measure that captures whether the slope changes quickly, a characteristic of sharp edges. We propose to use difference of differences in grayscale values of a median-filtered image (ΔDoM) as an indicator of edge sharpness"[30, p. 2].

F. Crete et al. obtain "a no-reference perceptual blur estimation $blur\_{_F}$ ranging from 0 to 1 which are respectively the best and the worst quality in term of blur perception" [31, p. 6].

Result

The results can be seen in and

Image	Score	Min-Max
1	0.94645	0.96047
2	0.94780	1.00000
3	0.93262	0.55671
4	0.93551	0.64120
5	0.92680	0.38693
6	0.92203	0.24785
7	0.91354	0.00000
8	0.92492	0.33211

Table 14 Score of sharpness estimation for document and scene images with cropped images

Figure 39 Graph of sharpness estimation for document and scene images with cropped images

Image	Score	Min-Max
1	0.44503	0.40256
2	0.42307	0.00000
3	0.45418	0.57040
4	0.45628	0.60889
5	0.47761	1.00000
6	0.46095	0.69449
7	0.47434	0.93998
8	0.45333	0.55483

Table 15 Score of estimate strength of blur with cropped images

Figure 40 Graph of estimate strength of blur with cropped images

7.4.3 Combined Sharpness Estimation and Strength of Blur

The results of the programs that have been used to evaluate the quality of the data can be combined to get an average of the two methods.

Method

The normalized values that were obtained by the Sharpness Estimation and Strength of Blur for each picture are summed. The normalized values of the blur estimation are inverted. This is done to make sure the normalized values have the same order, with 0 being the blurriest and one being the sharpest.

Metric

The scores can range from 0 being the blurriest to 2 being the sharpest image.

Result

The results of the experiment can be found in Table 16 and Figure 41.

Image	Normalized Value of Sharpness Estimation	Inverted Normalized Value of Strength of Blur	Combined Normalized Value
1	0,5766	0,486	1,0626
2	0,7035	1	1,7035
3	0,729	0,8578	1,5868
4	0,4662	0,3057	0,7719
5	1	0,5546	1,5546
6	0,6541	0,8155	1,4696
7	0	0	0,0000
8	0,5256	0,6724	1,1980

Table 16 Combined normalized value

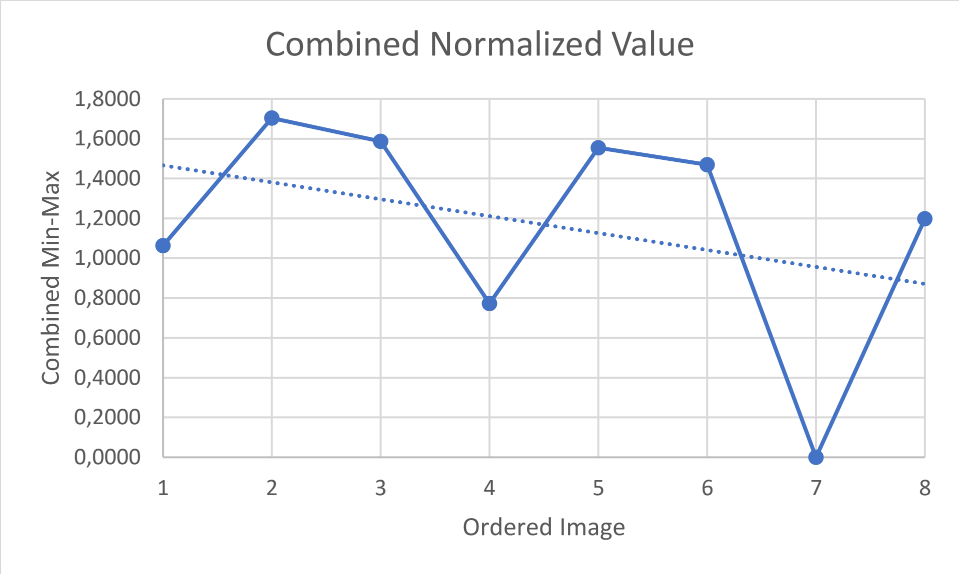


Figure 41 Combined normalized value

7.4.4 Manual Sharpness Review

In this experiment the sharpness of 50 pictures is reviewed.

Method

The 50 pictures, that got captured in the experiment that is covered in section 7.5.1, are reviewed one by one. A picture can fall in two categories: sharp or blurry. The amount of sharp pictures is divided by the total amount of pictures that are reviewed. This number resembles the percentage of sharp pictures. A sharp image is defined as an image where you can clearly see the beak and eyes of the 3D-printed bird and where there is no major movement blur.

Metric

The metric in this experiment is the percentage of sharp pictures.

Result

The amount of sharp images is 32. The total amount of pictures is 50. The percentage of sharp images is calculated:

$$\frac{32}{50} = 0.64 = 64\%$$

The percentage of sharp images from this series of images is 64%

7.5 IR Beam Sensor

7.5.1 IR Beam Sensor Reliability

There were many different IR sensor setups which are covered in the 6. Realization chapter. In this experiment, we test the final IR Beam senor setup, which is located in the nest box (see Figure 28).

Method

The smart nest box was fully assembled and installed on the nest box. The code that was running on the smart nest box was very similar to the standard code but slightly changed. The program would comment “beam broken” every time the IR sensor observed the beam was broken. The code can be found in Appendix A8. During 15 minutes, the 3D printed bird model is inserted and pulled out of the nest box entrance 50 times. The time interval between each removal and insertion is at least 5 seconds. This is because the program checks if the bird is still blocking the IR beam 5 seconds after the photo is made. If that is the case, no photo is made.

Metric

This experiment tests whether the sensor is reliable. The metrics to judge this are precision and recall. From the test results, we can have four different types of observations which are stated below:

True positive (tp): The bird is inserted in the nest box and at that time 'beam broken' is printed.
False positive (fp): The bird is not inserted in the nest box, but the program prints 'beam broken'
True negative (tn): The bird is not inserted in the nest box and the program does not print 'beam broken'
False negative (fn): The bird is inserted in the nest box, but the program does not print 'beam broken'

Precision and recall can be calculated by the following formulas:

$$Precision = \frac{tp}{tp + fp}$$

Equation 3 Precision

$$Recall = \frac{tp}{tp + fn}$$

Equation 4 Recall

Precision is the fraction of relevant instances among the retrieved instances.

Recall is the fraction of relevant instances that were retrieved.

Result

During the test, there were 50 print statements, each of which was printed directly after the bird was inserted. We can thus conclude that:

$$\begin{aligned} tp &= 50 \\ fp &= 0 \\ tn &= unknown \\ fn &= 0 \end{aligned}$$

From this data the precision and recall can be calculated:

$$Precision = \frac{tp}{tp + fp} = \frac{50}{50 + 0} = 1$$

$$Recall = \frac{tp}{tp + fn} = \frac{50}{50 + 0} = 1$$

7.6 Light

7.6.1 Amount of Light in the Nest Box

In this experiment, we test the amount of light in the nest box. There is a LED strip installed in the smart nest box, which is facing the entrance of the nest box. The LED strip consists of 5 LEDs which are individually programmable

Method

In this experiment test different setups with the LED strip. Since the LED strip is programmable, we can adjust the color of each individual LED and turn them on or off. The LEDs are set to emit light that resembles daylight (150, 150, 60). The smart nest box is installed on the nest box and the system is closed as it would be when it is in actual use. A live preview of the camera is shown on an external monitor and the number of LEDs that are on are changed. We test the use of 1, 2, 3 and 5 LEDs which are on (see Table 17).

