To Find A Mocking Bird

Urban Bird Watching Product Design For Leica Sport Optics

Leica

TU Delft Delft University of Technology

SUPERVISORY TEAM

Chair

Dr. Ir. A.J. Jansen

Design Engineering—Product Architecture Design

Mentor

Dr. Ir. Song. Y.

Design Engineering—Mechatronic Design

Company Mentor

Markus Klug

Senior Industrial Designer at Leica Camera AG

AUTHOR

Yuan Tian

MSc. Integrated Product Design

Faculty of Industrial Design Engineering

Delft University of Technology

Foreword

Here I'd love to take time to express my gratitude to everyone involved in this project.

Big thanks to Arjen and Wolf, my chair and mentor at Delft, for your guidance and suggestions in this project. I'm super lucky to have you as my supervisors and I appreciate your creative and pragmatic spirit in product design. Remote communication is a challenging part of this project, and I could not make it without your consistent guidance, tolerance, understanding and encouragement along the way. Thank you from the bottom of my heart.

Thanks to all my colleagues in the Leica design team, for your support and careness during this project. Thanks to my manager Mark, for making this collaboration come true, and keep on supporting my needs and giving me maximum flexibility in the project, I am very grateful for that. Thank you Anna, for always being so helpful and considerate. I am more than lucky to join such a brilliant team and have an experience in an amazing company like Leica.

Many thanks to many people at Leica who lend their hands during this project. Thank you Song, Jose, Martin and Sylvia for your help from the technical side. Thank you Matthias, Ronald, Ferdinand, Renate and Mark Karn for your deep insights towards user needs and products. Your help really made a difference to the project.

Thank you Whitney, Laura, Nanette, Swetha, Rohan and Uday for sharing your awesome stories with birds and providing your precious opinions towards the concepts. Your brilliant insights and positive attitude contributed greatly in building a solid user research.

Thanks to my friends and family who sent their help and warm regards along the way.

Finally, great thanks to my company mentor Markus, for always being helpful, patient, positive and contributive during the project. I am lacking words in expressing my gratitude. Shall I have the chance of becoming a company mentor in the future, I'd pass the same spirit and attitude to my students.

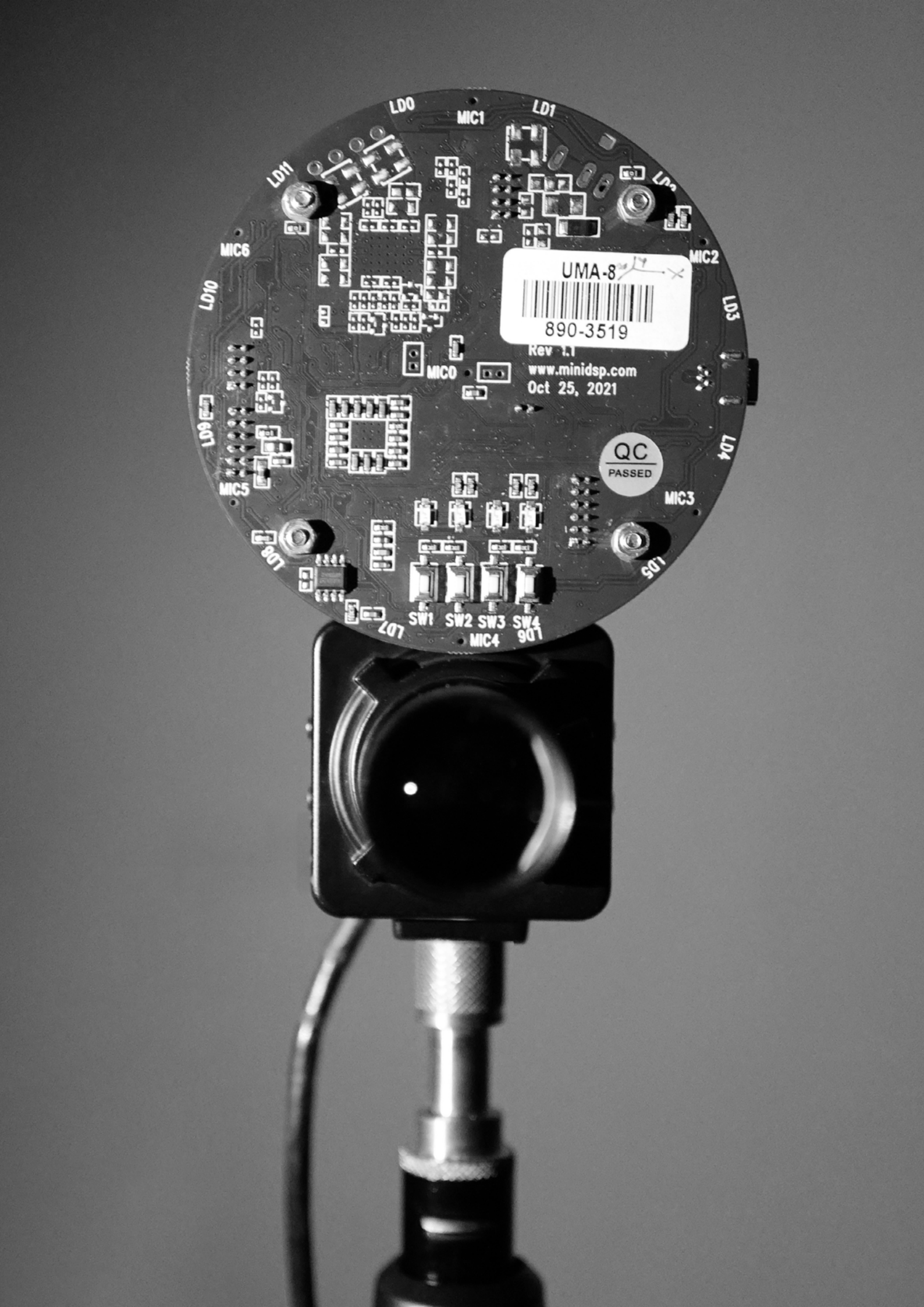
Enjoy the report :)

Yuan Tian

Contents

Glossary

FOV: Field of View
HUD: Head-up Display
DOA: Direction of Arrival
SSL: Sound Source Localization
SST: Sound Source Tracking
SSS: Sound Source Separation
ODAS: Open Embedded Audition System


LD0
MIC1
LD1
LD11
MIC6
LD10
MIC2
LD3
UMA-8
890-3519
Rev 1.1
www.minidsp.com
Oct 25, 2021
MIC0
LD9
QC
PASSED
LD4
MIC5
MIC3
LD8
LD5
SW1
SW2
SW3
SW4
LD7
MIC4
LD6

Abstract

Urban Bird Watching Product Design for Leica Sport Optics

Bird observation, as one of the most popular nature exploration activities in Europe, has a large user group, a profitable market and contributes positively to the environment. Optical devices are almost a necessity for bird observation since they provide a magnified view with vivid details at a far distance.

Leica, a premium product manufacturer in the camera and sport optics industry, has a current user base of professional and elderly customers in bird observation. As the number of novice observers that start bird watching in urban environments keeps on increasing, the needs from this user group are becoming less neglectable. Therefore, designing for novice bird watchers could potentially help Leica open a new market and create more business value.

The design is defined under an urban context, which is a starter-friendly environment since birds are more active in cities. One of the biggest difficulties for novice bird watchers is 'finding birds', including catching sight of birds in the environment, and finding them again later in a magnified optical view. This can be a process that is both tricky and time-consuming for beginners. Some extra digital assistance "just like a slight nudge" is appreciated during the process.

To improve the experience for this process, multiple design ideas were generated and different adaptable technologies were mapped out in a morphological chart. The selected concept is an innovative bird watching optical device with a built-in 3D sound localisation system that is able to generate 3D directional vectors of the detected birdsong source, convert it into 2D information, then project a directional hint of birds' position on the optical view. To test the feasibility of the selected technology, a functional mockup was built, which is composed with a digital camera, a microphone array, a computer processing power and a camera view finder display. At the end of the project, the mockup is able to perform sound source localisation of multiple sound sources within a distance range of 0-8m.

The mockup build in the project could serve as a starting point for Leica's future exploration under the sound-related innovation area. Though currently the relevant technology is not mature and cost-efficient enough to bring much value to the viability aspect, a technology roadmap was proposed to the company suggesting a step-by-step further development process. With technical improvements from experts and engineers, an optimized setup with a better performance and a lower cost can be achieved within a more compact package.

01

Background

/ Design for Leica sport optics
/ Design for bird observation industry
/ Optical products for bird observation

A Dark-eyed Junco(Spring Is Here and Birds Are in the Air!, 2022)

1.1 Design for Leica sport optics

1.1.1 Leica sport optics: a brief overview

Leica, full name Leica Camera AG, is a German company that manufactures cameras, optical lenses, photographic lenses, and sport optics[1] like binoculars and rifle scopes. The company was founded by Ernst Leitz in 1869 in Wetzlar, Germany. Over the years, Leica has grown up to be one of the most well-known manufacturers of camera and optic products.

Leica started its sport optics product line in the early 20th century, with the first series of Leitz binoculars released in 1907. After more than a century-long development, today Leica has a broad sport optics portfolio including different product series in binoculars, monoculars, spotting scopes, rifle scopes and others.

1. The phrase "sport optic" is most commonly used to reference a rifle scope for hunting or competitive shooting. While correct, this limited usage often overlooks binoculars, rangefinders, nature cameras, spotting scopes and other use-cases like bird-observation, home defense, or even astronomy(Sector Optics, 2021).

Figure 01 Leica sport optics advertisement pictures (Sport Optics - Hunting | Leica Camera AG, n.d.)

1.1.2 Better nature exploration with digital augmentation[2]

With more people going on all kinds of outdoor activities for part-time leisure, more scenarios of usage are created, which means the corresponding nature-related optical products will go diverse in their functionality, to cope with different types of needs.

2. The content here is from design brief. Check appendix RA for design brief

To respond to the growing needs of users, Leica and its competitors have been applying digital features and extensions into optic products. Nowadays, adventurers take their binoculars and spotting scopes out into the field not only for live-observing, but also for adding photographic extensions for recording the beauty of nature; with rangefinders and its collaborative technologies, hunters and sports players are able to perform better under the guidance of the collected data; by adding a thermal camera in rifle scope, hunting for excessive wild animals has never been easier.....What's next for digitalization in optic products?

As a popular topic in the technology era, digital augmentation (enhancing sensory presence by using digital content) has been applied into many practical fields. This project will be mainly focused on applying certain augmentation technologies into nature-related optic solutions to make it clearer and more intuitive for users.

Figure 02 Leica pinmaster (Leica Pinmaster | Leica Camera AG, n.d.)
A rangefinding monocular designed for golf sport

Figure 03 Leica Calonox View/Sight
(LEICA Calonox 2.5x42mm Thermal Imaging Monocular (50502), n.d.)
A thermal imaging camera designed for night hunting

1.2 Design for bird observation

Some definitions are introduced here to help users understand the context before further introduction.

Birding
The general activity of in-depth observation and study of birds (with twitching as a specific type of birding focused on rare bird species) (Redirect Notice, 2023) [3]

Figure 04 context pic for Birding (Oakley, 2023)

Bird watching
The act of observing birds in their natural habitat for recreational, educational, or scientific purposes, more casual and less intense than birding or twitching. (Redirect Notice, 2023)

Figure 05 context pic for Bird watching
(Find Your Birding Community | U.S. Fish & Wildlife Service, 2022)

Bird observation
A word created by the author to include both activities in the project scope.

3. The boundary between "Birding" and "Bird watching" is not clearly defined and they are usually mixed up in most of the online sources, but they do indicate 2 different professional levels and purposes.

1.2.1 Why bird observation?

A brief evaluation towards multiple nature exploration activities and interviews under 3 candidate activities(hiking, bird observation, urban sightseeing) were done[4].

'Bird observation' is selected to be the target activity due to its focus on the 'observation' purpose that makes optical devices almost a necessity in the whole experience.

4. Check appendix RC for more information on activity filtering and brief insights collected from interviews

1.2.2 Bird observation as an industry

A big user group

Europe is estimated to have over 90 million bird observers, with the UK, Germany, France, and the Netherlands being among the countries with the highest number of bird observers (2017, European Bird Census Council).

A promising market

Attributed to the increasing popularity of bird observation as a recreational activity, the rise of eco-tourism, and the development of new and innovative bird observation equipment, the global bird observation equipment market is expected to grow at a compound annual growth rate (CAGR) of 4.3% from 2021 to 2031. (2021, CBI Ministry of Foreign Affairs)

Benefits to environment & society

More than a third of bird species in the EU are currently in decline. This highlights the importance of conservation efforts to protect these species and their habitats (2020, European Commission). Bird observation has helped to prevent the extinction of many bird species and played a key role in the recovery of several endangered species. It also contributes to scientific research by collecting data on bird populations, migration patterns, and behavior which help scientists better understand the impact of environmental changes on bird populations and inform conservation strategies

Besides, bird observation generates more than €10 billion annually in Europe, supporting thousands of jobs and providing economic benefits to local communities. (2015, BirdLife International)

Figure 06 A marbled godwit being ringed for studies on bird migration
(Wikipedia contributors, 2023)

Figure 07 bird observers testing spotting scopes
(Mid-priced Scopes Round-up 2009 - by Michael and Diane Porter, n.d.)

5. See appendix RB - product principle for detailed product set up introduction and a functional analysis towards binoculars and spotting scopes from the author.

1.2.3 Optical products for bird observation[5]

Optical devices play an essential role throughout the bird observation activity, since they make it possible for observers to catch the vivid details of birds by having a closer look at them while keeping a distance that is less disturbing for the birds. Since the project is about implementing digital features related to bird observation optical devices, it's important to provide readers with an idea of the category of these devices and their functions.

The most commonly used optical products for bird observation are monoculars, binoculars and spotting scopes.

As the most popular selection, **binoculars** are the most ergonomically pleasant choice since they support two-eyed observation and are relatively lightweight and compact(usually with a magnification between 10-15x).

A **monocular** can be regarded as half binocular and is therefore the lightest, smallest and cheapest device to go for(usually with a magnification between 6-10x).

A **spotting scope** has a configuration that is similar to a telescope but is designed for observing live objects, it is usually mounted on a tripod, provides a very big magnification power(usually between 20-100x) and allows users to effortlessly catch details of birds at a long distance. It is the most expensive choice among all.

And of course, some observers with a higher demand for photography will also go for a **(super) zoom cameras** since they enable a gradual zoom, capture the bird instantly and can achieve a magnification similar to monoculars and binoculars. Nevertheless, cameras are usually quite heavy to carry around and are usually regarded as substitutes.

Figure 08-11 (from top to down)

Leica Noctivid 8x42 (Leica Noctivid 8x42 Binoculars, n.d.)
Leica Monovid
(Leica Monovid 8x20, Black | Leica Camera AG, n.d.)
Leica APO-Televid 65 W
(Leica APO-Televid 65 W (Winkeleinblick 45°) | 65 | 3030582, n.d.)
Leica C-Lux (Sven, 2023)

1.3 Design approach

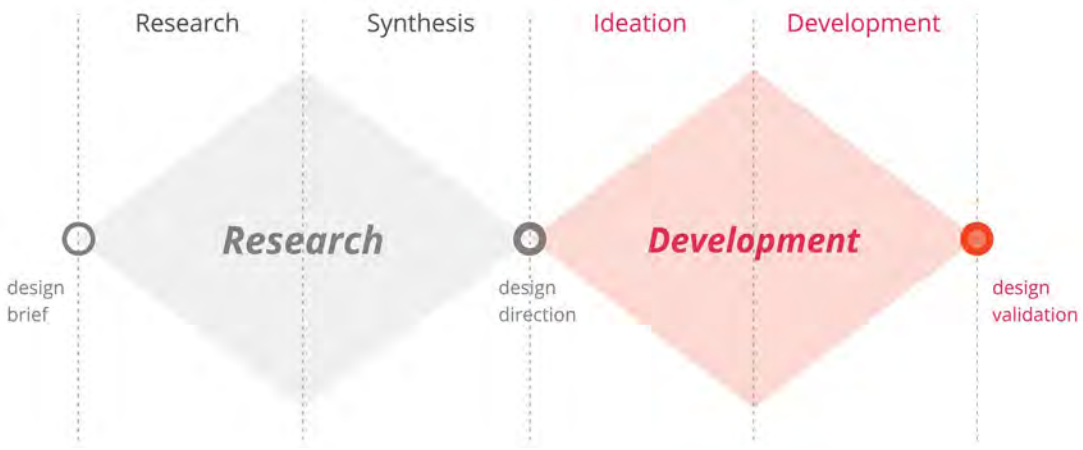


Figure 12 double diamond approach

The project is guided by the double diamond approach, which consists of the research stage and the design development stage.

During the research stage, user research and market research are done while insights from literature and relevant stakeholders are collected. Through analysis and synthesis, the target group and design scenario are defined. The research phase concludes around the mid-term with a clear problem definition and a focussed design scope.

Following the research stage, the design development stage begins with ideation and conceptualization, during which different ideas and different applications of technologies were explored. After the concept is defined, a detailed technology selection towards required hardware and software was done, followed up by a test towards the selected technology and a mockup design procedure.

At the end of the project, a mockup with the envisioned feature of the product concept is built and a possible product image is created, further suggestions on how to proceed with the project are also listed.

02

Research

/ Goals and methods
/ Research results

Author doing bird watching with a Leica Ultravid 10x25 (taken with a Leica Q2)

2.1 Goals and methods

2.1.1 Research Goals

The goals fo the design research is to learn:

> ***01 Different user groups in bird observation***
>
> ***02 User journey of bird observation activity***
>
> ***03 What digital functions are in current bird observation products***
>
> ***04 Factors that affect customers' selection towards optical devices***
>
> ***05 Leica's opportunity areas in bird (nature) observation***

2.1.2 Research Methods

01 User research on bird observation journey & product selection [6]

Desktop research

To get familiar with different groups of bird observers and get an overview on what are their current experiences, desktop research was done by collecting literature data from bird observation websites like all about birds and eBird, and user insights under Reddit groups. A huge amount of data was collected, therefore categorizing and analyzing work was done with the help of AI tools like Atlas.ti and OpenAI API.

Interview and personal experience

To have a further understanding of the whole user journey and the needs behind each step of the journey, online interviews were done to achieve a focussed and in-depth insight collection (check table 01 for the basic information of 6 participants). Personal experience was also included in the research result for it conveys the designer's honest opinion and thoughts as a real user without chances of miscommunication.

6. See appendix RD and RE for a full documentation of user research.

Table 01 General information of interviewees and the author

	Gender & Age	Origin	Experience(yrs)	Profession	Place for bird watching
A	Female, 32	Europe	>10 (enthusiast)	Art director	Belgium and Europe
B	Female, 37	North America	around 15 (professional)	Nature training manager	United states and worldwide
C	Female, 22	Asia	around 2 (starter)	Product design master student	Currently based in Delft, the Netherlands also watch birds in Bangalore, India
D	Female, 50s	Europe	>30 (professional)	Optical device product manager	Germany and worldwide
E	Male, 26	Asia	1 (starter)	Product design master student	Currently based in Delft, the Netherlands also watch birds in India
F	Male in his 30s	Asia	4-5 (enthusiast)	Civil engineering master student	Currently based in Delft, the Netherlands also watch birds in India
G	Female, 24	Asia	2 months (fresh starter)	Product design master student	Munich, Germany

02 Market research on digital products and brand information

Literature and desktop research

A literature and desktop research was done to understand what digital technologies are already applied in bird observation products and accessories, and how Leica's main competitor, Swarovski, is selling its nature observation devices. Information was mainly collected from brand's website and product evaluation articles.

Interview

To understand the factors that affect user's choice towards premium sport optics devices and Leica's unique selling point in the sport optics industry, interviews had been done with product managers at Leica[7].

7. See appendix RF for a documentation of interviews.

03 Organizing Insights

Value Proposition

The insights towards user research were collected and organized in a qualitative way with the value proposition method. With user insights categorised under gains and pains that lead to user needs.

2.2 Research results

2.2.1 Bird observation user groups

4 typical user groups in bird observation are described below. They are derived under an European context with the information from desktop research and interview insights.

01 Professional observers (usually in their 20-50s)

The most professional bird observers usually started from their teenage time or younger adulthood and have had decades of experience. They work in relevant industries and are both skillful in bird observation and knowledgeable on a wide range species of birds. Many of them will go on world wide birding trips and work as tour guides for newbies (User insight,2023).

Percentage: 5 -10%
Travel range: Worldwide
Skill level: +++++
Collected species: +++++

Figure13 Professional observer context pic (Birding | Reserva Ecológica De Guapiaçu, n.d.)

02 Leisure-based travelers (mostly retired elderly people from 50-80)

Retired elderly people are another very big user group in bird observation in Europe. They have time, money and energy for leisure-based activities like bird observation. Many of them attend cross-continent bird trips guided by professionals, to not only see birds but enjoy the traveling experience. Their skills vary between novice and professional levels (User insight, 2023).

Percentage: 45-50%
Travel range: Worldwide
Avg. skill level: +++++
Collected species: +++++

Figure 14 Leisure-based traveler context pic (Living, 2020)

03 Starters with a casual mood (mostly younger people in their 15-30s)

Novice observers usually start this activity around their house(e.g. backyard, little forests) and gradually go further for more experience. They are generally less skillful and regard bird observation as a casual activity for fun (Mark Karn, Leica account manager,2023). A lot of starters begin their observation with a professional guide or with friends or family members that have similar interests.

Figure 15 Professional observer context pic (Joyner, 2021)

Percentage: 20-30%
Travel range: around their living area
Skill level: +++++
Collected species: +++++

04 Motivated enthusiasts (without specific age range)

Enthusiasts work in different industries and treat bird observation as a hobby, while they are crazy about birds and are always eager to learn more about them. They'll visit specific nature hotspots usually with the purpose of finding certain birds. They make good use of every bird observation trip to improve their learnings, some of them will submit their witness and documentations to certain websites to help with local research (User insight, 2023).

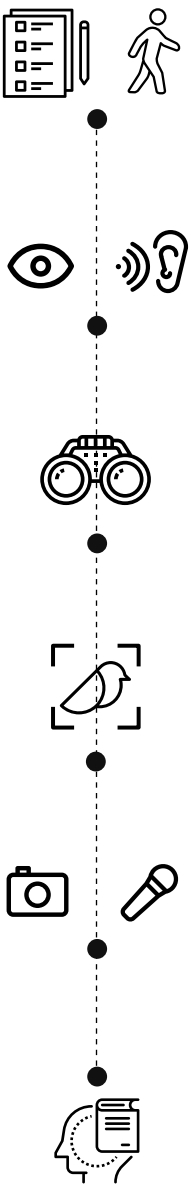
Figure 16 Motivated enthusiasts context pic (The Search for the Perfect Set of "Big Eyes" for Long-distance Glassing, n.d.)

Percentage: 10-15%
Travel range: within the country they reside in
Skill level: ++++++
Collected species: +++++

2.2.2 User journey and functions of digital products

A user journey with important quotes and user insights for the current bird observation experience is included below. Current digital functions in relevant products are also listed within the main journey.

The content come from literature and interviews with bird observers from the 1st, 3rd and 4th user group mentioned in chapter 2.3.1. The context for this user journey is limited within ‘watch tree birds in the same country or area the user is residing in’.



01 Before trip

Planning and commute

02 (Attract or) Find birds

Go to birds or get birds to you

03 Observe birds

04 Identify birds

Tell the species

05 Document image and sound

Take picture/record birdsong

06 After trip

Learning, sharing and submitting

01 Before trip

Decide when, where and who to go with

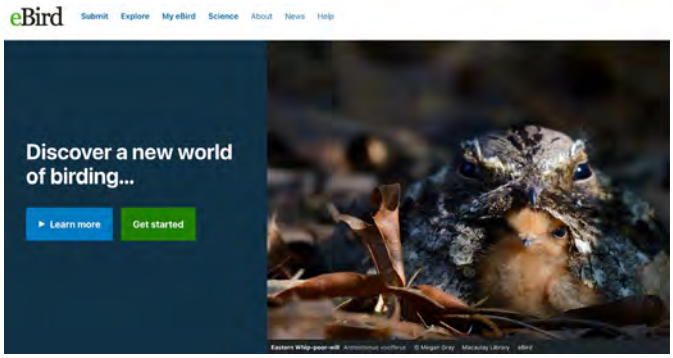


Figure 17 eBird provides several hot spots (bird gathering places) that suggests observers on places to go to see certain birds. (eBird,

User Quotes

'I'd love to go birding with others, but I don't know anyone nearby that has the same interest.'(Starter)

'Many people started bird observation by joining group birding trips guided by a professional.'(Professional)

'Big hotspots I'd definitely approach during migration or early/late summer), where I see the migration of birds.[x]' (Enthusiast)

'There are actually quite a lot of birds in cities! They are closer to people and easier to be found.' (Professional)

'I feel a bit awkward carrying a binocular in the city, because people might relate binocular users as peepers.' (Starter)

Collected insights

+ Urban areas(city parks, little forest, etc.) are proper for beginners to start bird watching.
+ Digital supports like eBird provide helpful information on where to find certain birds.
+ Following a professional or joining a group bird watching trip is helpful for starters to improve skills quickly.
- Starters fail to get detailed suggestions on where and who to go with for a bird observation trip

02 (Attract or) Find birds

Go to the birds or get birds to you

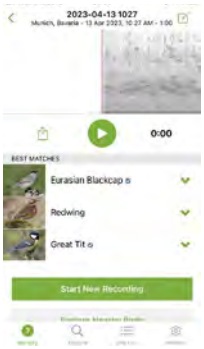


Figure 18 Merlin Sound ID helps identify what birds are singing in the environment

Figure 19 Thermal binoculars (OpticsPlanet.com, n.d.)

Figure 20 a laser pointer for sharing the location of birds(NHBS, n.d.)

User Quotes

'Usually I have Merlin sound ID on to identify what species are singing around, then I try to find and observe them.' (Starter)

'In foresty areas, bird songs get reflected by the leaves on the trees making it hard to tell the direction with ears. Also some birds sings with different volumes in different seasons, making it hard to estimate the distance. ' (Enthusiast)

'When you find it hard to find a certain bird, playing their song could be a good way to attract them.' (Starter)

'I feel that birds are around more according to their movement in the trees. Birds move continuously, which draws attention and on the other hand makes them hard to be observed. ' (Enthusiast)

' Some birds are super good at hiding, and they are small in size making it even harder to catch sight of them.' (Enthusiast)

' In group birding we sometimes use a laster pointer to circle around birds (must be careful to not let the laser touch the bird) or discribe verbally to communicate locations. We also use clock system to navigate, but it still can be hard.' (Professional)

Collected insights

+ Playing birdsongs is helpful in attracting birds(but not always good ethically).
+ Merlin Sound ID helps tell what species are singing in the environment.
+ A laser pointer could help professionals to share bird location in group birding.
- Current communication in group bird observation is less efficient and not ideal.
- It could be hard to locate birds with their song in a foresty environment
- A laser pointer could bring the potential risk of hurting the bird.
- Some (tree) birds are very hard to find because they are good at hiding.

03 Observe birds

Figure 21 Digital binoculars with a camera in the optical system(Australia, n.d.)

Figure 22 Night vision binocular (with a digital view) (Night Vision Binoculars, 300m Vision Range 960P Video 7-Level Infra. . ., n.d.)

User Quotes

' The auto-focusing function of a camera allows you to focus on a jumping bird quicker than using binoculars' (Enthusiast)

' It could be frustrating to just go birding with a camera , you can not see the birds very well through the lens.' (Professional)

'With a camera you can gradually zoom in the view until birds get bigger so you don't lose target.' (Starter)

' Some binoculars' eye cups do not feel good, a heavy body can also lead to a sore wrist under long observation.'(Enthusiast)

'I am not used to the binoculars, it needs complex adjustments and take time to set up - we missed birds this way.'(Starter)

Collected insights

+ Functions like gradual zoom and auto-focus can be really helpful in bird observation
+ 2-eye observation and a fully optical view quality can greatly improve user experience.
+ A light weight and compact device can make the observation easier.
- Some binocular products are tricky to set up and are less pleasant to use(ergonomically)
- For starters, finding birds in binocular again after seeing them with bare eyes could be difficult.
- Long time observation could be physically challenging for some bird observers.

04 Identify birds

Figure 23 Sybley eGuide, a digital field guide on your smartphone (Sibley Birds V2 App – Sibley Guides, n.d.)

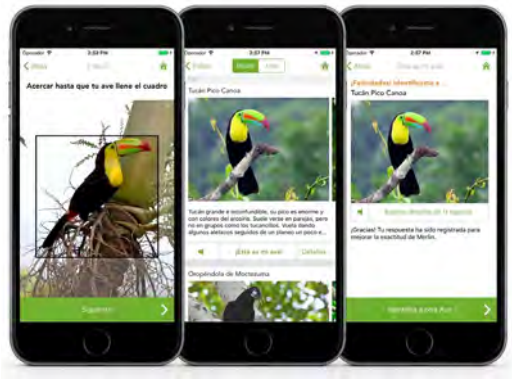


Figure 24 Merlin photo ID (Chente, n.d.)

User Quotes

' Would be nice to know the name of birds in foreign language as well. Sometimes when I go birding with people(who speak foreign language), I fail to tell the name of the bird in another language, that makes me feel inexperienced.' (Enthusiast)

'Sometimes I can not identify on site, then I take pictures first and use Google lens to tell what birds they are later.' (Starter)

'Merlin is very helpful with its photo ID feature but it does not support live view.' (Starter)
'Merlin sound ID is already telling you what birds are there before you even see them.'(Starter)

'A paper field guide is quite helpful to tell the difference of very similar birds. Merlin is helpful for starters but sometimes it provides wrong result. As we become professional we rely on field guides. A digital field guide app is even better.' (Professional)

Collected insights

+ A field guide works better for telling the detailed difference between species
+ Merlin bird ID and Google lens are helpful in simple bird identification
+ Taking pictures is helpful for identification later.
- Digital identification supports, e.g. Merlin and Google lens, are not always accurate
- There are currently seldom digital supports that can lively recognise birds visually

05 Document image and sound



Figure 25 Smartphone digiscoping (ATC/STC, n.d.)
Figure 26 Swarovski DG monocular has a built-in camera that takes pictures and enables streaming (Swarovski, 2023)
Figure 27 Digital binoculars with a camera in the optical system (Australia, n.d.)


Figure 28 Record with a recording pen (Sound Recording Tips, n.d.-b)
Figure 29 Record with a parabolic microphone (Sound Recording Tips, n.d.-b)

User Quotes

' I don't expect good pictures and only take pictures for identification when I can not identify on site.' (Starter)

' Good pictures are important! I sometimes submit pictures to certain websites.' (Enthusiast)

' Some bird song lovers do record using very professional devices, but I just use my smartphone microphone.' (Enthusiast)

' Smartphone digiscoping is interesting, but it is hard to set up without an adapter.'(Starter)

'I don't remember digiscoping being hard. If it's not for good photography but witness proof, the quality is okay.' (Enthusiat)

Collected insights

+ Good pictures are important for some observers for a proper submission.
+ Taking pictures is helpful for later identfication.
+ Digiscoping is a helpful way of taking pictures of an okayish quality.
- Smartphone digiscoping can be hard to setup without an adapter for starters.
- Some documentation devices are heavy and space consuming.

Figure 30
Smartphone digiscoping is hard without an adapter

06 After-trip

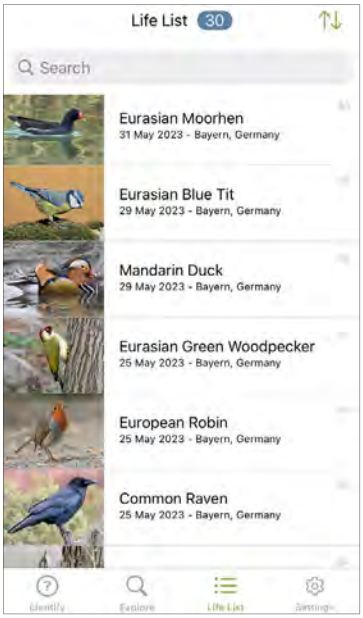


Figure 31 Life list on Merlin app

User Quotes

' Now the main motivation I do birding is for collecting more species - It feels like a Pokemon collection!' (Enthusiast)

'I take pictures of birds for self-documenting, website submission to report a witness and reflection after coming back from the trips. I will go through all the pictures taken carefully and check if I have accidently captured any species that I failed to see before.' (Enthusiast)

' I will write down the name of birds (on a notebook) so I remember their name next time I see them.' (Starter)

' I am constantly revising the bird songs I've known also stay familiar with the songs from the birds that I haven't met yet.'

Collected insights

+ Keeping notes and revising features of birds is helpful for improving skills.
+ Keeping a bird collection can motivate the observers to add more to their life list.
+ Submittion to local websites and bird-related organisations can help with research.

Insights overview

	Gains	*Pains*
Before trip	*Urban areas are good starting point for bird watching(for starters).* *Digital supports like eBird provide helpful information on where to find certain birds(mostly used by more skillful observers).* *Following a professional or joining a group bird watching trip is helpful for starters to improve skills quickly(for starters).*	*Carrying a binocular could be seen awkward.(starters)* *A camera is helpful in getting good pictures but can be very heavy to carry.(for all)* *Starters fail to get detailed suggestions on where and who to go with for a bird observation trip.(starters)*
(Attract or) Find	*Playing birdsongs is helpful in attracting birds(but not always good ethically). (usually done by starters when they can not find birds properly)* *Merlin Sound ID helps tell what species are singing around you(starters).* *A laser pointer could help professionals to share bird location in group birding(used by professional when guiding a bird trip).* *A thermal binocular helps find birds in forests (professionals)*	*Current communication in group bird observation is less efficient and not ideal. (professionals and starters)* *A laser pointer could bring the potential risk of hurting the bird. (professionals)* *It could be hard to locate birds with their song in a forest.(for all)* *Some (tree) birds are very hard to find because they are good at hiding.(for all)*
Observe	*Functions like gradual zoom and auto-focus can be really helpful in bird observation. (for all)* *2-eye observation and a fully optical view quality can greatly improve user experience. (for all)* *A light weight and compact device can make the observation easier. (for all)*	*Some binocular products are tricky to set up and are less pleasant to use(ergonomically).(for all)* *Finding birds in binocular again after seeing them with bare eyes can be difficult, they might move during the shift(for starters).* *Long time observation can be physically challenging for some users. (enthusiasts and professionals)*
Identify	*A field guide works good in telling the detailed difference between species.(mostly used by enthusiasts and professionals)* *Merlin bird ID & Google lens are helpful in simple identification. (starters)* *Taking pictures is helpful for identification later.(starters and enthusiasts)*	*Digital identification supports, e.g. Merlin and Google lens, are not always accurate.(starters)* *There are currently seldom digital supports that can lively recognise birds according to their visual features.*
Document	*Good pictures are important for some users for a proper submission. Some only take pictures for later identification(starters and enthusiasts)* *Digiscoping with smartphones works well in getting pics okay in quality.*	*Smartphone digiscoping can be hard to setup without an adapter. (mainly for starters)* *Some documentation devices are heavy and space consuming. (for enthusiasts and professionals)*
After trip	*Keeping notes and revising bird features can help learning.(for all)* *Keeping a bird collection can motivate the observers.(for all)* *Submittion to bird-related websites can help with local research.(for enthusiasts and professonals)*	

8. Information from literature and interview results with a Leica account manager and product managers, see appendix RF

2.2.3 Factors affecting users' choice for optical products[8]

Price

Customers would choose optic products that are affordable to them.

Aesthetics

Products with appealing looks attract more users.

Good ergonomics

Optical devices that are light weight and compact in size are preferred.
It's also important that the device feels comfortable for long-time holding and observing. e.g. monocular products are not widely selected as binoculars since they only support one eye observation that is not intuitive for human eyes.

Other users' choice

Customers' selection towards certain products and brands is also greatly influenced by other users' choices. If a bird observer is surrounded by Leica users, it's less likely that he or she will go for another brand(regardless of the price).

Good view quality

Customers prefer a clear, bright, stable, no reflection, color-neutral optical view. Full or half digital binoculars are not preferred since they are usually poor in image quality and viewing experience. Many customers will also check the field of view and close focus ability of the product to see if it is suitable for bird observation.

Weather proof

Customers hope that the product can withstand harsh weather conditions.

Pure experience

More experienced customers would pursue pure birding experience with a fully analog product without any digital supports. They are skillful enough to enjoy the experience without any further assistance.

2.2.4 Opportunities for Leica in nature observation[9]

9. Information comes from literature and interview results with a Leica account manager and product managers.

Opportunity 01 : Improve story telling and create diverse product lines

When it comes to sport optics, Leica is being perceived more as the brand leader for hunting, instead of nature observation.

Currently Swarovski is the leading premium sport optics brand in Europe in the nature observation area, due to the fact that the brand tells good stories in terms of user experience (Mark Karn, Leica account manager, 2023). Besides, Swarovski has quite a broad product line targeting different scenarios and user groups. Chances are there for Leica to become more competitive in nature observation area by enhancing its story telling and creating diverse product lines.

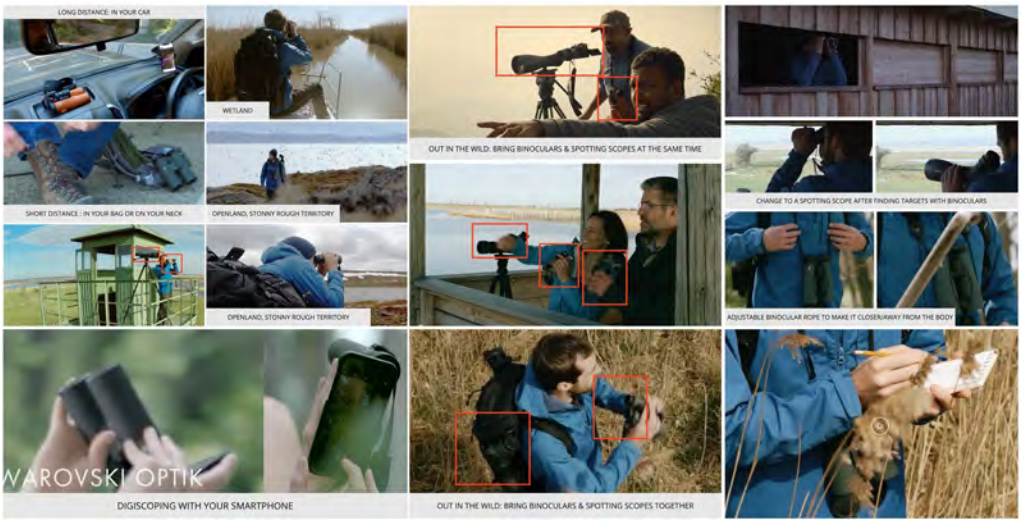


Figure 32 Swarovski's story telling (images are screenshots from Swarvoski marketing

Opportunity 02: Enhance Leica's unique selling point in optical area

Product wise, thanks to the company's special lens-coating technology, Leica's unique selling point is its color neutral optical view that shows the authentic color as real life (Matthias Raff, Leica Sport Optics Product Manager, 2023) . This feature is great for bird observation, since color plays an important role in bird identification and an authentic optical view definitely brings a good experience. As this feature is only well-known among professionals and is not very well highlighted in Leica's story telling, some marketing work can be done in this area.

03

Synthesis

/ Target group and design context
/ Problem definition
/ Reframing and scoping down
/ List of requirements

Sing birds on the tree (Sparks, 2023)

3.1 Design definition

3.1.1 Design for starters for urban bird watching

10. Check appendix RG for personas.

After explorative research, 3 personas are built under 3 user groups and general information and quotes regarding their needs were demonstrated for each persona[10]. '***Starter birdwatcher'*** is selected as the target group.