Setups	LEDs				
1 LED on			■		
2 LEDs on	■				■
3 LEDs on	■		■		■
5 LEDs on	■	■	■	■	■

Table 17 LED strip setup (Black is on)

Metric

Initially, we wanted to measure the amount of light in the nest box with a lux-meter. The client, however, mentioned she had bad experiences with lux-meters. Therefore she recommended to judge the light in the nest box ourselves.

Result

From the test, it becomes clear that the number of LEDs that are on does not affect the image quality significantly. Slightly more details can be seen when the 3 or 5 LEDs are on (see Table 18).

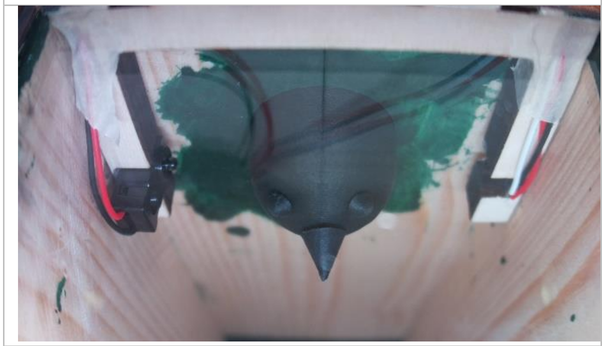
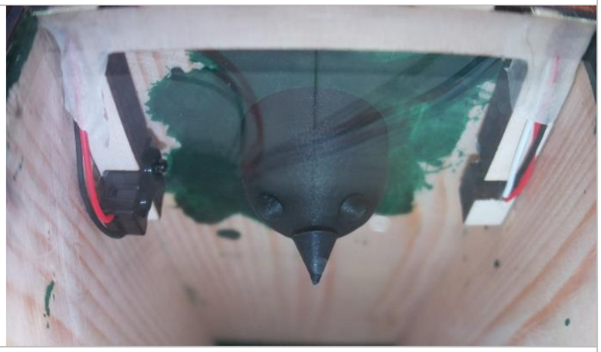
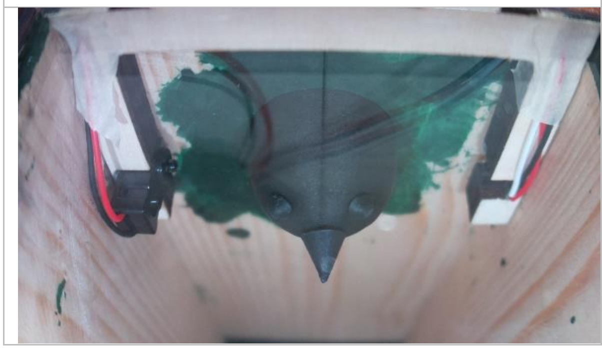
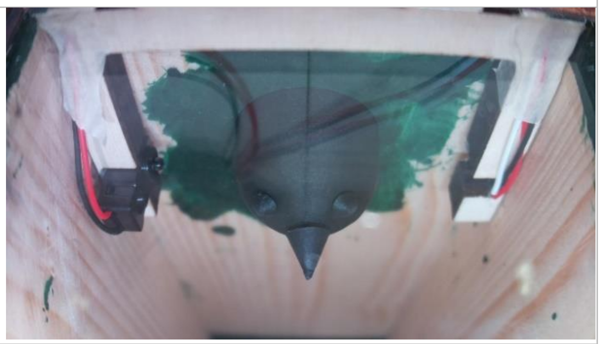
LED Test (150, 150, 60)	
1 LED on	2 LEDs on
	
3 LEDs on	5 LEDs on
	

Table 18 LED test results

8. Discussion & Future Work

In this chapter, the results of the experiments that are covered in chapter 7 will be discussed. Next to this, the overall design and performance of the system will be discussed. Based on these insights, recommendations for future work are made.

8.1 Discussion

8.1.1 Acceptance rate of birds

The two experiments that were done regarding the willingness of the birds to enter the nest boxes when the prototype was placed on top showed promising results. The number of observations that were done in the experiments was very limited. Therefore no real conclusions can be made. Once the bird successfully entered the nest box with the prototype, the time between entrances with the prototype was not that different from the control period. This can be interpreted that once the bird got over its initial fear of the prototype that was installed, it behaved fairly normally.

8.1.2 IR Sensor

The IR beam reliability experiment that was covered in section 7.5.1 had promising results as the precision and recall were both 100%, which is the highest possible value. This indicates that the IR beam sensors in their current setup are a reliable way to detect entering objects. It must be said that this is an approximation since the experiment is not tested on a real bird. Another important metric of the IR beam sensor is the response time. From the 50 pictures that got taken, the position of the bird differed. An example is given in Figure 42 and Figure 43. The difference in the images can be explained by three factors. Firstly, it is possible that the bird got inserted at different speeds in the two situations. Secondly, it is possible that the response time of the IR beam sensor differs. This would mean that the bird could be inserted with the same speed, but a different photo is taken because of the varying response time. Lastly, it could be the case that the IR beam sensor has a constant response time, but one of the other components that are used when making a picture has a varying response. This could be the case for the Raspberry Pi and/or the camera.