Starter birdwatcher

Natalie started watching birds at her family's backyard, later she follows a professional to spot more birds around the city green lands and parks with a camera. She learned a lot from her friend, but it's sometimes tricky that they need to share the same binocular.

Recently Natalie got a pair of binoculars on her own, so she started doing bird watchig alone as well. However, without the help of her friend, she feels it can be really hard to find birds in the city forest by herself and through binoculars. Besides, she don't know where else to go to to find more birds after constantly seeing the most common 5-6 species.

Need:
Find birds without much effort
Get familiar with the common birds in the cities

Age: 23
Level: +++++
Experience: around 4 months
Job: Art student

Figure 33 Targeted persona (image generated with midjourney)

The reasons for this selection are:

1. Many beginners go bird watching by themselves, yet they are not skillful enough and need extra support from time to time. This need copes well with the design topic of 'introducing digital augmentation technology'.(user insight, 2023)

2. Professionals and enthusiasts are usually very skillful and hardly need digital supports (Whitney, 2023)

3. The designer can better relate to the needs as a target user.

4. Currently the product targeting the need of starters . Efforts towards this target group could help Leica create a low-price market.

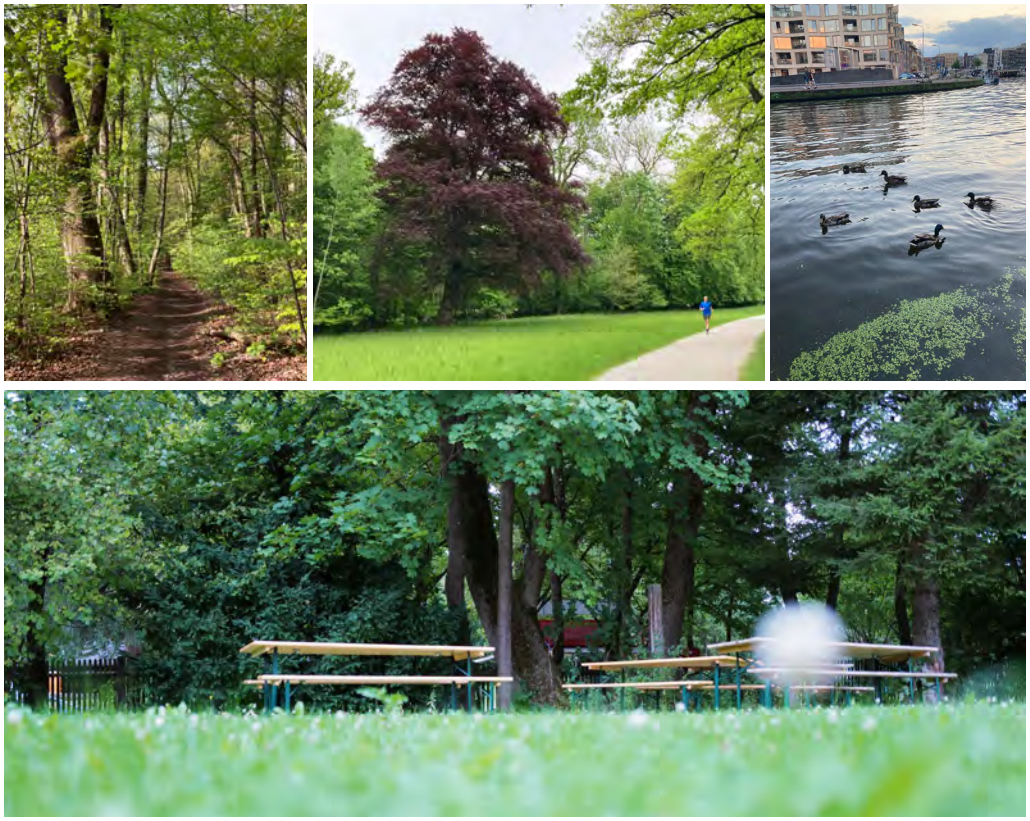


Figure 34 Urban area context pics (little forest, city parks and riverside, backyard, etc.)

The project context is defined within urban areas[11] ,because an urban context:

1. Creates a casual vibe for the activity that copes well with the target group, since many observers started bird watching around their house and don't want to commute far to observe a bird (user insight, 2023).

2. Is usually less challenging for bird watching, since birds there are usually louder and closer to human beings, making it easier to find them (user insight, 2023).

3. Contain birds that are more diverse than expected, allowing starters to explore them gradually.

4. Provides better network service than rural areas, which facilitates scenarios like streaming content to other devices.

11. "Urban area" in this thesis assignment means places within city outskirts and should be easily reachable by public transportation.

3.1.2 Problem definition for the target group

HMW create a more efficient way of sharing the location of birds?

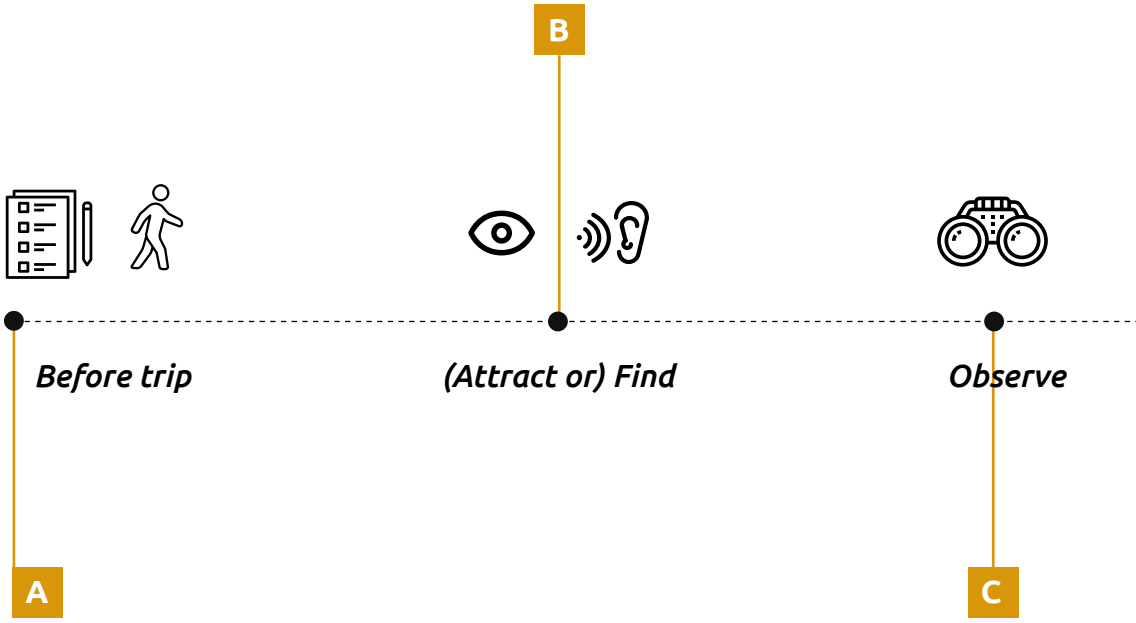
A better way of sharing the bird location is needed

Currently, location sharing of birds in group bird observation is done via gestures and verbal communication, which is not efficient. A laser pointer, however, has the potential to cause harm to the birds.

Starters need assistance in finding birds independently

It can be quite frustrating if it takes too long for starters to find a tiny bird in a foresty environment with limited audio and visual clues.

HMW h to find themse effort?



Starters need suggestions on where & who to go togther for a trip according to their situations

There is currently no support for starters that connects nearby bird watchers and detailed bird location information within urban areas.

Better experience with optical p

The set-up of optical products could time due to their complex controls. currently available optical products a ergonomically pleasant to use under observation. Besides, the look of the could also be improved to fit in an ur setting.

elp starters
birds by
lves with less

A media capturing method that is light weight and easy to set up(for handheld optical devices)

Cameras are usually too heavy to carry and can not zoom as much as optic products, while smartphone digiscoping takes long to set up without an adapter or tripod.

HMW create a media capturing tool that is light weight and easy to set up?

D

Identify ***Document*** ***After trip***

E

roducts

take
Many
re not
long
product
ban

HMW 'redesign' the form and experience of bird observation optical products?

(Potential need) a good reflection tool

For starter bird watchers, every bird watching trip is a good chance of learning. Therefore, chances are there to explore to help them make the best out of each experience afterwards.

HMW add more value to users 'before' and 'after' their journey?

3.2 Design direction

3.2.1 Scoping down

The problem definition is summarized into 'How Might We' questions indicating 5 different design directions:

> *1. HMW create a more efficient way of sharing the location of birds?*
>
> *2. HMW help starters to find birds by themselves with less effort?*
>
> *3. HMW create a media capturing tool that is light weight and easy to set up?*
>
> *4. HMW 'redesign' the form and experience of bird observation optical products?*
>
> *5. HMW add more value to users 'before' and 'after' their journey?*

The 5 questions add up to result in a quite broad solution space. To make the design direction specific enough for development, only one HMW question will be chosen to proceed.

Viability and desirability aspects are compared for each direction (the feasibility aspect is not discussed since the optimized technology or solution towards each direction is unknown)[12].

12. Check appendix RH for the comparison result.

The direction of ***'Find birds with less effort'*** was selected to proceed because it opens up a new innovation area to explore, connects tightly with the usage of optical devices, and solves the biggest need of customers.

3.2.2 A deeper look into the design direction

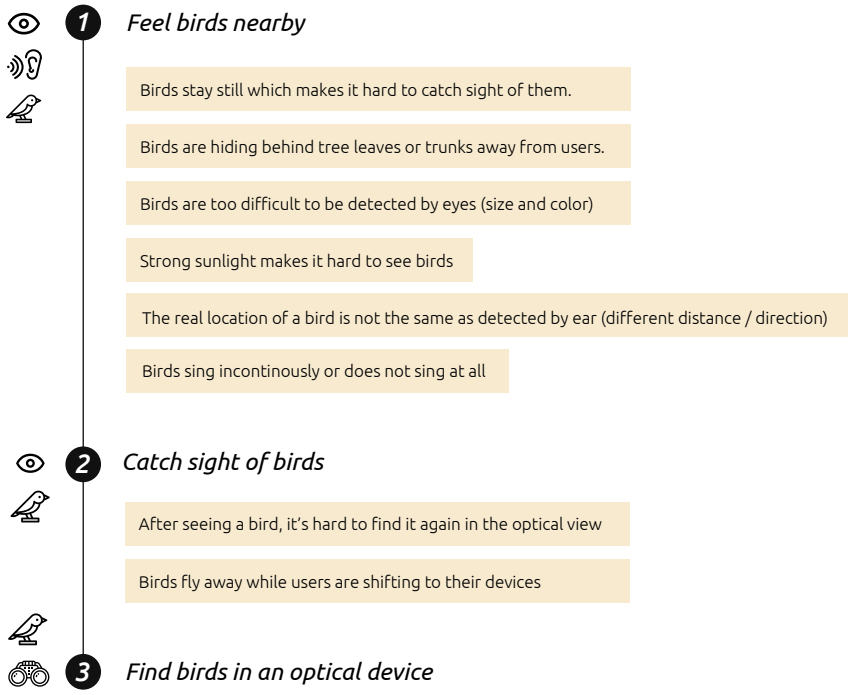
As the current design direction 'help starters to find birds independently with less effort' is very general and lack of definition, a detailed procedure of finding birds is looked into before stepping into development stage [13].

13. Water birds in an open area like wetlands and lakes are usually bigger in size, move slower and easier to find.

People have trouble mainly in spotting birds on the trees or environments, who are usually smaller in size, sing more frequently, and hide better in trees.

Bird watchers gradually find birds by receiving their information visually and auditorily. The usage of eyes and ears in this procedure are almost equally important. Specifically, binaural sound localisation is more used for telling a rough direction of birds, as bird watchers get closer, visual clues become more helpful in detecting bird movements and characteristics.

Many factors can influence the reception and perception of the information in this process. A list of detailed painpoints exploited from user research are listed below.



With the pain points stated upon, the design direction was reframed as:

Help starter bird watchers to catch sight of birds and find them in their optical devices independently with less effort, relying on the audio and (or) visual clues they make.

3.2.3 List of requirements

Must

01. The design must include at least a digital feature (either built into an optical product or in the form of accessory)
(As stated in the design brief, also a basic requirement for the master thesis of Integrated Product Design)

Should

02. The product should be relatively compact, lightweight and portable.
(According to the result of user and market research, 'small size and light weight' score high in users' preference in product selection.)

03. The product should help starter bird watchers to catch sight of birds and find them in their optical devices independently with less effort, with the audio and (or) video clue they make. (from users' painpoint in finding birds, info from interviews)

04. The product should be low-cost.
(Cost is a main influential factor for customer's selection towards products. The higher the cost, the higher the selling price will be, the less appealling the product is for beginners)

05. The product should be easy to set up and use.
(From user research. Many users find it cumbersome and time cosuming to adjust their optical devices. The setting up procedure and product usage shouldn't distract users from their focused experience)

06. Features of the product, if built in an optical device, should enable a good viewing experience.
(From market research, the digital features should not bring negative effects to the viewing experience.)

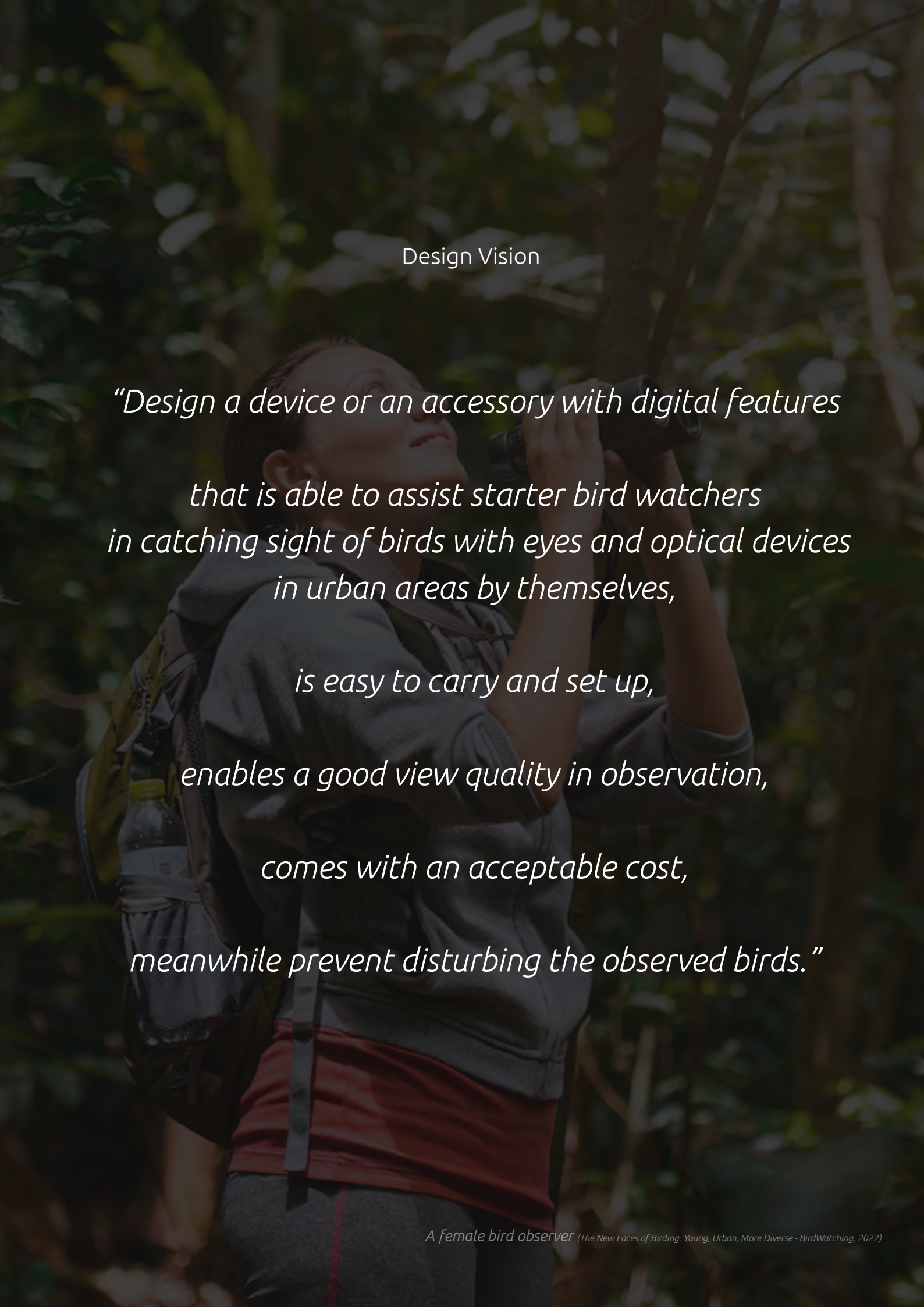
07. The product, if used properly, should prevent hurting or disturbing birds.
(From user research, it's important that birds stay unhurt and preferably undisturbed during the activity)

08. The product should be upgradable.
(From market research interivews, it's important that the product is upgradable for long-term use)

Could

09. The product could include additional functions to fulfill more needs.

(summarised from design research)



Design Vision

“Design a device or an accessory with digital features

that is able to assist starter bird watchers
in catching sight of birds with eyes and optical devices
in urban areas by themselves,

is easy to carry and set up,

enables a good view quality in observation,

comes with an acceptable cost,

meanwhile prevent disturbing the observed birds.”

A female bird observer *(The New Faces of Birding: Young, Urban, More Diverse - BirdWatching, 2022)*

04

Development

/ Ideation and conceptulisation
/ Technology selection
/ Build a functional mockup
/ Design validation

4.1 Ideation and conceptualisation

4.1.1 Ideation tools

Before direction selection: brainstorming session with Leica designers

An 1.5 hour brainstorming session was held with the Leica design team to explore different solutions before the selection of design direction. The reason for this is to explore wider opportunity areas and discuss which HMW question has the best potential to go for.

During the session the team brainstormed under the first 4 'How Might We' questions and provided product based solutions. 48 ideas were clustered after the ideation session[14].

Figure 35 brainstorming result

14. For a full result of the brainstorming session documented in text, see appendix DA

After initial sketching exploration[15]: Co-creation with real users

After initial exploration in certain envisioned functions, an online co-creation session was done with real target group users in the form of filling in their real situation and opinions on a Miro board created by the author. Ideation cards were created beforehand to help use to combine and extend on the base of existing ideas.

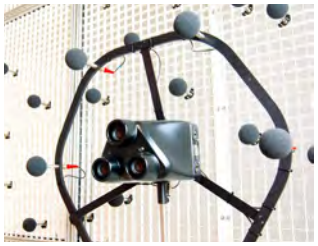
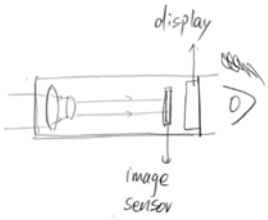
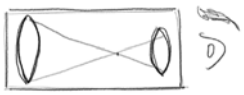
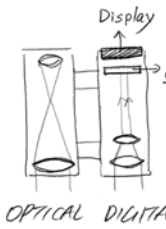
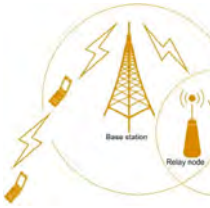
15. See appendix DB for a full list of ideation sketches in the form of ideation cards

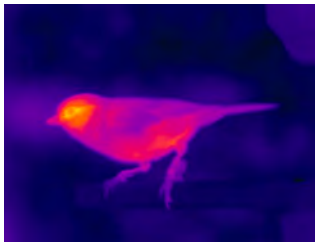
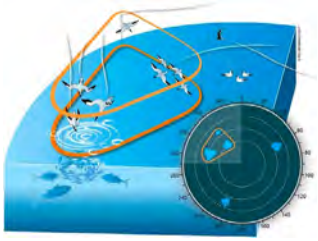
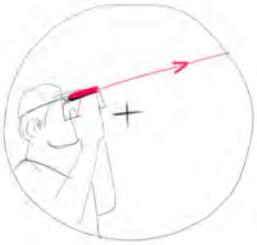
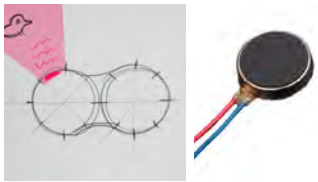
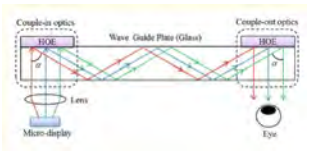
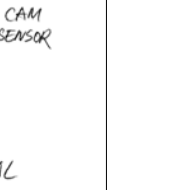
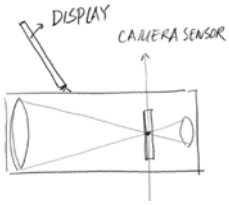
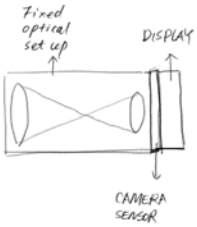
Figure 36 part of ideation cards (left) and co-creation board (right)

Along with ideation: Technology Morphorlogical chart

A morphological chart is considered as an efficient ideation method that explores different approaches under different needs. A table with available technologies for different functional modules of the product are listed below.

Table 2 Technology morphorlogical chart

	Solution 01	*Solution 02*	*Solution 03*
Locate bird	*Sound localisation tech e.g. beamforming* 	*Machine learning object identification* 	*motion detection tech e.g. o* 
Communicate location information	*A heads-up display (HUD) in optical path* 	*Digital screen/smartphone* 	*Transparent display in optica* 
Digital/ Analog	*Full digital view with optical zoom* 	*Full optical view* 	*Merged optical & digital view* 
Signal Processing	*Raspberry Pi* 	*ESP32* 	*Arduino* 
Sharing data (Optional)	*Bluetooth* 	*Built-in wifi hotspot* 	*Cellular network* 

	Solution 04	Solution 05	Solution 06
ptical flow 	*thermal imaging* 	*radar* 	*track another device's direction* 
l path 	*Vibration actuator around device* 	*Waveguide* 	*Plain optical sight* 
v CAM SENSOR 	*Optical view + Digital view* 	*Full digital view without optical zoom* 	*On another device e.g. smartphone* 
	*Smartphone* 	*Computer* 	
	*No data sharing between devices*		

4.1.2 Conceptualisation

4 concepts are built taking reference of the morphorlogical chart and user's preferred solutions

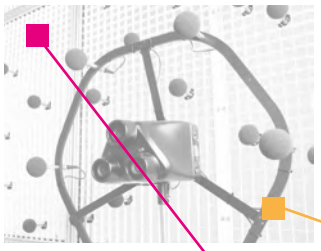
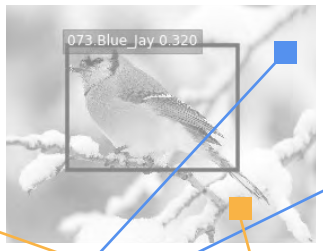
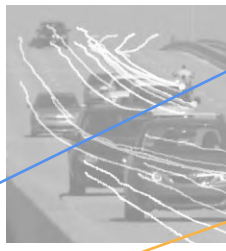
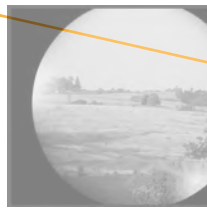
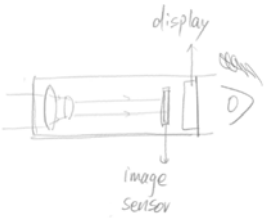
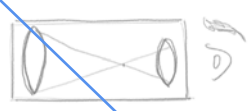
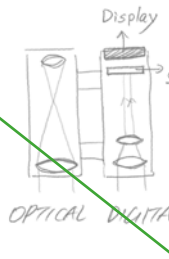
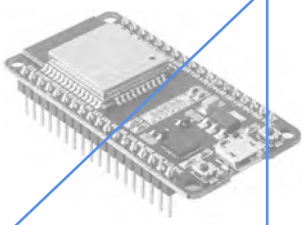
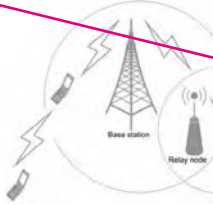
Table 3 Conceptualisation

Concept 01

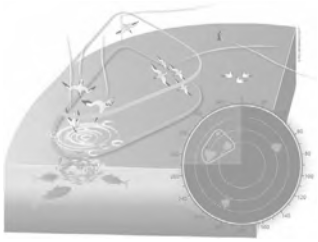
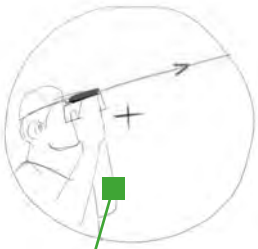
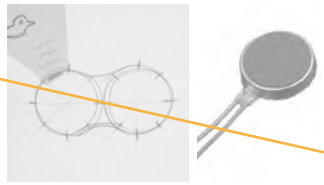
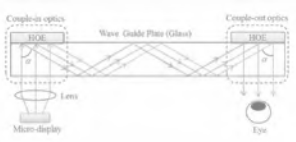
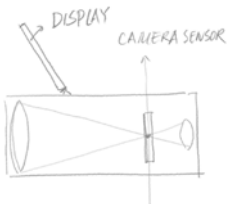
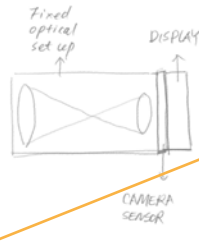
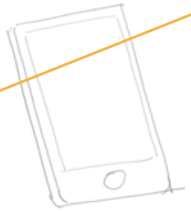
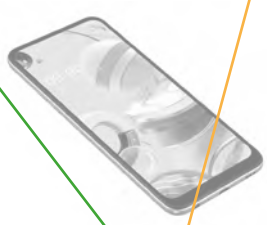
Concept 02

Concept 03

Concept 04

	Solution 01	*Solution 02*	*Solution 03*
Locate bird	*Sound localisation tech e.g. beamforming* 	*Machine learning object identification* 	*motion detection tech e.g. o* 
Communicate location information	*A heads-up display(HUD) in optical path* 	*Digital screen/smartphone* 	*Transparent display in optica* 
Digital/ Analog	*Full digital view with optical zoom* 	*Full optical view* 	*Merged optical & digital view* 
Signal Processing	*Raspberry Pi* 	*ESP32* 	*Arduino* 
Sharing data (Optional)	*Bluetooth* 	*Built-in Wi - Fi Hotspot* 	*Cellular network* 

in the co-creation session. Concepts are introduced in details from the next page.

	Solution 04	*Solution 05*	*Solution 06*
ptical flow	*thermal imaging*	*radar*	*track another device's direction*
			
l path	*Vibration actuator around device*	*Holographic display*	*Plain optical sight*
			
v	*Optical view + Digital view*	*Full digital view without optical zoom*	*On another device e.g. smartphone*
			
	Smartphone	*Computer*	
			
	No data sharing between devices		
			

Concept 01 'Digital laser' attachment for group bird observation

In group bird watching scenarios with a professional guide, sharing the location of birds takes time and effort and is low-efficient.

With a location-tracking accessory attached to observers' device, everytime the guide sees a bird from his/her device, other observers are able to find the same bird by tracking the direction of the guide's optical device.

The concept would not be very hard to develop and will definitely facilitate the group bird observation experience.

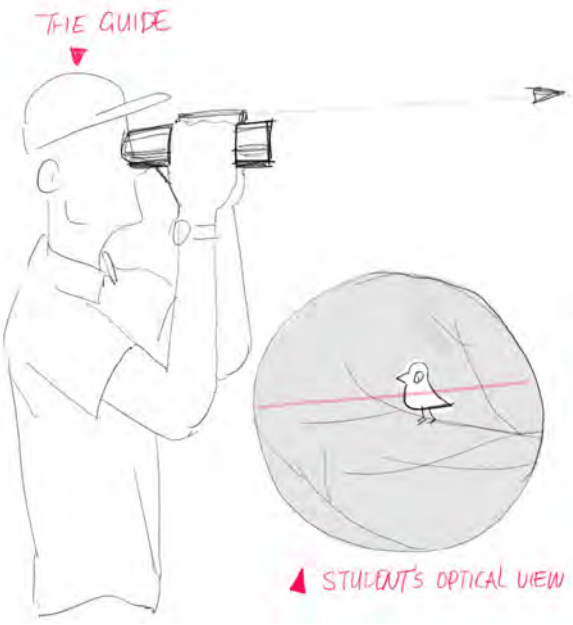


Figure 37 Concept 01

Concept 03 Digital assistance via a smartphone

This concept integrates digital features on users' smart devices that can assist them in finding birds both visually and auditorily.

In collaboration with bird related softwares that can help identify birds with their songs, the concept goes further in telling the rough direction of each bird singing in the environment with its built-in microphones (to perform binaural localisation). This allows birdwatchers to simply go to certain birds following the real time indication on their smartphone camera view.

This concept only serve as an assistance in finding birds, the real observation will still be done from an optical device.

Figure 39 Concept 03

Concept 02 Bird location hints in optical view via sound localization

The concept targets the scenario when birdwatchers are already close to a singing bird but fail to catch sight of it, or need a bit of a location clue after shifting to an optical view.

The concept locates birds by their songs with a microphone module connected to the optical device, and provides hints in the optical view that lead users to birds.

An additional feature of the concept is to record pure bird songs without background noises.

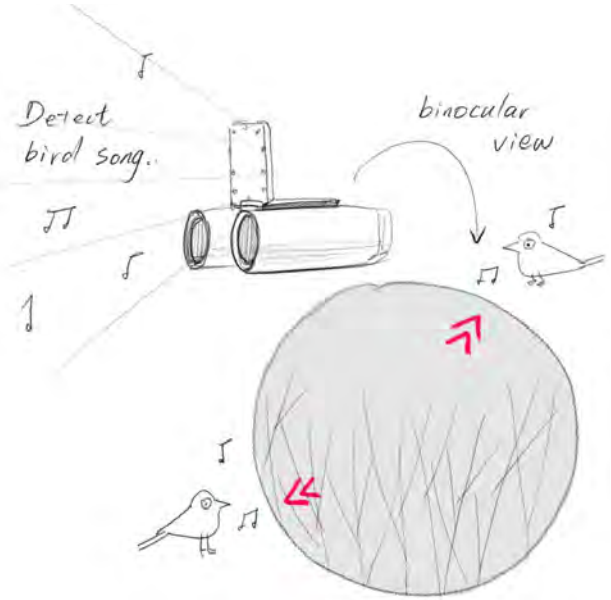


Figure 38 Concept 02

Concept 04 A zoomable digital camera with visual identification

The concept is going fully digital to achieve a lightweight housing and the possibility to gradually zoom in(without a sudden change in magnification).

The camera enables visual-related technologies to detect the motion and shape of birds that serves as assistance information for finding birds. The concept can further integrate the possibility of identifying birds after finding them in the camera view.

Since it is fully digital, the concept is also providing streaming possibility to other devices.

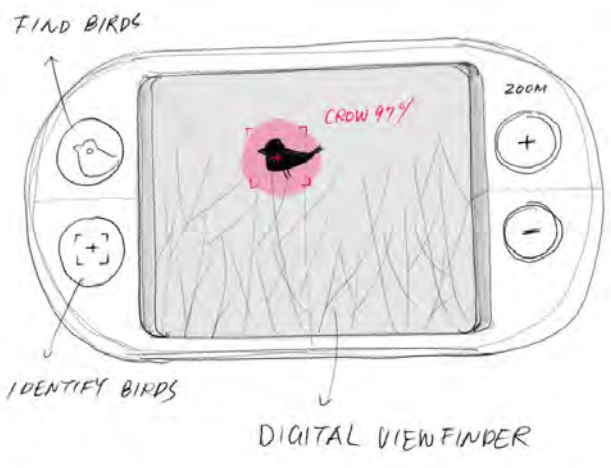


Figure 40 Concept 04

4.1.3 Concept evaluation

A Harris profile was built to evaluate the 4 concepts(see table 4 on the right). The evaluation criteria come from the list of requirements. According to the result, ***Concept 02*** and ***Concept 03*** are both scored the highest. User evaluation results are taken into consideration under this situation.

Evaluation from users [16]

16.
Check appendix DC to see the full evaluation result from users. The author is not involved in this evaluation.

> *Selection from user A: Concept 4*
>
> *' I would love concept 4 even more if it could be combined with the sound and microphone thing in concept 2. Because I already do use a camera so the gradual zoom already applies and I actually value it a lot. It helps me with spotting on my optics. But with bird information I think I would really enjoy the experience more. What would also help is having an integrated microphone to help me spot birds that I can only hear.'*

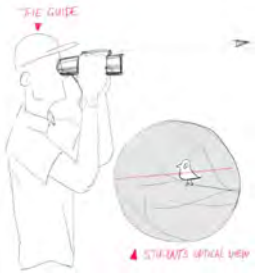
> *Selection from user B: Concept 2*
>
> *'I like the bird identification as well, as it might be the easiest way to spot birds, maybe for amateurs. Hunting for birds using optics is fun tho. Also, I'm not sure if this will be useful if there are no birds in the view.'*
> *'Would be nice to have a video recording function too.'*

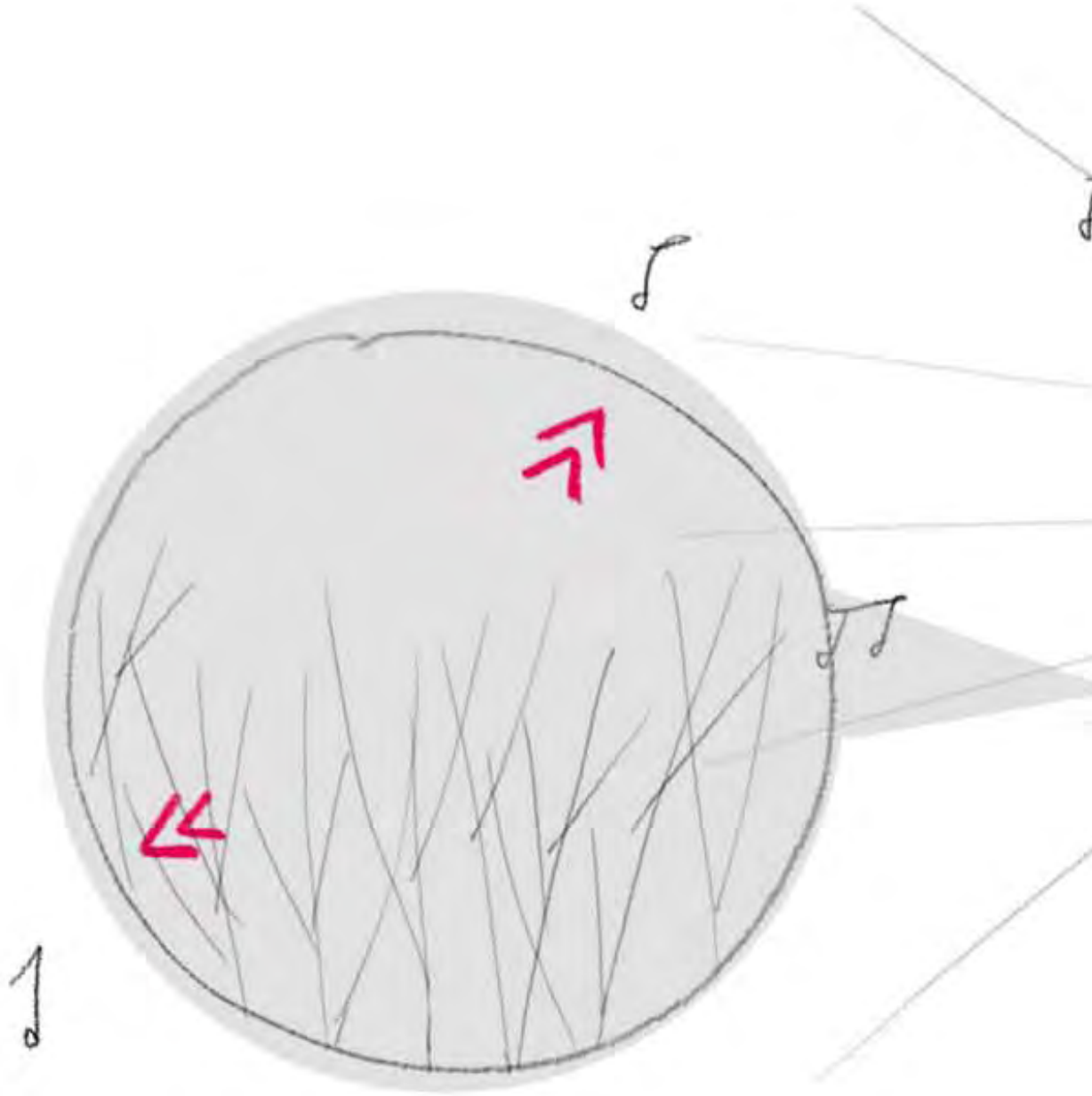
> *Selection from user C: Concept 3*
>
> *No reason was provided.*

> *Selection from user D: Concept 2*
>
> *' Make sure to not only track songs but also track the most low volume noise like wings slapping when flying, leaves on branches cracking, then this concept should be more accurate. Surely AI can help to filter out noises in a certain direction or distance.'*
> *'An additional function of sound recording is awesome and I love it! It can not only be helpful for learning but also for submitting the recorded file to certain websites.'*
> *'I love concept 3 as well, can we combine them? With a smartphone, tracking movements could be easier.'*

In general, users prefer concept 2 because it is relatively precise in locating birds meanwhile has a side function of recording separated audio files.