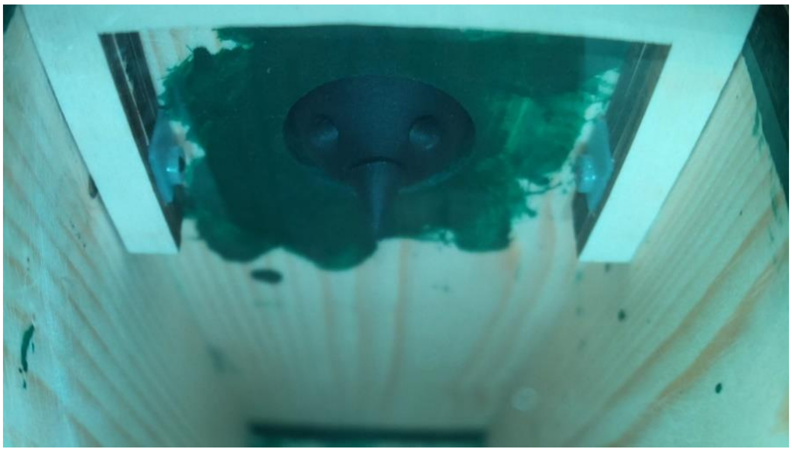


Figure 42 Bird in entrance

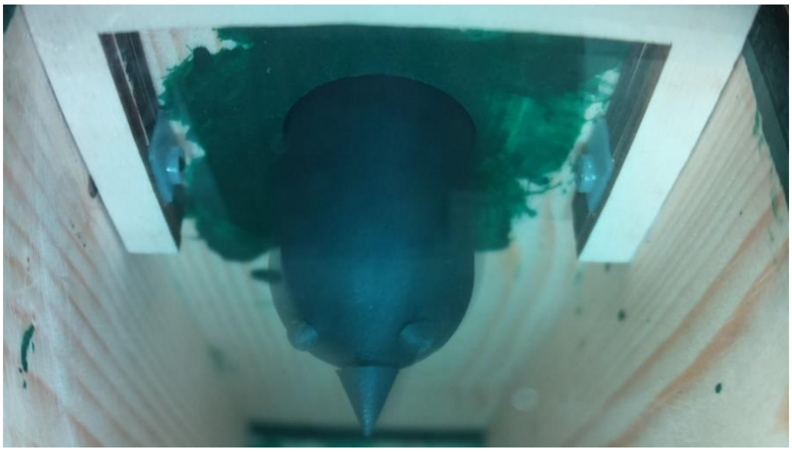


Figure 43 Bird in nest box

8.1.3 Power Usage

The results from the 7.2 Energy Efficiency experiments showed that the system used 7,7Ah when running for 16 hours. The power usage is quite large since the client mentions she wishes that the system would run for a week or more without replacing the battery. The energy usage is higher than expected since the task the system does is relatively simple. The Raspberry Pi that is currently used is a great tool for prototyping but may be too overpowered for this system, thus consuming more energy than required.

8.1.4 Image Quality

The image quality tests that were done with the images that were not cropped cannot be used to quantify the quality of the images with much confidence as the scores of the tests are all very similar. Next to this, the normalized scores also do not show a strong relation to the quality of the pictures. This is also the case when the normalized scores of the two tests get summed. The results of the images that were not cropped are considered unreliable.

At the end of the project the image quality tests were done again with the same pictures, but they were cropped. The bird in the image is now a significantly bigger part of the image. The results with the cropped images showed more promising results. This is especially the case for the results of the sharpness estimation test as the trendline has a steep angle, which shows much difference is observed between the blurriness of the pictures.

The images that have been made in the 7.5.1 IR Beam Sensor Reliability experiment are not all equally sharp. Some images seem to be blurry since the 3D-printed bird was still moving whilst the picture got taken. From the manual sharpness review experiment (section 7.4.6) it became clear that 64% of the images was considered sharp. It must be said that this reviewed by a single person, so the judgement is not totally objective.

8.1.5 Camera setup

In the final stages of the Ideation phase, there was an idea to have three cameras installed in the system. The reason for this was to obtain an image of the prey from multiple angles to make it easier to classify the prey species. There is a camera extension board that allows multiple cameras to be attached to a single Raspberry Pi board. An attempt was made to use this, but eventually this was not done due to software problems. A connection was established between the camera and Raspberry Pi via the extension board. However, there were software problems regarding a library (libEGL). Because of time constraints, this could not be fixed. In hindsight, this may also have been a better choice when considering power usage. The power usage of an individual camera was not measured and could also not be found in datasheets, but it is expected that having two extra cameras in the system will increase the power usage significantly.

8.1.6 LED strip

The LEDs on the LED strip that is used in the smart nest box are individually addressable. This implies that each LED can individually illuminate a color on the RGB spectrum and can be turned on or off. This is ideal for prototyping since different setups can easily be tested. The downside of this LED strip is that it uses relatively much power compared to other LED strips.

8.1.7 Materials

The prototype that has been built is made with materials for rapid prototyping. The compartment is made from 10mm poplar plywood, which is laser cut to exact dimensions. This is a soft wood that is generally not meant to be used for outside use. It may degrade quickly due to the elements.

8.1.8 Testing the system with an actual bird

In order to test the system, experiments were done using a 3D printed bird and inserting this prop in the nest box by hand. This was an easy and fast method to test the nest box however, this method of testing does not precisely resemble how the system would actually be used by birds. Therefore the results and conclusions that are made from the experiments can be used to get insights on how the system functions and to improve this.

8.1.9 Software

The software that runs on the Raspberry Pi seems to work well. The downside is that the software has to be manually started, which requires a keyboard, mouse and screen. When installing the product on a nest box that is in use, this is not ideal.

8.2 Future Work

From the discussion, it has become apparent that there were multiple aspects that could be improved or required more research. In this section, a proposal is made for the future steps of the project.

When doing bird acceptance rate experiments, it became clear that the prototype did not fit on the next box. This is because the dimensions of the nest boxes that get used for research slightly differ. A different design should be made to ensure the prototype always fits on the nest boxes. This can be done by making the sleeve that is attached to the compartment slightly larger (longer and wider), so it fits over the largest nest box. If this is done, the nest box will fit over all the nest boxes and the sleeve can be securely attached to the nest box using wood screws.

The prototype is made from popular multiplex wood, which is a soft wood that may degrade quickly due to the elements. If this wood is used in the final prototype, it should be treated in order to make it resistant to the elements. The IR sensor holder is located in the nest box and is covered by the same wood. From the interview with WMS and meetings with the client, it became clear that the birds may pick at unusual objects in the nest box, such as a camera. All the electronics are enclosed in a different compartment which the bird can’t reach except for the IR sensor holder. This is located in the nest box, so it could be picked at by birds. Replacing this part with a tougher material may be necessary when testing the product with real birds. It should also be said that the electronics inside the smart nest box are connected using breadboard jumper wires and breadboards. For prototyping, this is ideal since connections can easily be changed; however, it is not as reliable as soldering the connections. When a final product is made, the connections should be soldered to make their connections more reliable. The size of the compartment can also be reduced if no extra cameras or components are installed.

When changes are made to the nest box’s sleeve, the bird acceptance rate experiments can be done with the prototype properly installed on the nest box, as this was not the case in the previous experiments. Next to this, the experiments had very little data. Therefore, it was not possible to make real conclusions. These experiments should be done again and more data should be gathered in order to make reliable conclusions.

The prototype should get tested in its actual environment. This can be done by installing the prototype on a nest box that birds are nesting in or by installing the smart nest box and waiting for birds to nest in that nest box. When running the system, this will give much insight into how the system functions and may lead to new problems or insights which have not been considered. The IR beam reliability and image quality can also be tested when the prototype is installed on a nest box with actual birds that enter. Then it can be seen if the results are similar to the initial experiments. Before testing the system with real birds, it should be reviewed by experts from the field to see if the nest box will not harm the birds.

When reviewing the images that the camera captured, it became apparent that the quality is not consistent as some pictures are blurry whilst others are blurry. Generally speaking, the image quality can be improved by increasing the shutter speed. When this is done, however, the amount of light also has to be increased, which may harm the comfort of the birds. Another option is to increase the F-value of the aperture, which makes the image darker. Again this requires a bright environment which is not ideal. An alternative could be to make a short video (1-3 seconds) and analyze the video to find the sharpest frame. It may even be possible to combine multiple frames to make a sharp image. When recording a video, the amount of data is much larger. Therefore, the chance that there is a sharp image is also increased. The downside, however, is that there is limited data that can be stored, but opposed to continuous video (which is used in other monitoring nest boxes), it is significantly less data. It is also possible that the image quality is sometimes blurry because a component has a varying response time.

It is advised to investigate if the components have varying response times. If one or multiple components have a varying response time, this will make the system less reliable as the time that the data gets captured differs. The component or components with a varying response time could be replaced with components that do not have a varying response time.