Table 4 Harris profile comparison

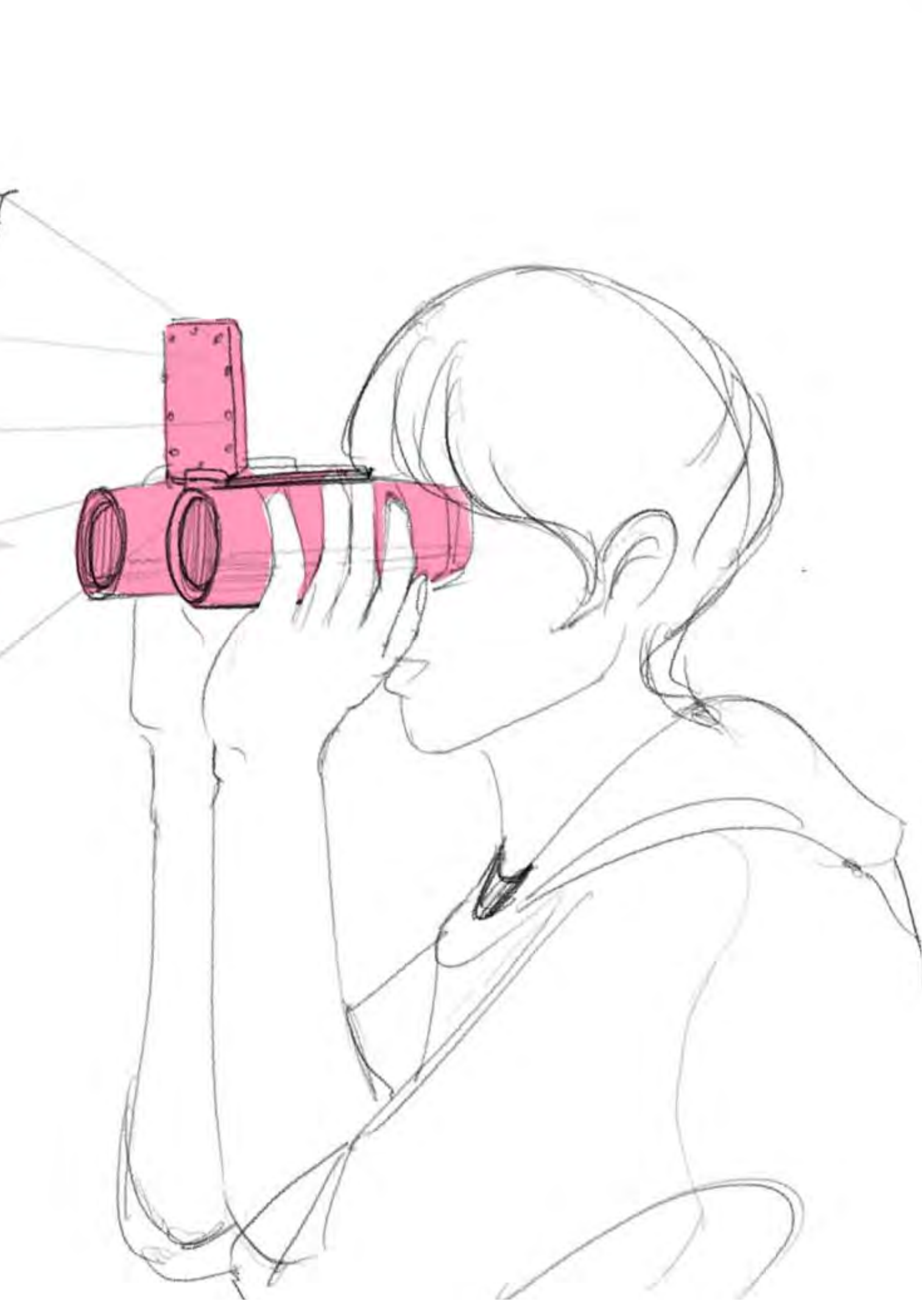
	Concept 01				Concept 02				Concept 03				Concept 04			
																
	- -	-	+	++	- -	-	+	++	- -	-	+	++	- -	-	+	++
Use on one's own																
Guidance in finding birds																
Precision in localisation																
Compact & light weight (the functional module)																
Low cost (the functional module)																
A good view quality (from observation device)																
Easy to carry and set up																
Prevent birds from being hurt or disturbed																
Upgradable																
Additional functions other than object-finding																
Final score	5				8				8				3			



Selected concept:

Bird location hints in optical view with sound localisation technology

+ Locate birds with a series of microphones that performs a precise result
+ Extract separate birdsongs from a mix of various sounds



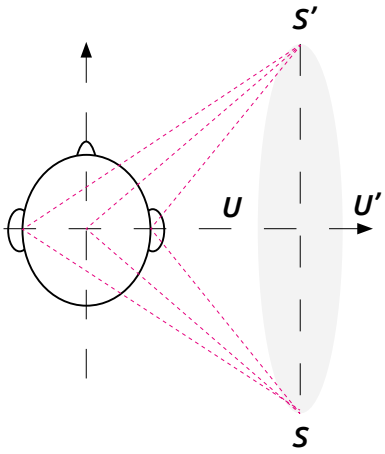
4.2 Technology selection

4.2.1 How human beings localise sound [17]

17. Check appendix RI for human's ability of sound detection and some general bird song information

Sound source localization is paramount for comfort of life, determining the position of a sound source in 3 dimensions: azimuth, height and distance. It is based on 3 types of cue: 2 binaural (interaural time difference and interaural level difference) and 1 monaural spectral cue (head-related transfer function). (Risoud et al., 2018b).

Interaural time difference (ITD): the sound propagation time between the two ears
Interaural level difference (ILD): intensity difference between the two ears for the same sound.
Spectral shape cues : arising from the acoustic filtering of the outer ears, head and upper torso, that shape the spectrum of the incoming sound wave according to the sound source direction. The function that describes this spectral shaping is called the head related transfer function (HRTF). (Andéol et al., 2013)



ITD and ILD provide precise localization in the azimuthal plane, with the exception of what is known as the "***cone of confusion***" . For sounds coming from the circumference of this cone, the axis of which is the interauricular line, there are no time or level differences, leading to confusing perceptual coordinates: the subject is unable to tell whether the sound is coming from in front or from behind, above or below, or from anywhere else along the circumference.

Sound source localization consists in determining the position of the source of a sound in 3 dimensions comprising 2 angles and 1 distance :
azimuth in the horizontal (or azimuthal) plane: 0 ± 180°;
elevation in the vertical plane: 0 ± 90°;
distance in depth: 0 ± ∞.

Horizontally, the azimuth is mainly determined by binaural factors, e.g. ITD and ILD. Vertically, height is determined monaurally, involving just one ear, e.g. changes in incident spectral shape (reflection, diffraction and absorption) brought about by the pinna, head, shoulders and bust, known as the head-related transfer functions(HRTF). Depth distance is also mainly determined monaurally(1 ear).

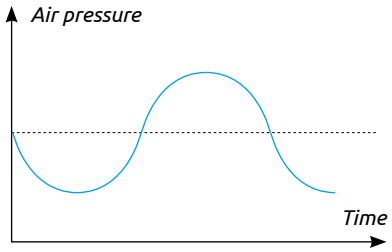
4.2.2 3D Sound localization

Before localisation: Digital audio processing

Digital audio is a representation of sound recorded in, or converted into, digital form. (Wikipedia contributors, 2023e) The 'recorded in' procedure is briefly explained below:

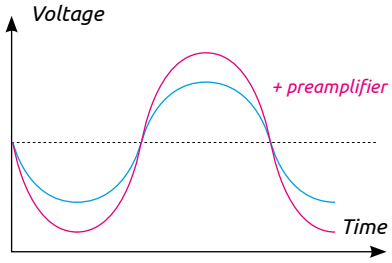
1 ***Receive sound***

Physical waveforms of sound is collected from the environment with a transducer, such as a microphone.



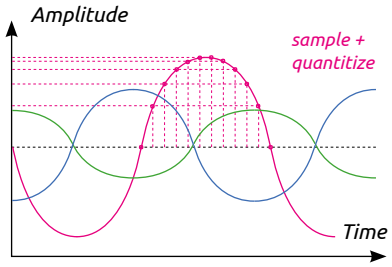
2 ***Analog-to-digital convertion***

In a digital audio system, an analog electrical signal representing the sound is converted with an analog-to-digital converter (ADC) into a digital signal, typically using pulse-code modulation (PCM).



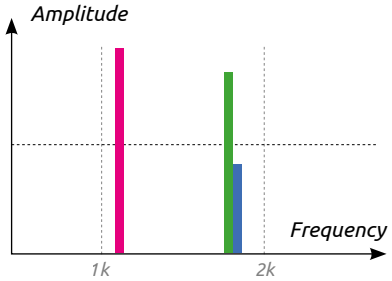
3 ***Sample + quantitize***

Digital audio recording does sampling by taking samples of the audio source along the soundwaves at regular intervals, then quantized at specific voltage levels.



4 ***FFT transformation***

If need, the sound can be translated from time domain to frequency domain with the help of fast fourier transformation. The FFT helps engineers determine the excitation frequencies in a complex signal and their amplitude.



After initial processing procedure, the sound signals can be further processed with 3D sound localisation softwares with the application of certain sound localisation principles, more information could be found from next page.

3D sound localisation principles

3D sound localization refers to an acoustic technology that is used to locate the source of a sound in a three-dimensional space (Wikipedia contributors, 2023a). This chapter briefly introduces 3 common 3d sound localization principles that are widely integrated in product solutions. Other principles like intensity difference, spectral analysis, etc. are not introduced here.

In real life, 3d sound localisation systems are usually more complex and apply multiple principles at the same time to reach a better precision.

Acoustic Beamforming

Acoustic beamforming is usually applied with a microphone array, which is any number of microphones operating in tandem. Acoustic beamforming adjusts the signals from each microphone in a way that they align and add up for sounds coming from the desired direction, but cancel out for sounds from other directions.

An acoustic camera is an imaging device used to locate sound sources and to characterize them. It consists of a group of microphones, also called a microphone array, from which signals are simultaneously collected and processed to form a representation of the location of the sound sources.

Applications: Teleconferencing and Communication Systems, Smart Speakers and Voice Assistants, Noise Cancellation, etc.

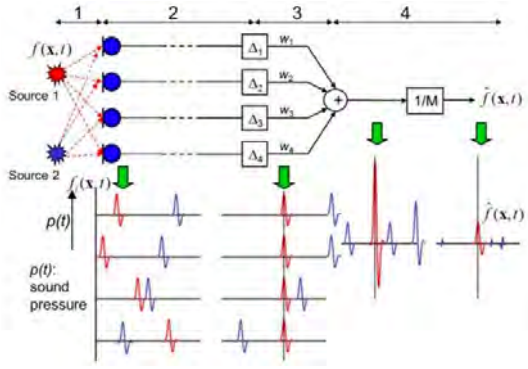


Figure 41 Sum-and-Delay Acoustic beamforming principle. The algorithm requires an array of sensors for determining the angle of arrival of a signal and then synchronizing all channels to enhance the signal coming from a certain angle. The result is that signals from a particular direction experience a constructive superposition, while others experience destructive interference.

Figure 42 The FLIR Si124 acoustic imaging camera can help locate pressurized leaks in compressed air systems or

Time Difference of Arrival (TDOA)

TDOA is based on the principle that sound waves from a source will reach two microphones at slightly different times, depending on the source's position. By measuring the time difference between the arrivals, the direction of the sound source can be estimated.

Applications: Hearing Aids and Assistive Listening Devices, Microphone Arrays and Beamforming, Robotics and Autonomous Systems, etc.

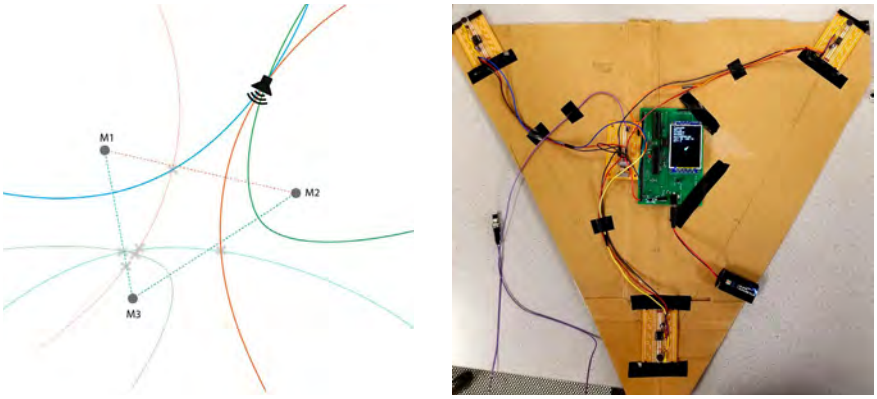


Figure 43 Explanation multilateration using TDOA.
Suppose there are 3 microphones in the environment forming a triangle, knowing the distance difference(could be calculated with time difference) between each 2 microphones and the sound source, hyperbolas can be drawn. The intersection of them indicates the sound source location in theory.
Figure 44 A triangulation localization test setup (Sound Localization, n.d.)

Phase Difference (PD)

Phase difference localization uses the phase shifts between signals received by different sensors to estimate the direction of the sound source.

Applications: Musical Instrument Localization, Underwater Acoustics, etc.

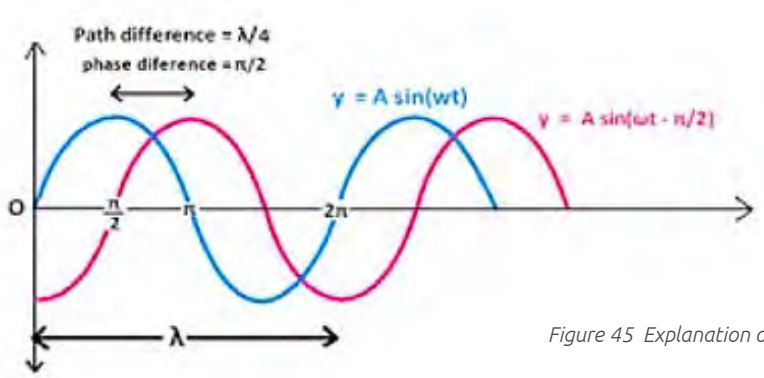


Figure 45 Explanation of phase difference

4.2.3 Solution exploration

The envisioned solution contain a hardware and software combination that is easy to set up, low cost, compact and relatively precise at a longer distance.

Adaptable approaches: software

Though there are currently numerous technological approaches/solutions in sound source localisation, the amount of the available and well-functioned open-sourced solution is quite limited. 3 potential solutions are listed below.

Table 5 Adaptable software approaches

Name	**Python HID library**	**HARK**	**ODAS**
Explain	Certain microphone arrays can be recognized by the computer as an HID device, some USB library can be used to connect to the device and send/receive commands to / from it	HARK is open-sourced robot audition software consisting of sound source localization modules, sound source separation modules and automatic speech recognition modules of separated speech signals. (Hark, n.d.)	ODAS is short for Open Embedded Audition System. It's a library dedicated to perform indoor sound source localization, tracking, separation and post-filtering. (Grondin et al., 2022)
Picture			
Precision	The solution is only reading the Dir(direction of arrival) of the sound arriving at each MEMS microphones and providing results on a 2D level. Not precise when the distance is further.	Relatively precise in an indoor environment and is able to detect multiple sound sources. No idea how well it works outdoors when more noises exist.	Relatively precise in an indoor environment and is able to detect multiple sound sources. No idea how well it works outdoors when more noises exist.
Principles	TDOA	Sound source localization in 2D using variants of the Multiple Signal Classification (MUSIC) algorithm Geometrically-constrained higher-order decorrelation-based source separation with adaptive step-size control	TDOA Level and phase difference Beamforming Generalized Cross-Correlation with phase Transform method(GCC-PHAT)
Processing power	Very low	Requires a significant amount of computing power(sometimes 3 computers) which makes it less suitable for use on low-cost embedding hardware.	Able to run flawlessly on a Raspberry Pi board
Hardware compatibility	microphone array (linear/circular/matrix,etc.)	microphone arrays are preferred	Microphone arrays(mostly circular microphone array. Rectangular microphone arrays with more mics can also be used).

ODAS(Open Embedded Audition System) is selected to proceed because it:

1. Provides higher precision in sound source localization from multiple directions(half a sphere) and is relatively easy to set up.
2. Require less processing power while provides relatively precise results.
3. Has compatible hardwares that are easily accessible.

Adaptable approaches: hardware

As stated before, a compact-sized, cost-efficient microphone setup that is able to work with ODAS to locate sounds is preferred. Single microphone modules that are too big in size are not discussed here. As ODAS is proved to work well with microphone arrays to perform beamforming, different microphone array products are compared in table 6.

Table 6 Adaptable software approaches

Multi-channel compact[x] microphone array products from different manufacturers				
Type	Linear array 	Circular array 	Matrix array 	Spherical array 
Size(cm)	15.7 x 1.7 x 0.3	9(diameter) x 0.2	13.2 x 20.2 x 1.8 (data from a 16 mic array)	very big, diameter can >50
Cost	€30-50	€90-200	€250-300	>€1000
No. of mics	2-6	4-8	16	48 (or even more)
Detection Range	not specified, <10m	maximum detection distance around 15m	not specified, should be further than 15m	from 0.5m till dozens of meters
Feature	sound localisation from only one single direction	sound localisation in all the directions	sound localisation in all the directions	Sound localisation from 360 degree directions, also the most precise type of microphone array exisiting
Limitation	Not able to detect sound from multiple directions	Limited number of microphones and test precison	Size too big to implement into the concept	Size too big to implement; too expensive to consider

A circular microphone array is selected to proceed because it:

1. Receives sound from all the directions instead of one limited direction
2. Provide relatively precise beamforming results at a distance
3. Small in size and easy to integrate into products
4. Has a price that is not very cheap but acceptable

4.2.4 Technology test

After the selection towards hardware and software is done, a technology test is done to check how accurate the localisation result is[18].

18. The precision really depends on the shape of the microphone array, the distance between sound source and the microphone, and the level of noise and reverberation.

According to the developer, an accuracy close to 5 degrees could be achieved with an ideal setup, but this can change depending on the aforementioned factors.

Setup: Hardware and software

Below is a brief introduction of the selected circular microphone array (Minidsp UMA-8) and ODAS(Open Embeded Audition System).

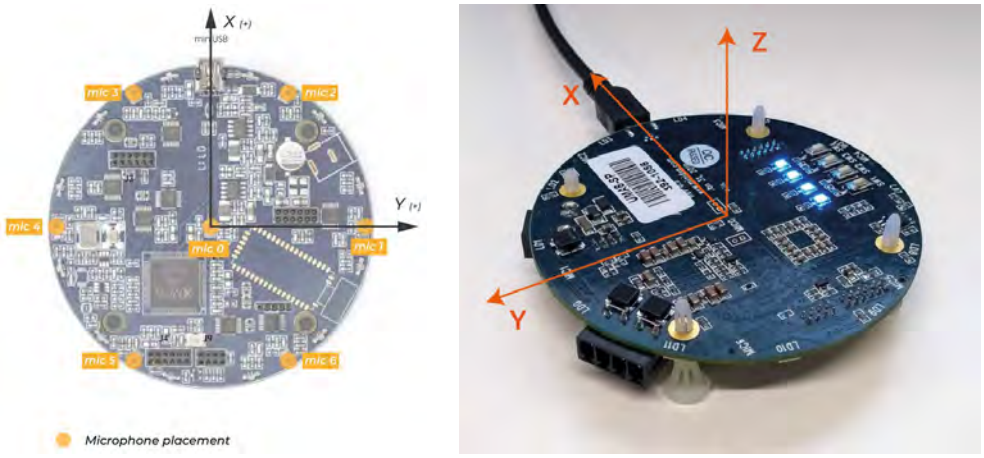


Figure 46 Minidsp-8 microphone array bottom view and perspective view

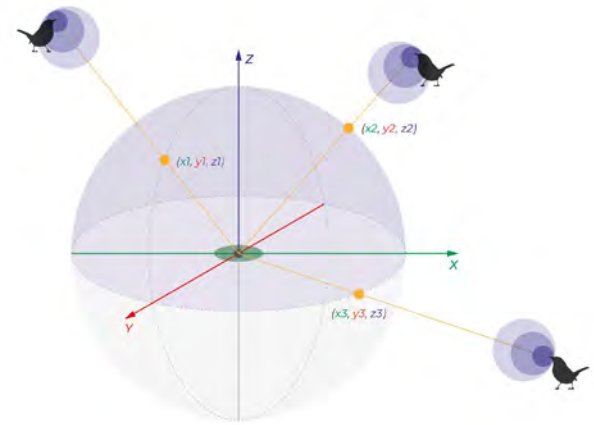


Figure 47 ODAS principle explaination

Microphone at the center of sphere, (x,y,z) values are 3D vectors output from the software indicating directions of the singing birds.

Minidsp UMA-8 is a 8-channel USB microphone array developed for human voice command, it has 7 MEMS microphones(labeled from mic0-mic7 in figure x) and a spare PDM port in the center. The device receives sound from every direction. After getting the sound from UMA-8, ***ODAS*** processes sound localisation algorithms and outputs the 3d vectors of the localized sound sources within the range of half of a sphere (in the output vectors, z value is positive forever, meaning the coming sound directions should be limited within half a sphere to get precise localisation results)[x].

Moving sound test

A rough precision test with a close distance between microphone and sound source (<2m) was done with ODAS_Ros, the GUI interface of the program. Though an average delay around 0.5 second could be observed, the setup was in general quite precise in detecting and tracking moving sounds in all 3 directions [19].

19. Check appendix DD to see videos on how ODAS tracks moving sounds from different directions.

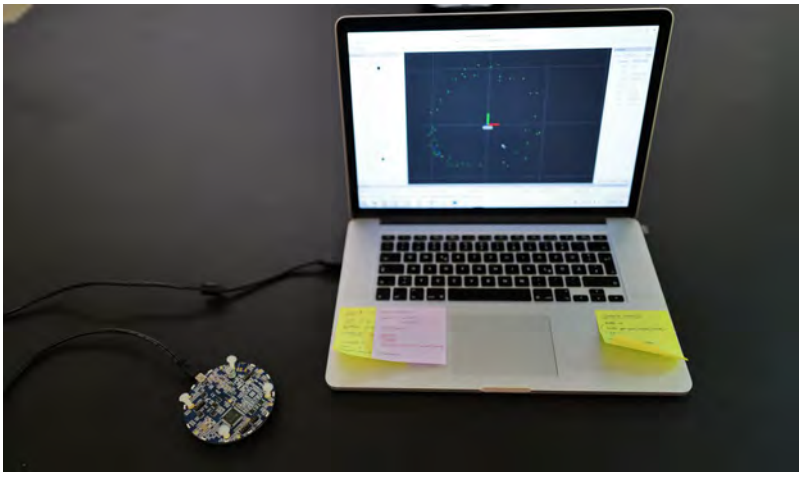


Figure 48 Moving sound test with ODAS_Ros (a GUI interface for ODAS)

Static sound test

A quantitative test was done with the raw output from ODAS (3d spatial vectors) to measure the precision of the system at close distances in an indoor environment. The sound is played by a recording pen (sound level range 0-30) in the front area of the microphone for around 10s every time. Every test is done 3 times to prevent accident

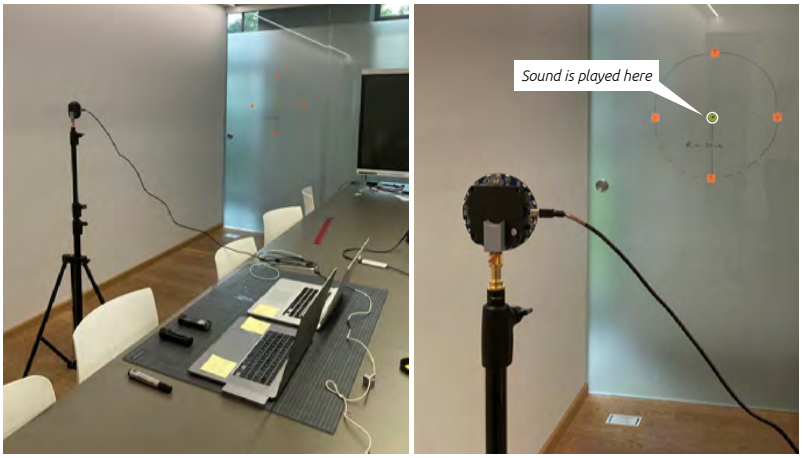


Figure 49 Static sound test

Table 7 Indoor static sound test result

Distance between source & mic (m)	No. of songs	Sound file	loudness (recording pen sound level 0-30)	Delay in detection (s)	Error caused by the setup(degree)	Real error [20] (degree)
3	1	Black bird song(01)	25	approx. 0.5	0 - 2	2 - 6
	1	Black bird song(01)	20	approx. 1	0 - 2	2 - 5
	1	Black bird song(01)	15	3-4	0 - 2	2 - 7
	1	Black bird song(01)	10	>10 / fail to detect	0 - 2	4 - 11
	1	Human talk(02)	20	approx. 1	0 - 2	2 - 5
	2	(01) + Blackcap song(03)	20; 20	4-5	0 - 2	2 - 7
5	1	Black bird song(01)	30	approx. 0.5	0 - 2	2 - 6
	1	Black bird song(01)	25	approx. 1	0 - 2	3.5 - 7
	1	Black bird song(01)	20	approx. 1	0 - 2	4 - 8
	1	Black bird song(01)	15	2-3	0 - 2	not detectable
	1	Human talk(02)	25	approx. 1	0 - 2	3.5 - 8
	2	(01) + Blackcap song(03)	25, 25	2-3	0 - 2	4 - 9

20.
$[\text{real error}]_{max} = [\arctan(n/z)]_{max}$
$[\text{real error}]_{min} = [\arctan(n/z)]_{min}$
$n=y$ or $n=x$

Conclusions:

1. The longest distance that the setup can detect is between 8-10m. The sound has to be played at a very big volume to trigger the microphone.

2. The test setup can reach an error between 0-8 degrees, if the sound is played loud enough at a distance of around 3m. At a distance of around 5m, the error can reach less than 4 degrees.

3. The sound localisation result is not much affected by the types of sound but more by the loudness(the louder the sound is, the better localisation precision the system has) and continuity(the more consistent the sound is, the better localisation precision the system has) of the sound. The setup is able to detect sound direction more precisely when the amplitude of the sound source is strong. As the volume of sound becomes lower, the delay in detection will become longer, with a drop in precision as well.

4. Though ODAS is built with Kalman and particle filters that roughly eliminates the environmental background noise, its current version is created without any deep learning capabilities (e.g. built in neural network) to more efficiently filter other noises from the envisioned sounds, which means the system can not separate the bird song with other types of sounds (e.g. human voice). This limitation might lower the accuracy of the localization and lead to a higher demand for the testing environment.

The coming chapter: build a funtional mockup

4.3 Build a functional mockup

4.3.1 Expectation

21.See the author's calculation in appendix RJ.

An average distance between the observer and the birds in urban observation is estimated to be around **5-20m** (max. around 45m), concluded from the literature, user interview and the author's calculation with digiscoping pictures[21]. As the tested microphone array has a limitation in the detection distance(around 10m), it would already be ideal that the mockup can **detect 1-2 birdsong(s) played at a strong level within a distance of 8-10m (indoor) and is able to effectively track and locate the sounds in a camera view**.

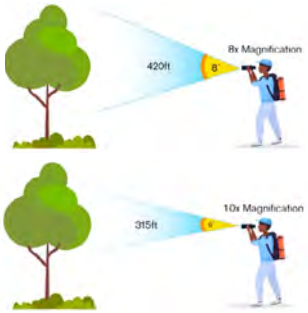


Figure 50 Field of view - the width of the area you can see

It is expected that the sound localisation system project the 2D location direction hints of birds at the edge of the view in the form of image patterns, or in the view when the bird is visible from the device. The pattern should be noticable while not interfering with the viewing experience (some possible patterns are shown in Figure 51).

Figure 51 Possible forms of direction indication pattern in a optical view

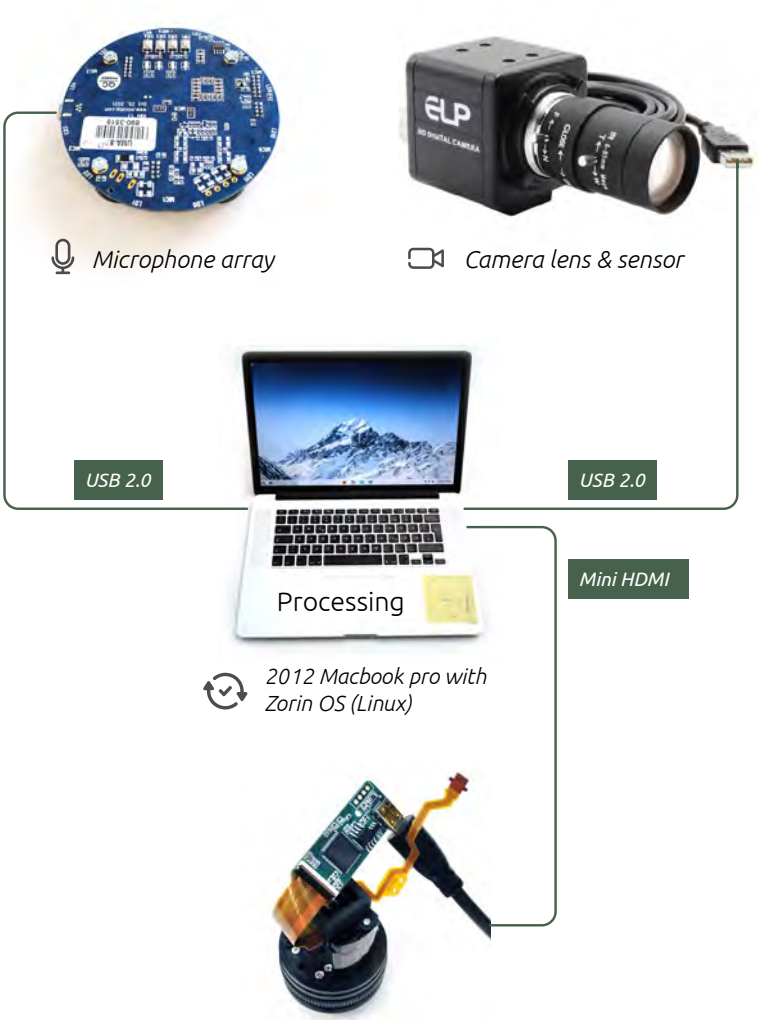
4.3.2 Mockup process

Mockup setup

The goal for the mockup is to test the feasibility of the expected effect at a minimum cost. Therefore, the specific mockup setup might not be the same as expected in the previous morphorlogical chart.

Figure 52 Projection result with a head-up display(HUD) is usually centralised (Gradišnik, 2022)

The hardware of the mockup is composed of audio and video input devices, a processing power and an output display module. Different to the optical viewing solution chosen in the morphorlogical chart previously, a digital viewing setup is selected due to its low cost and its flexibility in projecting content on different areas of the view. However, a digital display results in a rectangular view instead of a circular one which leads to a little bit different projection calculation.



Software processing procedure

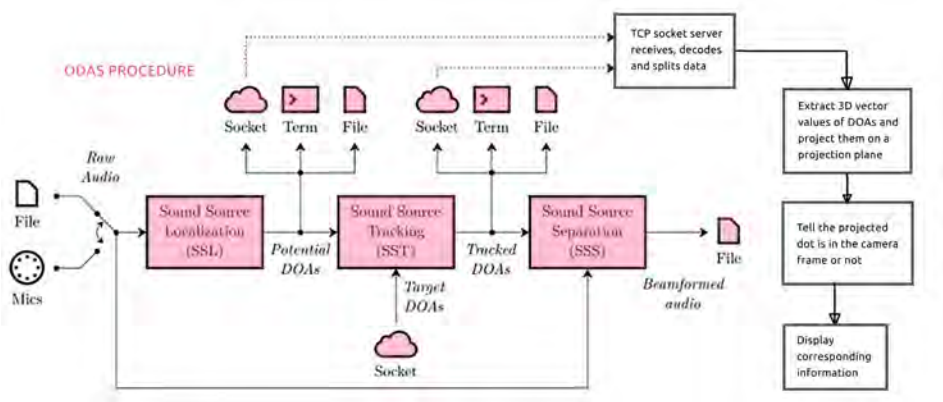


Figure 53 processing procedure

22. See appendix DE for a detailed set up procedure for ODAS and the selected microphone array.

1 *ODAS performs SSL, SST and SSS* [22]

ODAS's Sound Souce Localization (SSL) module generates a fixed number of potential DOAs, which are fed to the Sound Source Tracking (SST) module. SST identifies tracked sources, and these DOAs are used by the Sound Source Separation (SSS) module to perform beamforming on each target sound source. (Grondin et al., 2022b).

Under the context of this project, the SST result is especially important to get the tracked DOAs. Therefore the source code of ODAS was altered to only print SST information. The printed data line looks like below:

1st potential source *3rd potential source*

1298 0.000 0.000 0.000 -0.458 -0.807 -0.374 0.000 0.000 0.000 0.000 0.000 0.000

timestamp *2nd potential source (detected)* *4th potential source*

23.See appendix DF for the python code made for the 2nd, 3rd and 4th steps

2 *Transferring data output* [23]

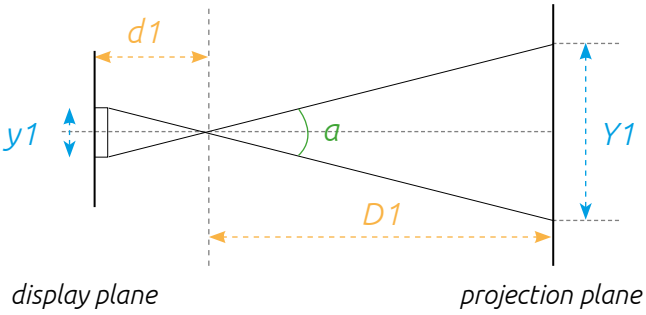
The generated DOAs from ODAS can be sent in JSON format to a terminal, to a file or to a TCP/IP socket(Grondin et al., 2022b). A TCP socket server was built in python to receive the DOAs locally, for a TCP socket requires less memory, constantly updates information while cleaning the buffer. As around 120-140 data lines are transferred per second and there can be 60 - 80 bytes of data in a line, a buffer size was adjusted for both ODAS and python server as 11000, to achieve a consistent and simultaneous data sending and receiving process.

3 *Translating output data*

Data received from TCP socket is decoded first, then splitted into single unit and stored in an array. For each line in the decoded and splitted data, 4 spacial vectors of DOAs are extracted, then normalised into vectors that have a same unit length.

Figure 54 projecting converted data in the form of an arrow on a camera view

The 3D to 2D projection is done under simple math calculations. Firstly, the size of the projected plane is in proportion to the display size (640 x 320 pixels) ; secondly, there is a trigonometric relationship between the projection plane distance and the projected plane's x or y dimension, which requires the angle of the camera's FOV. It is known that the selected ELP camera has an orginal FOV of 90 degrees, the FOV is calculated as 11.25 degrees under 8x magnification. In the end, the distance to the projection plane (D1 in figure 55) can be calculated and the projection of vectors can be done as follows.



$$d1 / D1 = y1 / Y1$$

$$y1 = 2*d1*\tan(a/2)$$

$$y1 = 320$$

$$a = 11.2$$

Figure 55 projection calculation

4 *Tell if the projected vector dot is visible in the display view frame*

If the projected vector value is within the camera frame range, then the dot is visible, otherwise not. If the dot is visible, a green circle is drawn around the sound source indicating the location area of sound source. If not, a smaller red circle is drawn around the edge of the view indicating the sound source direction.

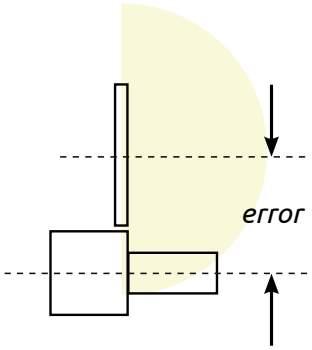
Figure 56 2 detected sound sources in the environment, one in the camera view(the SONY device) and one out of camera view (the processing computer)

5 *Display the view*

The capturinig and displaying of the image flow is done with OpenCV, a library of programming functions mainly for real-time computer vision(Wikipedia contributors, 2023b). The view will be displayed in a camera view finder built-in the mockup once it is connected to the processing power with a Mini HDMI cable.

Microphone configuration

As the idea of the mockup is to overlay data received from microphone on the camera view, it's really important that the 2 devices are aligned properly or within a small error range.



A decision of placing the microphone array on top of the camera is made to receive sound easier. However, a precision error could be caused by the vertical distance between the centre of the microphone and the camera's sensor. The longer this distance is, the bigger the error will be. In real situation, the influence of the error depends on the distance between the observer and the object, see Figure 59 for a visual explanation. By fixing or estimating the distance between the observer and the sound source, the error could be calculated and elimated. This calibration effort was only made after the submission of this file.

In addition, 2 different orientations of the microphone array placement (vertical and 45 degree tilted) were also compared. The vertical microphone configuration makes sure that the microphone is pointing at the same direction as camera and enables a simple projection calculation. The 45 degree configuration, though need to run a vector transformation (see Figure 60) to project the result correctly , could be helpful in concentrating on more sounds from an upper direction, which is good for observing birds on the trees. The 2 configurations were both tested in real life, the vertical setup was proved to have a better localisation precision and was chosen to proceed.

Figure 57 vertial orientation

Figure 58 45 degree orientation

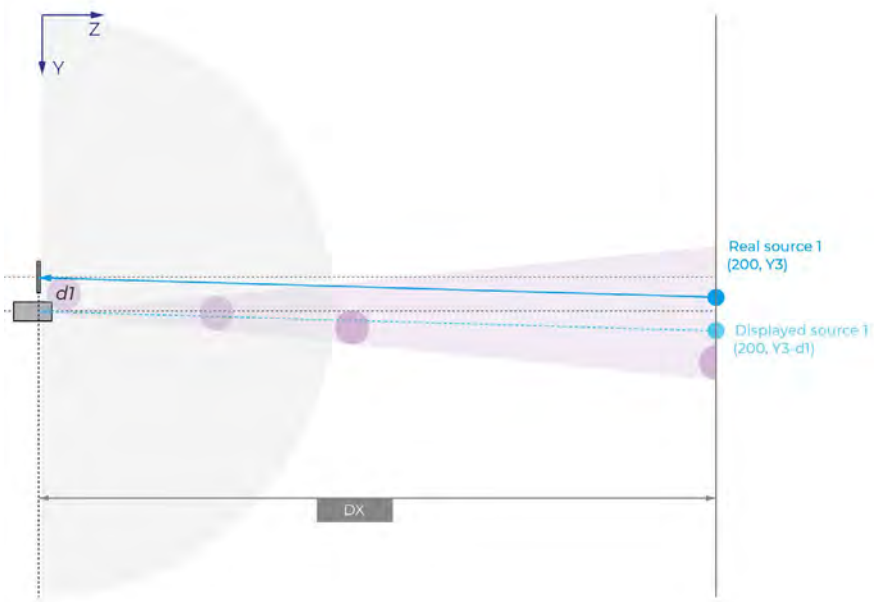


Figure 59 Error estimation of a vertical setup with the distance of the centres between camera sensor and the microphone array (FOV=11.2 degree)

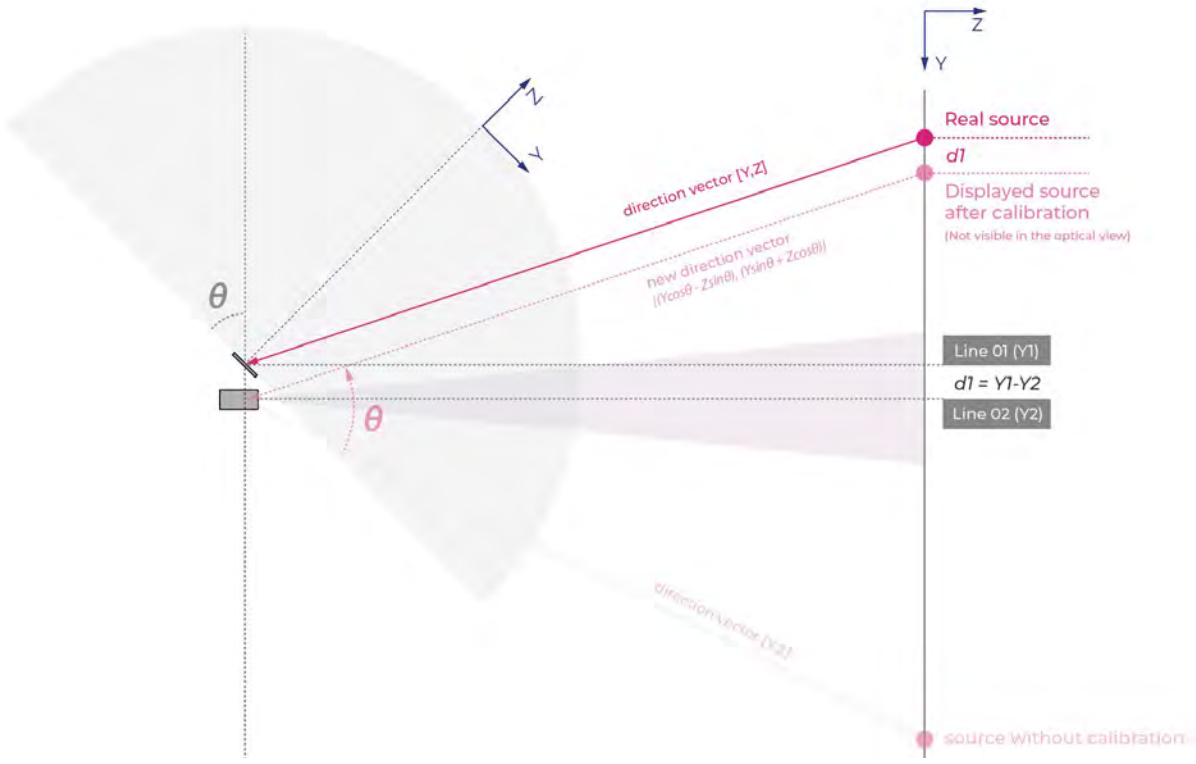


Figure 60 Vector transformation when the microphone array is tilted for certain degrees