The software should run when the system is powered. Currently, the software has to be started by using a keyboard and mouse. In addition, the system should only run when it is light outside. A library called sunwait can be used to achieve this. The coordinates of the nest box's location have to be set and a RTC clock has to be connected to the Raspberry Pi. When this is done, the script can run and stopped automatically when the sun rises and sets, respectively.

Once improvements are made to the prototype, an additional improvement could be to make the product more energy efficient. Three methods are proposed to achieve this. Firstly, by making a custom processor that is optimized for the specific task and replacing the Raspberry Pi with this. This is similar to the setup of Kubizňák et al. [20]. It must be said that their system is constantly powered by Power over Ethernet. So their system may not be very energy efficient. A second option would be to use a Raspberry Pi, which is less powerful and more energy efficient than the one that is currently being used. For example, the Raspberry Pi Zero 2 W, that has all the necessary connections which are required to build the system that currently is being used. The third option would be to attach a solar panel to the system, which can charge the battery. This has also been done by El Bouanani and Ayoub [15] and McBride and Courter [19].

The LED strip can also be replaced with other types of LED strips to decrease the power usage. An overview is given in Table 19.

LED strip	Power usage per LED	Pros	Cons
NeoPixel LED strip [33] (currently in use)	0,3W	Individually programable LEDs	Relatively high power usage
RGB LED strip [34]	0,23W	Color of LED strip can be changed	Individual LEDs cannot be turned on or off
Warm white light LED strip[35]	0.07W	Low power usage	Color cannot be changed and individual LEDs cannot be turned on or off

Table 19 LED strip alternatives

The prototype is capable of gathering the data and saving this to the Raspberry Pi. The prototype designed in this work is highly suitable to extend with edge intelligence. An algorithm can be run locally to analyze the images in the nest box. A different type of microprocessor will most likely have to be used, which is designed for such tasks. An example of such a microprocessor is the Google Coral DEV Board Mini 2 GB 4 x 1.5 GHz, which was also covered in the technical review.

9. Conclusion

This project was undertaken to design an optimal smart nest box and to evaluate it. In order to find out what an optimal smart nest box is, sub-questions were established to define the requirements and components needed to build the smart nest box. The overall goal was to design a smart nest box that is capable of capturing high-quality and precise data. From the background research, the most important lesson learned related to the requirements was that there is a trade-off between what birds accept and the quality of the data. Next to this, the most important requirements were that the system functions fast, reliable and that the system produces high-quality data. High-quality and precise image data can be obtained by having a high-quality camera, good lighting conditions and an accurate trigger. In order to make sharp images, the photo must be taken quickly, which requires the camera's shutter speed to be fast and the F-value of the aperture to be low. These types of settings, however, require much light, which may not be ideal for the comfort of the bird. The study has shown that the components needed to build an optimal smart nest box are a microprocessor, camera, detection method and a LED strip. This can be confirmed by the smart nest boxes that Prinz et al. [16] and Hereward et al. [17] designed.

This study has identified what defines an optimal smart nest box and a prototype of a smart nest box has been made. The prototype is able to detect when an object enters the nest box in a consistent matter. A limitation of the current system is that the quality of the data is not consistent, meaning that the images that get taken are sometimes in focus but other times blurry. Next to this, the system's power usage is relatively high.

Based on these conclusions, the system can be improved by changing the data capturing method. As mentioned in the discussion, this could be done by recording a short video and letting a program analyze the frames to find the sharpest frame instead of making a single picture. It would also be beneficial for the size of the battery capacity to make the entire system more energy efficient.

From the research that has been done, it has become clear what the requirements of an optimal smart nest box are. A well-functioning prototype has been made, which can easily be modified to make improvements for future work.

Appendix

A1 Interview Notes WMS

Trigger sensing: In many wild cameras PIR sensors are used. These are very energy efficient, but are not extremely fast in detecting movement. This may be a problem for the functionality of the system as the camera may start recording/ taking pictures too late. Nest box cameras are usually constantly filming and when a change in the pixels is detected an event is added at that moment. By doing this you won't miss data when something happens in the nest box. This method works but consumes a lot of data. If there is a sensor with a quicker reaction time this would be ideal. Idea: laser sensor just outside of the box.

Nowadays the reaction time is about 0.1 - 0.2 seconds when using a PIR sensor before a picture is taken. Back in the day this was 0.8-0.9 seconds. We should try to keep the reaction time as low as possible. Keep this in mind when searching for sensors.

LoRa, free network to send small amounts of data. Possible use send text file containing info to user for free. Example: a blue tit has entered nest box 3.

In the current nest box WMS sells there is a hole in the side (about 8 cm diameter) with a piece of plexiglass over it to let in light for the camera. Not much research has been done about this by WMS, they used the design of their supplier.

WMS has not experienced much problems with water damage. The times they did the wire from the camera left the nest box going upwards. This resulted in water leaking in via the wire.

WMS is using nest boxes that are 30 cm high at the back of the box. If the box is a bit smaller, say 2 cm, this is no big deal. But if the boxes are 20 cm high and a camera is mounted inside of a nest box, it is very unattractive for the birds. Possibly a camera could be mounted on top of the nest box with the lens through the box, however this may lead to issues with waterproofing and robustness.

Interesting to look into the power supply of the system. For their nest box camera's 12V 20Ah battery with 30 Watt solar panels suffice. For components and info regarding power supply, camping suppliers can be helpful.

Good to talk to security companies and experts on great and blue tits. Do these birds hunt during night time, if not should we focus on filming at night?

Idea from WMS. Having one AI processing unit surrounded with multiple nest box cams that send data to it. This will drastically reduce the costs compared to having a AI processing unit in each nest box.

A2 Interview Notes Marcel Visser and Christiaan Both

Meeting:

ARISE Nestbox Cameras

Date:

8 March 2022

Participants:

Daniel Kissling, Rotem Zilber, Emily Burdfield-Steel, Marcel Visser, Jacob Kamminga, Thijs Bianchi, Jesse Visser

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Aim: to facilitate an exchange between biologists who work with nestbox cameras and Jacob's team in Twente who is developing cameras for nestboxes. What has been done in the field and how we can connect it to innovation of nestbox cameras.

Christiaan's experience with nestbox cameras for diet analysis: *(presented by Daniel)*

- Nests are moved from original nestbox to a new box, in order to place a camera and LED lights for a few hours to gather data. A trigger by the entrance indicates to the camera when a bird is coming in. It is important to make a distinction between single prey loaders (one item of food), like a tit, vs. multiple prey loaders (multiple items of food) like flycatchers.
- Christiaan and his team have been going through all the images manually and noting down the number of items they see, and if they can, the species or at least the higher level taxonomic group they belong to. They have many images with information, but not annotated in the sense that annotations are assigned to a specific item. They use an access database to record information such as prey type and size estimate (length of prey item relative to width of the beak).
- Challenges for AI: difference between species and behaviors (single vs. multi prey loaders), quality of images (e.g. blurry), prey is often damaged or located strangely in beak, and taxonomic assignment, you can always get order, but family, genus and species is often not available.
- Challenges for hardware: the trigger at the nestbox entrance works well. The nestboxes do not fit the camera; the nest needs to be moved to a new box for the time the camera is in place. The camera can be noisy which can cause issues with birds accepting it. The light source does not seem to be a major problem for a few hours, but will likely be if it is a permanent fixture. The cameras are placed when the babies are ~4 days old, when they really need their parents. The birds did not like flash. Christiaan is also interested in the colors of the prey items, so infrared flash might not be the best option. There is a trade-off between what birds accept and the quality of the images.
- Ideal system: fits in a normal nestbox and is silent. Prefers photos over videos because videos take a lot of time. Either you have a high quality image or not, but you don't have to spend hours looking through it.