4.3.3 Final mockup

Figure 61 Mockup mounted on a tripod to ensure stability and better viewing experience (tak

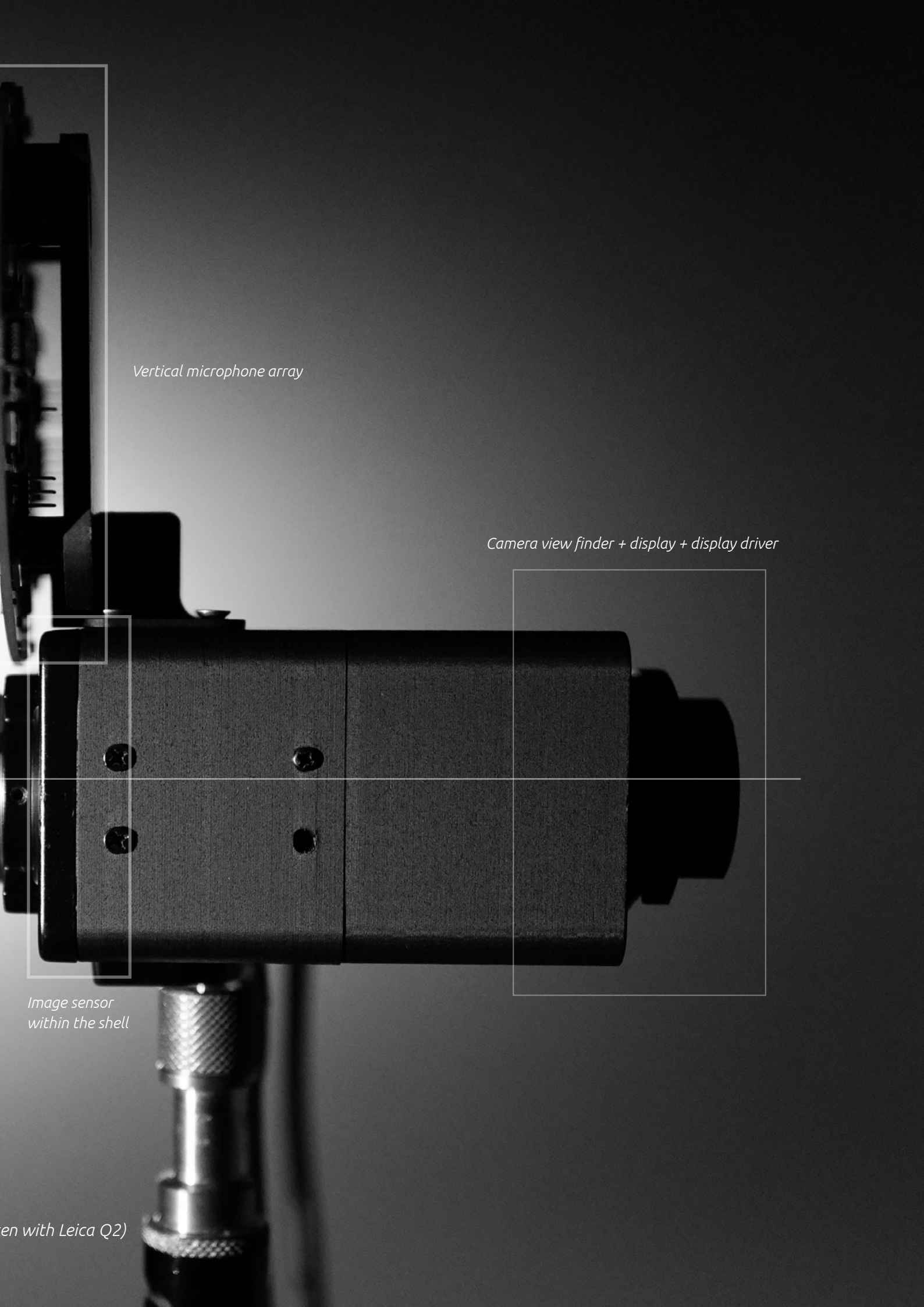

Vertical microphone array
Camera view finder + display + display driver
Image sensor
within the shell
en with Leica Q2)

Figure 62 Mockup front view (taken with Leica Q2)

Figure 63 Mockup back view (taken with Leica Q2)

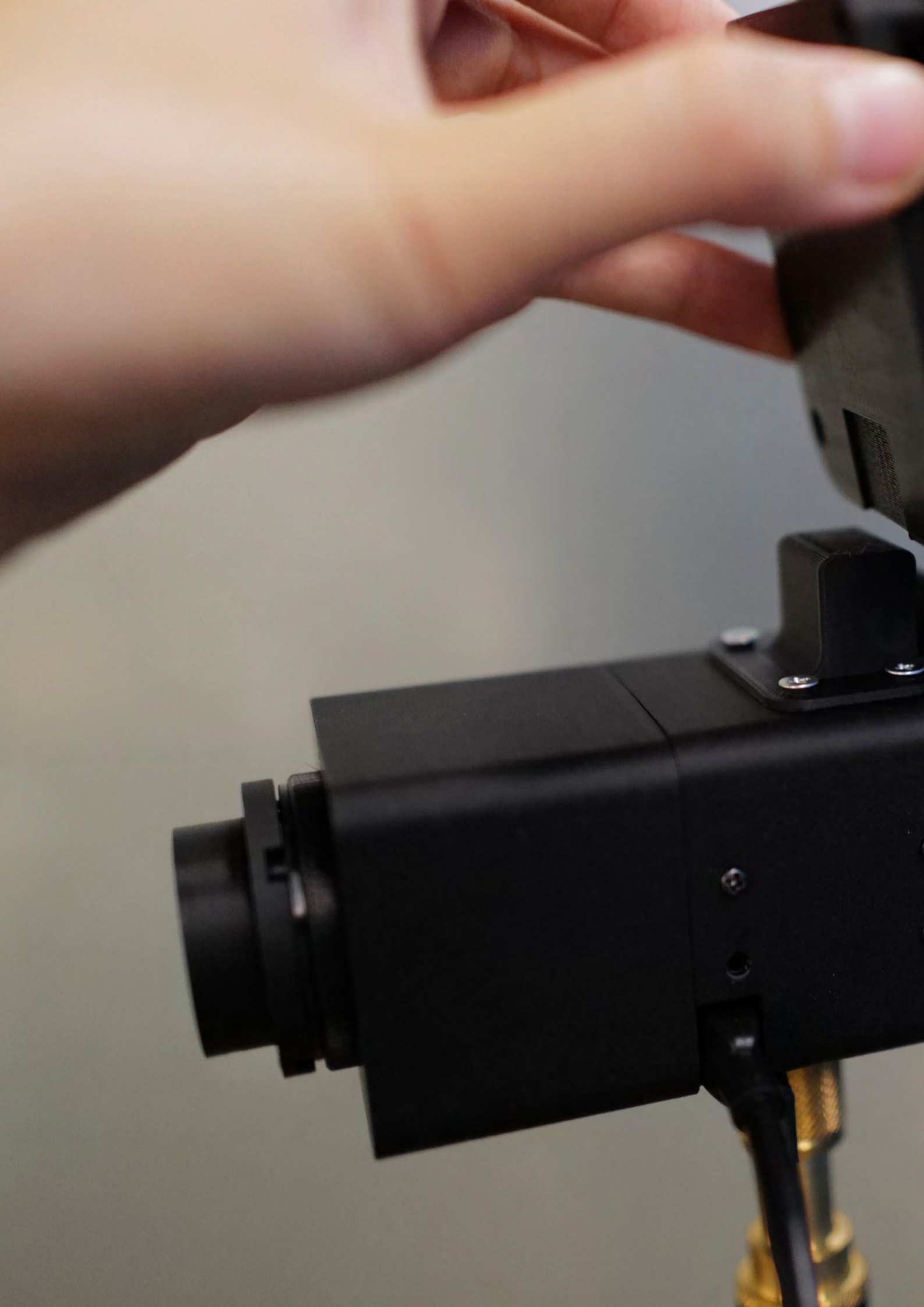


Figure 64 Detach microphone from the main body (taken with Leica Q2)

4.4 Design validation

4.4.1 Mockup performance

2 small tests are done to test the performance of the mockup.

The mockup is close to the expectation of **detecting 1-2 birdsong(s) played at a strong level within a distance of 8-10m (indoor) and is able to effectively track and locate the sounds in the camera view**. The precision test shows that the system is able to detect and locate a sound that is around 70-90 dB at a distance of 7-8m, but can hardly detect sound coming from a further distance (could also be due to the environmental setup, the test is down first in a room then extended to a corridor for distances longer than 5m).

The precision result was quite good within a distance of 0-4m, the mockup has no problem tracking and locating sound sources that are loud enough in this range. However, from 5m-7m, the result became very unstable and moves around quite a lot. The green circle can only be seen for a limited amount of time. An interesting phenomenon in common is that the location result is always on the left side of the real sound source, which is probably caused by the reflective wall on the left.

Information related to the tests are shown below. Real user tests in an outdoor scenario are not done, since the precision would not remain relatively accurate with all the environmental background noises.

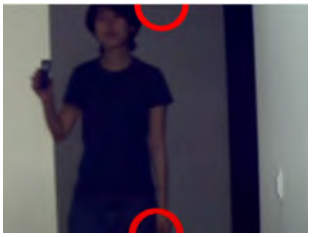


Figure 65 2 sound sources are constant being detected

Multiple sounds [24]

The mockup is able to display 0-4 tracked sound sources. The localisation result is the most precise when the sound sources are closed to each other and played at similar volume. If one or more sound sources are apparently louder than others, the location accuracy of other sources won't be very good.

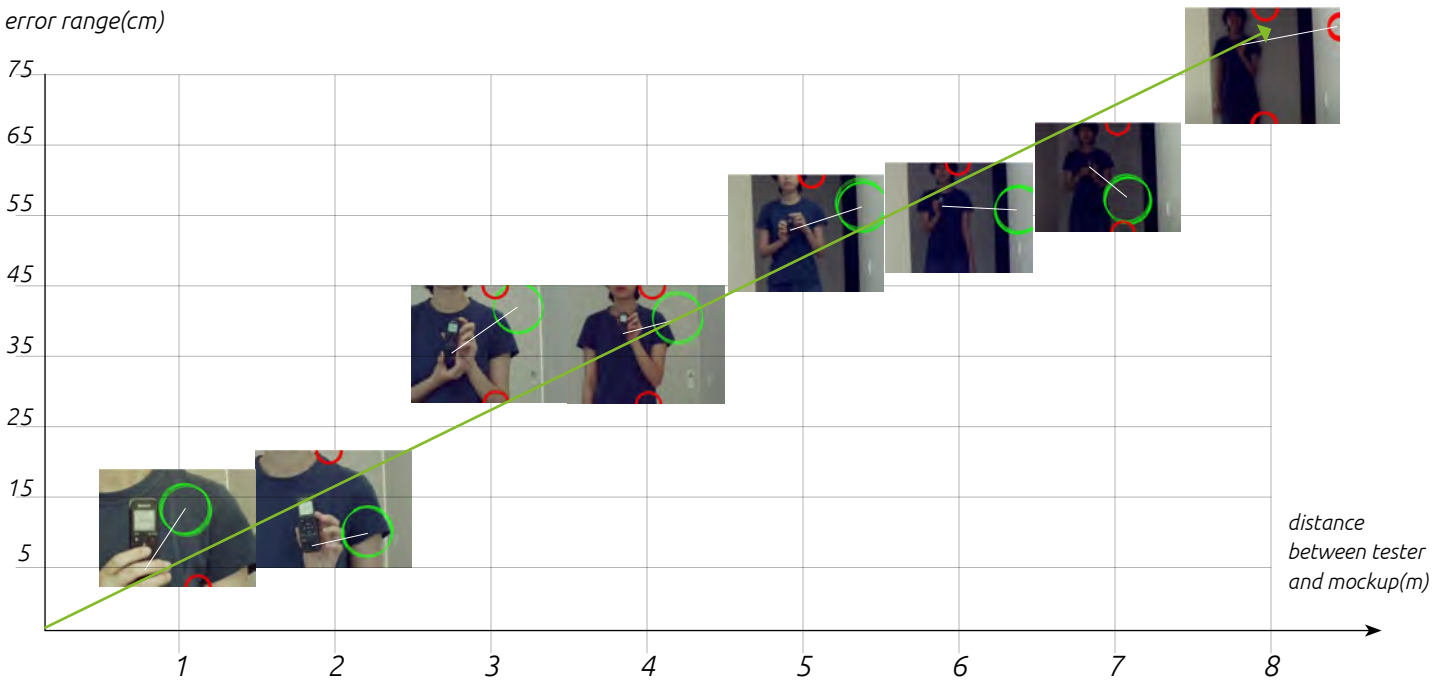
Besides, some noises are constantly detected no matter how strong the main birdsong is played[24]. Adjusting the parameters of sound filters in the configuration file might help solve this issue.

24. As the test is done in an indoor environment, it is probably due to the reflection of sound from the walls

Sound localisation precision

A sound localisation precision test was done in a indoor quiet room. A distance range from 1m to 8m was tested with a recording pen playing a birdsong file with a gradually increased volume of sound. From the final result, there seems to be a linear relationship between the sound detection error range and the distance between the tester and the sound source (see table 8).

Table 8 Sound detection distance result



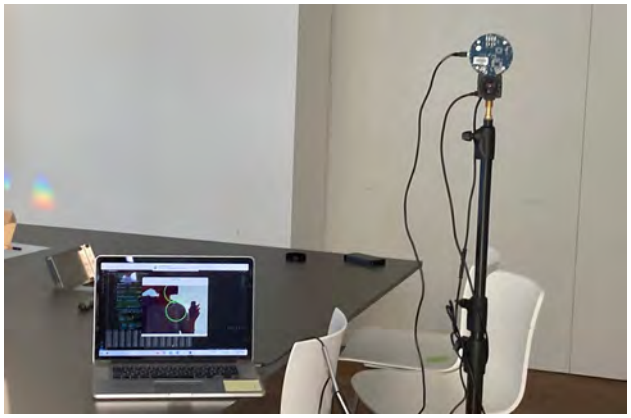


Figure 66 system precision testing

Figure 67 Sound playing device: SONY ICD-PX470 recording pen

4.4.2 A possible look of the product

Figure 68
Leica Ultravid 10x25

A concept image is created at the end of the development process to provide an idea on what the device could possibly look like. The dimension and the overall feeling of form is based on an existing model: Leica Ultravid 10x25.

The product has a flippable structrue with a microphone array built-in, with other electronical processing components and power unit integrated at the middle-bottom of the device. The product image will be further improved after the submission of this document.

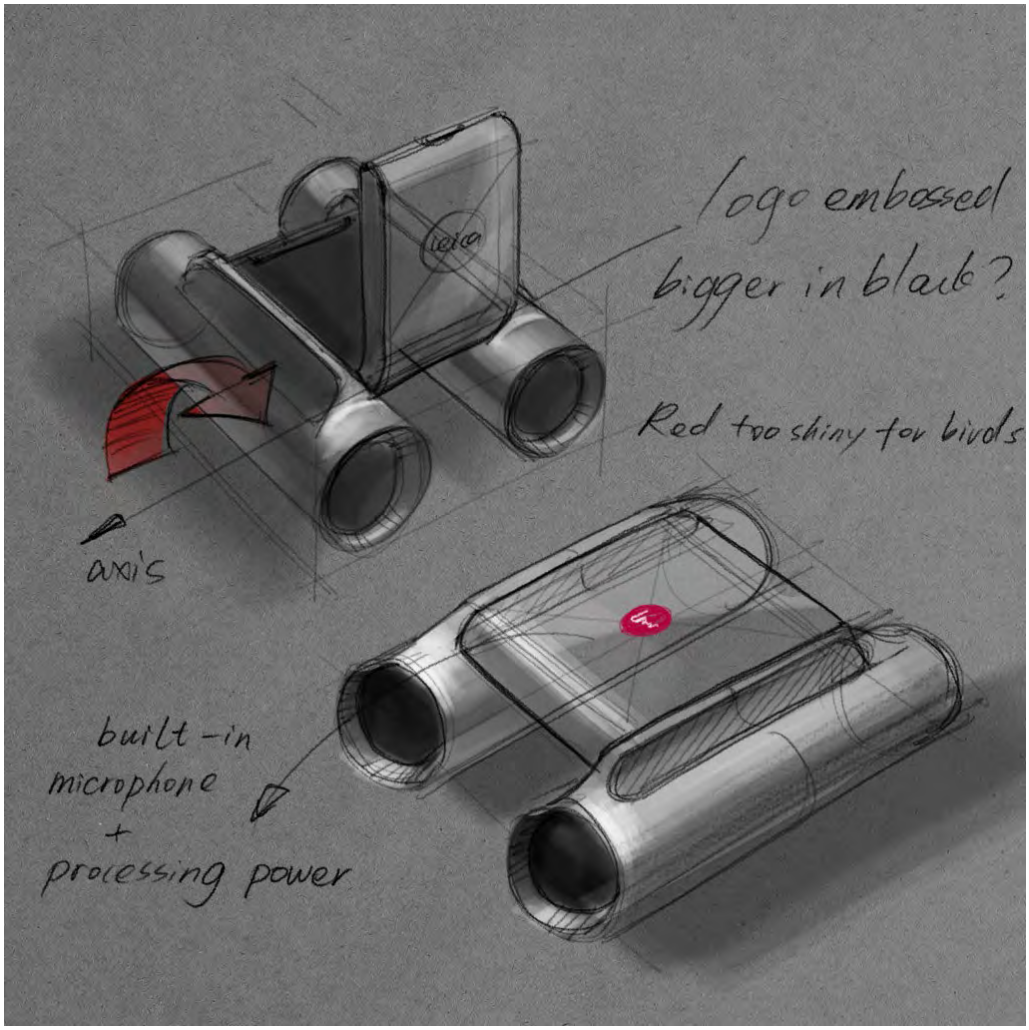


Figure 69 A possible look of the product

Envisioned product experience 01

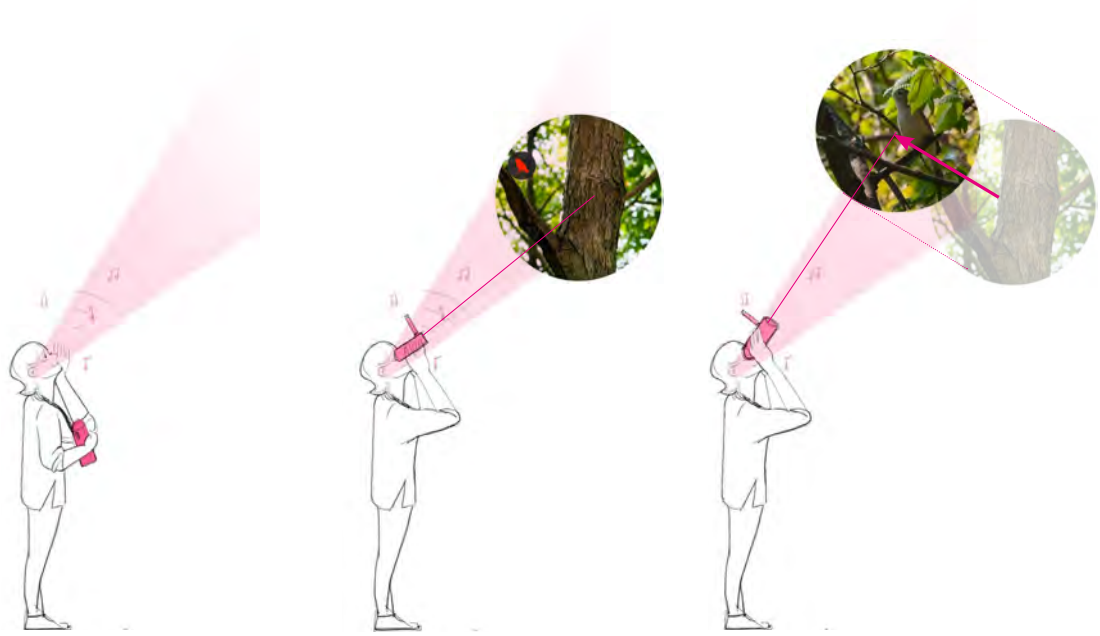


Figure 70 Envisioned effect 01: get the rough direction of birdsong => lift the optical device => find birds with the hint