Marcel: to some extent we use Christiaan's system as well. We only have a few of these cameras as they are expensive. It is also a lot of hassle to replace a nest etc.. The birds are eager to come in and feed their young, so you can fiddle around a bit without them deserting it. We also use the small spycameras, which we place in the lid of the nestboxes, usually for a few days at a time. You still need to go there every day to change the batteries and empty the SD card. The birds do not realize something has changed with the spycameras. However, the spycameras have bad resolution, look at birds from the top rather than from the front (which is better), and the light is also an issue.

Emily: I tried out a spycamera that you put on the top of the box. They worked for about a day, not amazing quality but not terrible. Light was an issue. If the birds quickly give the chicks food you cannot see what is happening. The commercial cameras that are supposed to be wifi enabled do not play well with wifi, so you still need to physically change the memory cards. In addition, I couldn't adjust the length of the video. They took 5 minute videos every time they detected movement. The wifi cameras were meant for use at ARTIS, not natural settings. I think images would be easier to handle than videos.

- **Jacob:** better to shoot a burst of images, so at least you can choose a good one and throw away the rest.

Jacob: on our end, I tried to make priorities. The first step is to go to pre processed high quality data. So filter out blurry images, that is already helpful. The trigger works nicely, so that is something we can continue to build on. The next goal is to cut out the beak with the prey in it. The long term goal is to have some processing on board.

Jesse: I will be looking at AI solution, to: (1) detect if there is a bird in the image and what species of bird, as well as if it has prey. Hopefully also what the prey is for single prey loaders, but either way it will narrow down the number of images you need to manually scroll through and classify. (2) do these things on site via a small microcontroller or computer in the nestbox so you don't have to send all data, but only what is relevant. I will also be looking into a small system that if you have any amount of image or video data, it can detect which frames are useable. I need to make sure the cameras do not get too hot etc., so even just getting the data from the camera is helpful.

- **Jacob:** for example, we can have an algorithm in the nestbox that already removes blurry images.
- **Daniel:** issues with sensor temperature?
  - **Jesse:** if raspberry pi, constrained which processing you can do. If we go into more purpose built processors we will need active cooling like a fan which can be noisy.
  - **Marcel:** the computer doesn't need to be inside the nestbox, it can be on the outside. In such a case the fan should be less of an issue.

Jacob: Thijs will focus more on the design. Ideally we want a prototype by the end of the project (end June). I don't think it will be in time to run for the whole nesting season, but the idea is to make something portable that can be fitted to existing nesting boxes. Emily already sent a few nestboxes to look at.

- **Daniel:** that means the camera will not be placed from the back but from side or top.
- **Emily:** phone camera could fit in the back
- **Marcel:** nestbox not directly to the tree, there is a piece between, and there is room. But the camera cannot be in the center, but it can be in the back on the side. Not good if the camera directly faces the entrance hole, as it will constantly need to adjust to the change of light.
  - **Jacob:** 45 degree angle good? (Marcel: not sure)

        - **Thijs:** you'd need a camera that is either quick to react to the light being blocked off by bird, or set settings.

Jacob: it is up to Jesse and Thijs to talk to Marcel and Christiaan to investigate the different options. Another option is to e.g. place 6 cameras in an arch to take a 3D.

- **Daniel:** energy consumption of using so many cameras?
    - **Jacob:** it can become an issue, but the biggest problem is the annotation. Annotation is ideally done on a lot of images at once. At the moment I wouldn't worry about energy consumption, first lets see what solution works best. The biggest challenges will be the birds accepting the sensors and getting good quality data.
        - **Marcel:** the light is the biggest issue there- the birds don't like so much light long term in the nestbox.

Daniel: what are your thoughts in terms of the light? With infrared you will not get colors in the images right?

- **Jacob:** we discussed that the birds only get prey during day time and I saw some nestboxes with windows, do they accept those?
    - **Marcel:** we haven't tried it. birds would normally breed in cavities in trees, so it could possibly work.
    - **Thijs:** also talked with Lennart Suselbeek from Wildlife Monitoring Solutions. He sells nestboxes with plexiglass windows of 3 cm diameter that let in light. They didn't experiment with the size and how much light it lets in, but birds definitely nest in it.
        - **Daniel:** it may also depend on the species, some may accept it and others not.
        - **Marcel:** the question is a little bit what happens if you switch nestboxes to one that has light in it, we can easily try it out. However, I'd be hesitant to move to it because we used closed ones for many years. You don't per se know what you are changing- e.g. the birds maybe lay less eggs. So we would not be keen on a new standard nestbox. Switching things for a day or two is ok, but as a standard having a new nestbox is not likely to happen. Additionally, in the Netherlands it can be dark on a cloudy day, and the camera needs a high amount of light.
    - **Daniel:** Christiaan's system worked well because they focused on such a short time. In that period they have led lights which makes them not care as much and leaves them relatively undisturbed. The question is if you have it from the beginning, will they accept such a nestbox when you have one next to it that is completely dark?
    - **Jesse:** what about a modified lid with a camera facing the entrance that can be fitted on the existing nestboxes? Even for a couple of days?
        - **Marcel:** yes, it is easy to put lid on or off. However, the nestboxes are all hand made. Therefore, there is not a single one that is the same as another. It makes it a bit challenging. Sometimes you have a lid that fits 3 nestboxes but not the 4th. So good to be aware that they vary. In addition, the type of wood can vary, so while the external dimensions are similar, the wood can be different thickness which changes the inside.

        - **Daniel:** in general if you focus on long term monitoring, you don't want to change nestboxes because of long term time series, but for other applications with new research that are not as long it is not necessarily a constraint.
            - **Marcel:** we just started a new area where we look at the eikenprocessierups. That is an interesting project to try different boxes. The question is to what extent they are eaten by great tits.

Jacob: we are thinking about a modular system that can fit to an existing box and a new box. For consistency between images we probably still need high light.

- **Rotem:** what about lights on a timer that turn off at night
    - **Marcel:** yes, that could be a solution. The lights don't have to be al on day, we don't need 8 hours of footage of the same nestbox every day, we just need a good snapshot, so a few hours is sufficient. If the birds are very motivated, they can be going in with prey every few minutes, which is also a lot of data to analyze.

Daniel: Jacob, Jesse and Thijs, from your perspective what are some specific questions you have that you need to understand for your work?

- **Jesse:** I mostly need data. If any of you have any amount of images or videos with or without annotation that would be great.
    - **Marcel:** We have some scored videos, apart from the videos you will get a table with time and prey. Christiaan uses images, and it would be good to ask him as well as his are higher quality.
        - **Jesse:** the bad images are also important so I can make comparisons.
        - **Daniel:** how closely you need to match the information from the database to an image and the region in the image?
            - **Marcel:** we use camera traps and use the metadata and read it in directly, you just have to say what species it is and the rest is automatically recorded.
            - **Jesse:** you can get a lot of metadata information from videos as well as images.
- **Daniel:** for the algorithm training, getting to a lower taxonomic level is challenging. Do you have an idea of what data is available and how accurate you expect it to be?
    - **Jesse:** for species level not sure, higher categories should be possible. It is very dependent on the images themselves. For example, the variety of prey- if there are lots of items then it is harder to identify the individual, and where one species starts and another ends.
        - **Jacob:** identification from bits and pieces of prey like shown in the slides is a nice challenge. To get to species level we need segmented images- annotating pixel for pixel. The next step is to identify the species by body parts- not sure if even taxonomists can identify what insect it is from just a (part of a) wing.
            - **Daniel:** some wing characteristics are very species specific but also requires a good image.
        - **Jesse:** I also wonder at the variety of prey, is there a specific set of insects that they bring in, or a wide range of different insects?
            - **Marcel:** it depends, the great tits are more on the caterpillar side, the flycatchers have more variation, for example they also eat flies.

- **Jesse:** specific species of caterpillar?
    - **Marcel:** varies from year to year. I don't think there are hundreds of species, I think if you have 5-6 species that would already be good.

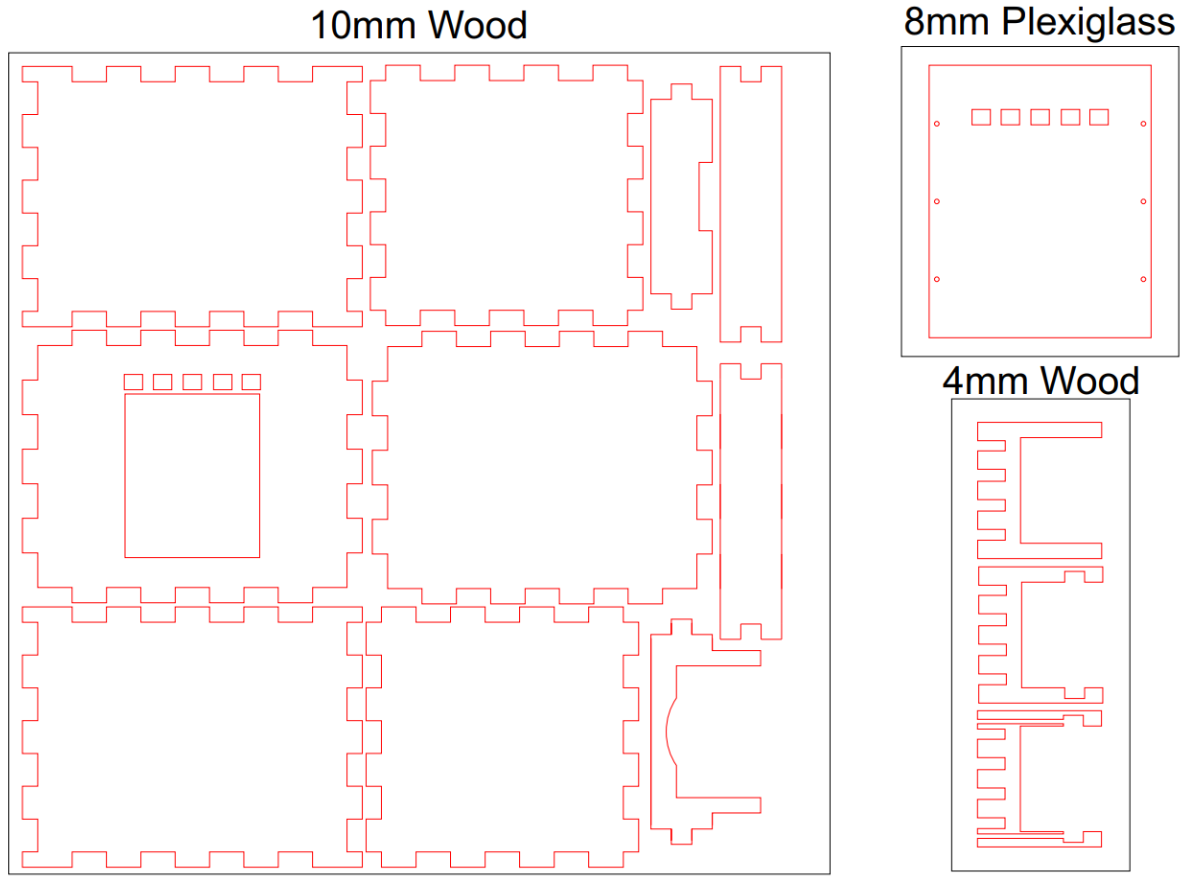
Jacob: Marcel, you do insect monitoring as well, how do you monitor them?

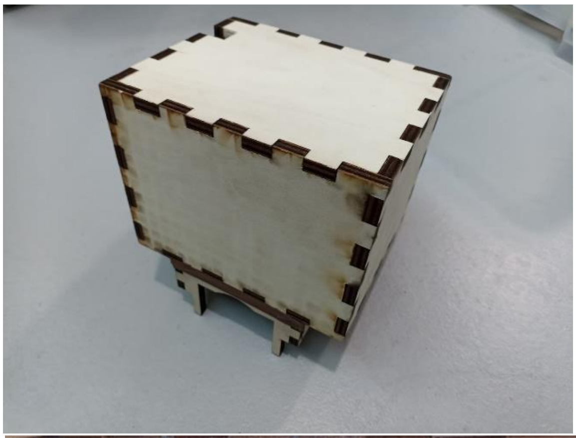
- **Marcel:** in pre breeding: sticky sheets and pit fall traps, but caterpillars by their droppings. We have a net under the tree and we weight the droppings. We do not know the species it corresponds to though.
    - **Daniel:** could probably do this with metabarcoding?
        - **Marcel:** we still have everything stored if someone wants to have a go at it.

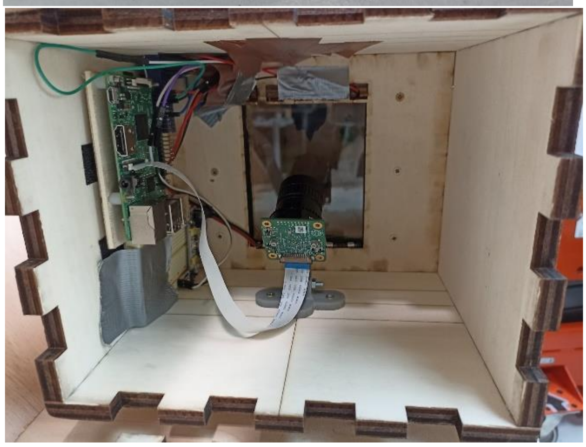
Daniel: Jesse and Thijs will follow up with Marcel and Christiaan by email.

- **Jesse:** if you have image data of the birds coming into the nest please send to this email: j.w.visser-3@student.utwente.nl
- **Thijs:** I have been looking at different set ups that exist, and made a google form to see what systems and components worked and how researchers experience was with them, it would be great if you could fill it in: https://docs.google.com/spreadsheets/d/1K8YvVz7TeypCWphQAbvos9XytmVJjv68O0kmFT5xYBw/edit?usp=sharing
- **Marcel:** you should come to my or Christiaan's site in early May to have a look what it is like in real life.

A3 Laser Cutting File and Pictures







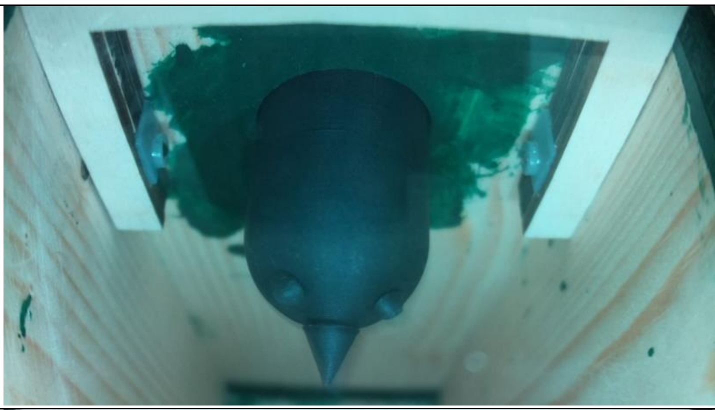
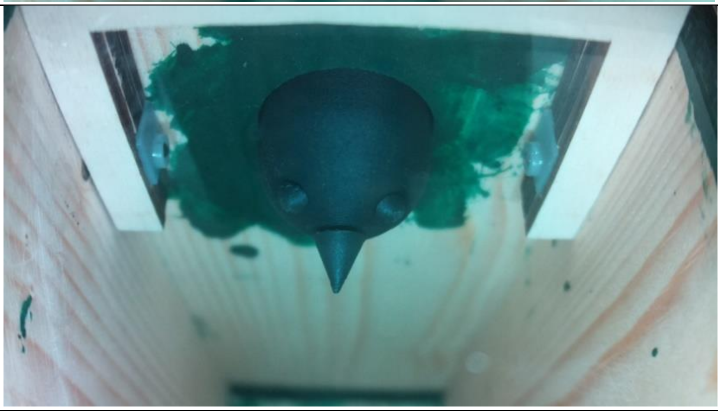
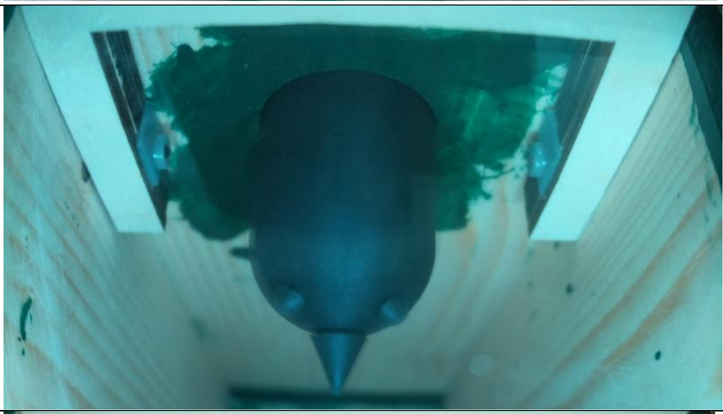
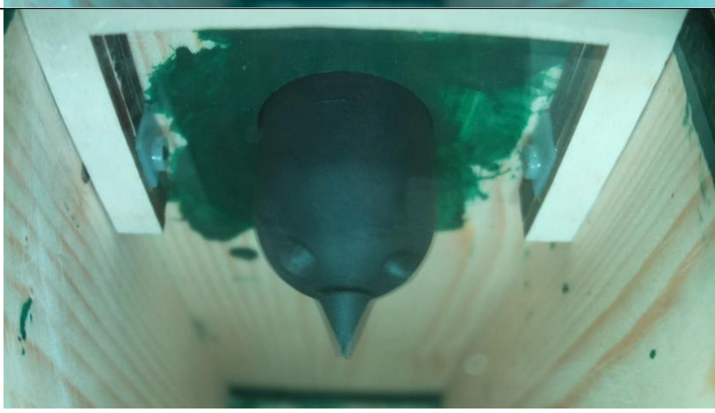
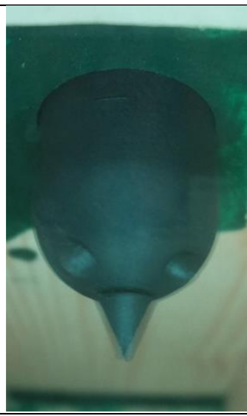
A4 Python Code Complete System

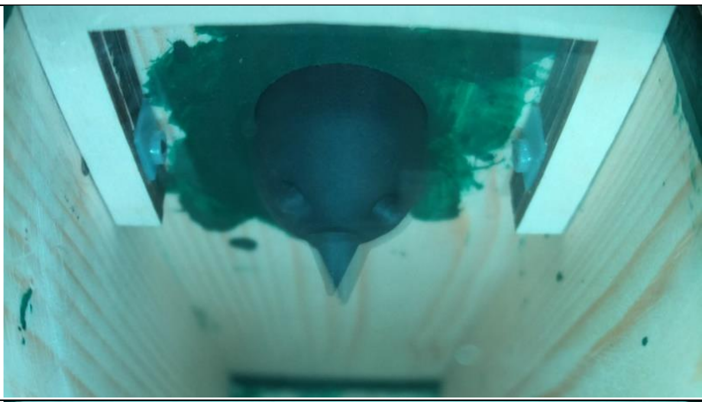
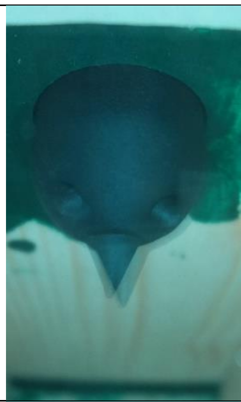
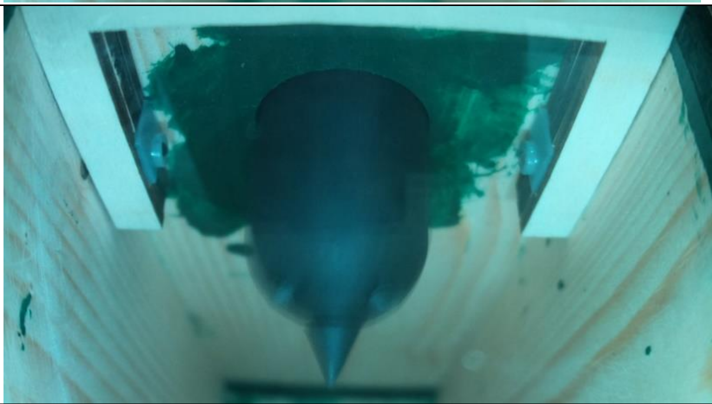
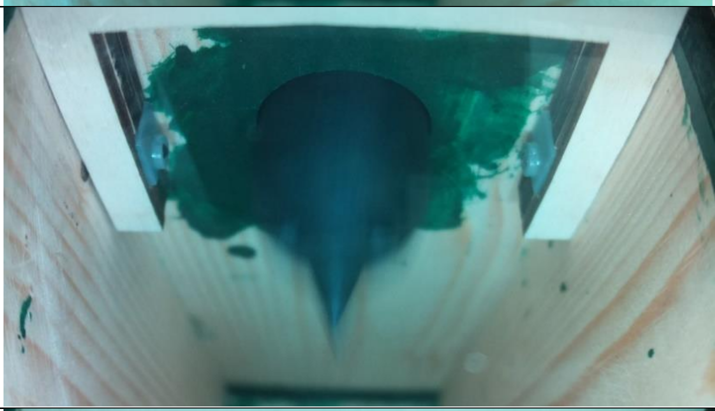
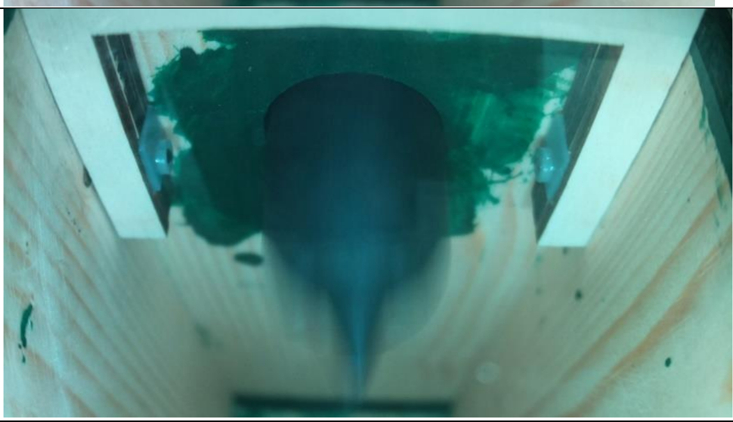
```
import RPi.GPIO as GPIO
from time import sleep
from picamera import PiCamera
from datetime import datetime, timedelta
import board
import neopixel

pixels = neopixel.NeoPixel(board.D18, 5)
LEDnr = [0,2,4]
IRpins = [2]

GPIO.setmode(GPIO.BCM)

camera = PiCamera()

def break_beam_callback(channel):
    for pin in IRpins:
        if not GPIO.input(pin):
            for i in LEDnr:
                pixels[i]=(150,150,60)

            date = datetime.datetime.now().strftime("%m_%d_%Y_%H_%M_%S")
            camera.capture("/home/pi/Pictures/"+ "speedTest"+ date + ".jpg")
            for i in LEDnr:
                pixels[i]=(0,0,0)
            sleep(1)
             while not GPIO.input(pin):
                 sleep(5)

for pin in IRpins:
    GPIO.setup(pin, GPIO.IN, pull_up_down=GPIO.PUD_UP)
    GPIO.add_event_detect(pin, GPIO.BOTH, callback=break_beam_callback)
message = input("Press enter to quit\n\n")
GPIO.cleanup()
```

A5 Python Sharpness Estimation for Document and Scene Images

```
"""
Sharpness Estimation for Document and Scene Images
by Jayant Kumar , Francine Chen , David Doermann
http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=33CD0038A0D2D24AE2C4F1A30B
6EF1A4?doi=10.1.1.359.7002&rep=rep1&type=pdf
https://github.com/umang-singhal/pydom
pip install git+https://github.com/umang-singhal/pydom.git
#Use difference of differences in grayscale values
of a median-filtered image as an indicator of edge sharpness
"""


from dom import DOM
import cv2

#img = cv2.imread("images/image_quality_estimation/02_2sigma_blurred.tif", 1)
img1 = cv2.imread("1.jpg", 1)
img2 = cv2.imread("2.jpg", 1)
img3 = cv2.imread("3.jpg", 1)
img4 = cv2.imread("4.jpg", 1)
img5 = cv2.imread("5.jpg", 1)
img6 = cv2.imread("6.jpg", 1)
img7 = cv2.imread("7.jpg", 1)
img8 = cv2.imread("8.jpg", 1)
# initialize DOM
iqa = DOM()

#Calculate scores
score1 = iqa.get_sharpness(img1)
score2 = iqa.get_sharpness(img2)
score3 = iqa.get_sharpness(img3)
score4 = iqa.get_sharpness(img4)
score5 = iqa.get_sharpness(img5)
score6 = iqa.get_sharpness(img6)
score7 = iqa.get_sharpness(img7)
score8 = iqa.get_sharpness(img8)

print("1:", score1)
print("2:", score2)
print("3:", score3)
print("4:", score4)
print("5:", score5)
print("6:", score6)
print("7:", score7)
print("8:", score8)
```

A6 Overview of Sharpness Images

Image number	Complete image	Cropped image
1		
2		
3		
4		

5		
6		
7		
8		

A7 Estimate Strength of Blur

```
"""
=========================
Estimate strength of blur
=========================
This example shows how the metric implemented in ``measure.blur_effect``
behaves, both as a function of the strength of blur and of the size of the
re-blurring filter. This no-reference perceptual blur metric is described in
[1]_.
.. [1] Frederique Crete, Thierry Dolmiere, Patricia Ladret, and Marina
   Nicolas "The blur effect: perception and estimation with a new
   no-reference perceptual blur metric" Proc. SPIE 6492, Human Vision and
   Electronic Imaging XII, 64920I (2007)
   https://hal.archives-ouvertes.fr/hal-00232709
   :DOI:`10.1117/12.702790`
"""
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import scipy.ndimage as ndi

import plotly
import plotly.express as px
from skimage import (
    color, data, measure
)
from matplotlib import image

from matplotlib import pyplot
blurmetric = np.array([])
blur2 = np.array([])
for i in range(1, 9):
    img = image.imread(str(i) + '.jpg')
    img = color.rgb2gray(img)
    c = measure.blur_effect(img, h_size=4)
    d = measure.blur_effect(img, h_size=28)
    blurmetric = np.append(blurmetric, c)
    blur2 = np.append(blur2, d)
```

```
plt.plot(blurmetric, label='h_size: 2')
plt.plot(blur2, label='h_size: 10')
plt.legend()
plt.show()
```

A8 Python Code IR Beam Sensor Test

```
import RPi.GPIO as GPIO
from time import sleep
from picamera import PiCamera
from datetime import datetime, timedelta
import board
import neopixel

pixels = neopixel.NeoPixel(board.D18, 5)
LEDnr = [0,2,4]
IRpins = [2]

GPIO.setmode(GPIO.BCM)

camera = PiCamera()

def break_beam_callback(channel):
    for pin in IRpins:
        if not GPIO.input(pin):
              print("broken beam")
            for i in LEDnr:
                pixels[i]=(150,150,60)

            date = datetime.datetime.now().strftime("%m_%d_%Y_%H_%M_%S")
            camera.capture("/home/pi/Pictures/"+ "speedTest"+ date + ".jpg")
            for i in LEDnr:
                pixels[i]=(0,0,0)
            sleep(1)
             while not GPIO.input(pin):
                 sleep(5)

for pin in IRpins:
    GPIO.setup(pin, GPIO.IN, pull_up_down=GPIO.PUD_UP)
    GPIO.add_event_detect(pin, GPIO.BOTH, callback=break_beam_callback)
message = input("Press enter to quit\n\n")
GPIO.cleanup()
```

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