Envisioned product experience 02

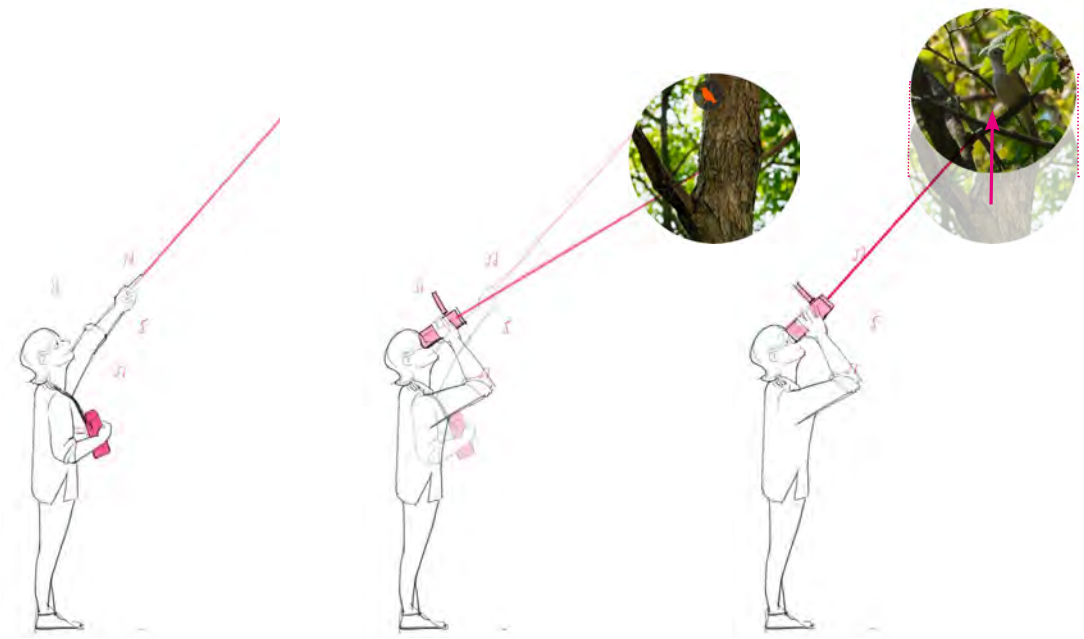


Figure 71 Envisioned effect 02: catch sight of birds first => lift the optical device => find birds with the hint

05

Conclusion and Discussions

/ Feasibility, Viability and Desirability
/ Check the list of requirements
/ Things left to be improved
/ Limitations
/ Technology roadmap

5.1 Conclusion

5.1.1 Feasibility, Viability and Desirability

Feasibility wise, it is proved in the mockup that the current application of technology can tell the direction of the sound quite accurately within a distance range of 0-4m and can detect the sound source at a maximum distance around 8m. Though a lot of improvements are still left to be done to elevate the overall performance, e.g. the environmental noise is not eliminated properly in the current mockup; the distance of the sound is not able to be measured yet; the listening range of the microphone is too limited for now, etc. , the mockup is for now fully functional and can serve as a good starting point for further development of the company.

Viability wise, the cost of the current mockup is around €544 without the price of 3D printing, view finder and processing power (with the microphone array €190, the ELP zooming camera €87 and the display & display driver €267). With the processing and power unit integrated, a summed up price can climb up to around €600, which could definitely be limited with better hardware selection and mass production. However, what being stated upon only serves for a full digital viewing solution, which is not usually good enough in terms of viewing quality. If an optical viewing solution is selected, the price of the sound localisation system (the microphone array, the processing and power unit and the HUD system embeded in the optical path) can be further limited, the main cost will be on the optical setup.

Desirability wise, the design concept targets at the general difficulty of 'Finding birds' for starters in urban bird watching and provided a helpful solution for those want to find birds with less effort, and those who enjoy the experience of gradually catching sight of birds but sometimes need 'a small nudge' during this process. Such a soluton can not only benefit the beginners, but can also further help other users that can not locate sound very well by themselves. Besides, as auditory information serve as important clues in many nature observation activities, sound localisation based solutions has a big potential of being applied under other scenarios of nature observation.

5.1.2 Check the list of requirements

01. The design must include at least one digital feature(either built into an optical product or in the form of accessory).

Sound source localisation and separation are introduced into the project.

02. The product should be compact, lightweight and portable.

As the effort of the integration of several parts is not being made, it is not predictable the size and weight of the sound localisation system in the final product. However, considering the fact that only the off shelf solution is applied, the size and weight of the processing and power unit can be very compact.

03. The product should help starter bird watchers to catch sight of birds and find them in their optical devices independently with less effort, with the audio and (or) video clue they make.

The product locates the direction of birds with their songs and display the 2d directional hints within the optical view. A maximum number of sound sources being detected is 4.

04. The product should cost low.

Same as with the requirement 02, if the product is done in mass production and with dedicated hardware, the main cost driver will become the housing and optics.

05. The product should be easy to set up and use.

Due to the limitation of the project time, the product still needs to be developed from the user experience perspective.

06. The features, if built in an optical device, should enable a good viewing quality.

Though the mockup is developed fully digitally, this requirement should not be a problem to fulfill, since there are already similar products on the market that use a head-up projection system to display information in the optical path, e.g. Leica Geovid rangefinding binoculars.

07. The product, if used properly, should prevent hurting or disturbing birds.

Since the product only listens to the birdsongs and do not have any actuators embeded that could possibly startle the birds, it will not cause harm to birds if used properly.

08. The product should be upgradable.

The software core applied in the mockup for now, ODAS, is an open-sourced and upgradable platform. The hardware sound localisation system could be designed modular to be upgraded easily.

09. The product could include additional functions other than the main ones.

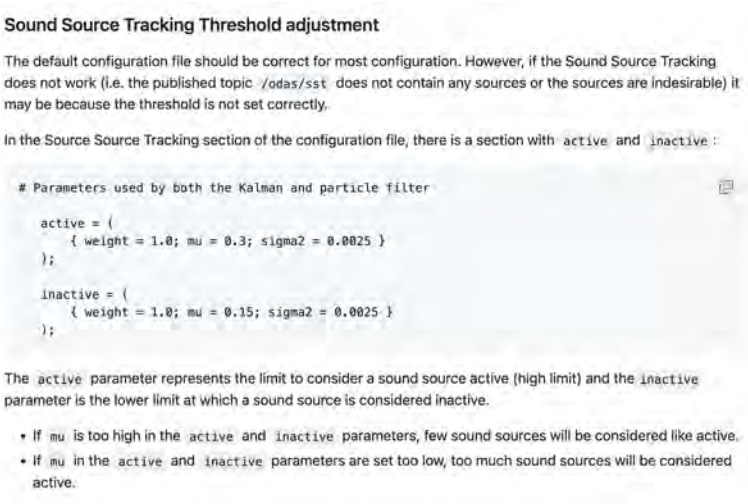
The sound source separation (recording) feature is an addtional function.

5.1.3 Things left to be improved

Some possible improvements that are planned within the project timescope but failed to be implemented are listed below.

01. Eliminate the environmental noise

Currently, some environmental noises are constantly detected during the sound localisation process, influencing the localisation accuracy. A possible solution is increasing the 'mu' value of the Kalman and particle filters within the configuration file to lift up the boundary for sounds being perceived as active. For now, 'mu' is set as 0.3 and 0.2 for active and inactive respectively. However, this might influence the localisation result for the real sound sources as well.



Sound Source Tracking Threshold adjustment

The default configuration file should be correct for most configuration. However, if the Sound Source Tracking does not work (i.e. the published topic `/odas/sst` does not contain any sources or the sources are indesirable) it may be because the threshold is not set correctly.

In the Source Source Tracking section of the configuration file, there is a section with `active` and `inactive` :

```
# Parameters used by both the Kalman and particle filter

    active = (
        { weight = 1.0; mu = 0.3; sigma2 = 0.0025 }
    );

    inactive = (
        { weight = 1.0; mu = 0.15; sigma2 = 0.0025 }
    );
```

The `active` parameter represents the limit to consider a sound source active (high limit) and the `inactive` parameter is the lower limit at which a sound source is considered inactive.

- If `mu` is too high in the `active` and `inactive` parameters, few sound sources will be considered like active.
- If `mu` in the `active` and `inactive` parameters are set too low, too much sound sources will be considered active.

Figure 72 Sound source tracking threshold adjustment (Introlab, n.d.)

02. Eliminate sound from behind

Though ODAS can only display the sound sources within the range of half a sphere (z>0), the microphone array can actually receive sound from all directions, which means in ODAS, the sound coming from the negative sphere (z<0) will be processed together with the sound coming from the positive sphere (z>0). Methods could be applied to prevent sound from being received from the negative sphere, e.g. creating a sound-proof casing to prevent most sound from passing through.

03. Reduce the error caused by the height between microphone and camera

In the current mockup, there's a height difference between the centre of microphone and the center of camera sensor of around 7cm, leading to an error in sound localisation result that is higher for 7cm. Therefore, when the direction of sound source is displayed on the screen, a relative error length can be calculated according to the projection plane distance. However, the projection plane distance constantly changes with the camera focus, making it hard to calculate the real error. Certain methods could be explored to adjust the relative error together with the change of the camera focus.

Figure 73 Error caused by the height difference

04. The sound source separation feature is not working now

Though ODAS has a built-in feature of recording sound files with separated DOAs, the author failed to make it work on the mockup now, which might be due to the the missing of some sound recording presets in the system. The sound source separation feature is helpful in separating each sound and tell what sound sources has been separated by the system, therefore could facilitate the process of eliminating the environmental noise as well.

5.2 Discussions

5.2.1 Limitations

01. The current localisation accuracy and detection range is not enough

The functional mockup can only tell the sound direction with a good accuracy of around 0-4m, while is not able to provide a precise result more than 5m and can hardly hear sound further than 8-10m. As the average distance of urban bird watching is 5-20m (max. 45m), a lot of improvements could be done in improving the localisation accuracy (mainly influenced by software) and detection range (mainly influenced by hardware).

Machine learning could be applied before the general ODAS procedure to filter out the environmental noises from the captured birdsongs, then conduct SSL and SST only towards the separated birdsongs. A pre-amplifier could be introduced to the system to amplify the collected sound. Hardware wise, applying sound cones in front of each microphone to create sound funnels can help better concentrate and amplify sounds from the environment.

Figure 74 Hear tiny sound with a sound cone (NASA Space Place – NASA Science for Kids, n.d.)

02. The view quality needs to be improved

The ELP camera applied in the mockup provides a 5M resolution while the OpenCV camera view is only 640x320 in pixels, result in an average image quality. Settings could be adjusted to achieve a higher display resolution. Such a problem won't exist if a full optical approach is applied for the further product development.

03. No considerations made to achieve an upgradable hardware setup

It is stated in one of the requirements, that the product should be upgradable to enable long-term usage. Though the software core (ODAS) for now is fully upgradable, there are no considerations made to make the hardware system more upgradable. A suggestion could be to make the hardware easily detachable from the main body to be able to be changed to a new one, or even design the hardware system as a modular or an accessory solution alongside the main product.

Figure 75 Nitendo switch accessories upgrade the gaming experience (Boyle, 2021)

04. The diversity of the form of location hints in the binocular view is limited, more viewing options could be available

The current indication in the mockup only shows the accuracy of the mockup in a very rough way. Different levels of indication ranging from ‘an ambiguous hint’ to ‘a straightforward guidance’ could be explored for different needs of users. Besides, it should also be possible to turn off the real time localisation guidance, or automatically shut down the system to save energy when the device is deteced not under usage.

Figure 76 A straightforward guidance (left) and an ambiguous hint (right)

5.2.2 Technology roadmap

A technology roadmap was suggested to the company on how to continue with the pro

Table 10 Technology roadmap

Timeline	Now	In 6 months
Releases	Current version - the mockup 	Version 1.1
Must-have capabilities	A funtional mockup that is able to project the directional information of the localised results on a camera view is build, sound source localisation can be done with a relative accurate result within 0-4m, the maximum distance detectable is around 8m.	Build up on the baseline fu ***ther finish all the things t be improved and try to so 4th limitations (also decia towards a digital viewing***
User experience improvements	--	Make the product more up hardware; Improve the interaction, in off to the visual guidance a the deployment of the mic bring any different effects viewing options on the cur setup
Performance improvements	--	Test the user experience o deployment of the microp Test the user experience o guidance

ject.

	In 1-2 years	In 3 years
	Version 2 -Delight	Version 3 - Scale
unctions, ***fur-hat are left to lve the 3rd and le on if going solution)***	Build up on Version 1.1, deal with ***limitation 01***, create a setup that is able to provide a precise localisation directional result within a longer detection distance (around 20m)	Based on version 2, achieve a light weight, cost efficient and compact setup, ***make sure all the limitations are dealt with***
ogrdadable in ntroduce an on/ and make sure crophone won't ; Provide more rrent hardware	Further improve user experience on the ergonomic aspects: e.g. hand-held feeling, eye cup, etc. Further improve user's experience on the direction hint provided in the view	Further improve form, aesthetics, CMF and ergonomics
on the hone; on the visual	Test the furthest distance the setup can detect; Test the accuracy of the system	Test how users like the weight and size of the product; Test how users like the look and feeling of the product

Reflection in the end

Reflection on the methods used

I've learned multiple design methods during my master study and used them by applying them into the 'right' moments of the project. Some methods can be used so naturally that I seldom question the necessity of using them and how they can bring value to the design process. In the table below, I am documenting the design methods applied in this project and reflect on if they were applied efficiently.

Table 11 Applied methods in the project

Project stage	*Method*	*Explanation*	*Is it helpful*
Background & research	Functional analysis	*https://en.wikibooks.org/wiki/Seed_Factories/Functions*	Very helpful in understanding how pr functions connects with physical mod finding design opportunities
	Interview		Very helpful in this project.
	Value proposition	*https://www.helpscout.com/blog/value-proposition-examples/#:~:text=A%20value%20proposition%20is%20a,by%20giving%20you%20their%20business.*	Yes. It is a helpful way of categorising Many user insight teams apply this m their design process.
Synthesis	Persona	*https://careerfoundry.com/en/blog/ux-design/how-to-define-a-user-persona/*	Not very much. Seems that it doesn't difference if the persona is created o
	User journey mapping	*https://www.coursera.org/articles/creating-user-journey-maps-a-guide*	Very helpful in this project. Good me derstanding how people do bird wat
	List of requirements	*https://arl.human.cornell.edu/PAGES_Delft/Requirements.pdf*	Not very much. It is helpful but seem necessary
Ideation and concept evaluation	Brainstorming		Yes, HMW questions are prepared be lots of great ideas were got from gre
	Co-creation	*https://medium.com/design-globant/co-creation-how-tos-e25696f56d6f*	Yes, the result would be even better prepared ideas to embark the creativ
	Morphorlogical chart	*https://arl.human.cornell.edu/PAGES_Delft/Morpholigical_Chart-deeper.pdf*	Yes.
	Harris profile	*https://toolkits.dss.cloud/design/method-card/harris-profile/*	More or less. Good method in evalua concept in a qualitative way
Suggestions	Technology roadmap	*https://www.productplan.com/learn/three-example-technology-roadmaps/#:~:text=A%20technology%20roadmap%20is%20a,Internal%20IT%20roadmap*	Kind of. It's a good template for givin suggestions on a project that is techn prospective and needs long-term dev

	Takeaways
roduct dules, also in	Personally the method can either be used in exisiting product analysis - to have an overall understanding of the product, or in explaining your own product design - what functional elements are put into your product and why. It's helpful not only in developing a rigorous and holistic thinking but also in serving as a checklist so that designers won't design anything extra or skip any parts.
	Always prepare a list of questions beforehand and highlight several of them as important ones.
g insights. ethod during	Designers collect tons of insights during their research, while not all of them are valuable and contributive enough for the project. The value proposition can serve as a funnel that help designers in telling which insights are more useful in defining certain needs.
t make much r not.	I understand that the persona is a fictional representation of an ideal customer and they should come from real users, but when the number of participants is very limited to summarise personas, the necessity of applying this method is maybe not that high.
thod in un- ching.	A lot of people add emotions in user journeys, I think it maybe better works under the situation when users' emotions really play an important role in their design.
s not very	Maybe the list of requirements is more necessary in the real development of products that have very clear goals on different aspects to achieve. A design vision could be enough for this project, since what I did was a try out in the innovation field, it is brand new and won't become a well-developed product at least in the project timescope.
eforehand and eat minds	A well prepared and structured brainstorming session will bring good results.
with some vity	Sometimes users don't know what product or function they want, and this method is helpful in exploiting their potential needs.
	One of my favorite methods ever, a great combination of creativity and logical thinking. But I don't think it is applied in a way that can bring most value in this project, because my starting point in this project was more or less a digital feature instead of a product with multiple functional modules.
ting the	Seems designers have different ways of scoring criteria - so reading others' Harris profile can be sometimes confusing without his/her explaination. Considering this, I'd prefer weighted criteria more - it evaluate concepts on a quantative level and is usually more convincing. One thing I have been wondering is: if the 4 columns (--,-,+,++) have a value of -2,-1,1,2 respectively, then can we give a value of 0 as well, if certain concept is just neutral under certain criteria?
g nically velopment.	Seems it makes more sense under the situation when the designer is really able to suggest a specific order of technology development that makes sense. Personally, I would summarise all the limitations and things not done in the project, then throw them to those smart and experienced engineers and ask them to figure the development order by themselves.

General reflection

Apart from all the technical and methodology learnings that I gradually gained from the project, here briefly lists some general reflections of mine.

A positive thing is that I stayed persistent during the project and did not give up. Writing an academic report and developing a technical-heavy product concept are the two main tasks in this project, and I am not good at either. Thanks to the help from Arjen, Wolf and Markus, I managed to go through the project with many takeaways.

The main learning from this project is that, it's necessary to have a rational expectation for the project beforehand. I was too optimistic about the concept development stage before the project started and planned the same amount of time in parallel for technical development and the aesthetic exploration. But the technical challenge requires so much learning both in hardwares and softwares that it went through the whole development of design, resulting in no time for aesthetics and user experience evaluation - It's always ideal to say 'I want this and that...." but it's rational to say 'This is enough for me'.

Communication and documentation are also two things to improve. Remote tutorial requires frequent communication back and forth, but at the wrap-up stage of the project, I was too stressed and stay less communicative with the university. The quality of this report could be better shall I keep a fluent and constant communication. Besides, taking good process pictures is a good thing I've learned during my exchange in Sweden, but I constantly forget about doing that during this project when I am too focussed on the task itself. Setting date reminders for documentation could be a helpful way to improve this.

Besides, I'm not always physically doing well during this project, which caused some procrastination in the progress (it's usually not a thing for me), such a situation will less likely to happen next time if I take care of myself well and stay healthy.

With everything being said, I am generally very happy with the result and had fun during my thesis. Good to wrap up my student life with this special and memorable experience. Deepest thanks to Delft and Leica!

Figure 77 3D printed mock up shells - trials and errors (taken with Leica Q2)

06

Reference list

Spring is here and birds are in the air! (2022, March 30). Audubon California. https://ca.audubon.org/news/top-10-birds-california

White, J. (2023, May 28). What Is The Average Age Of Birdwatchers | Birda. Birda. https://birda.org/what-is-the-average-age-of-birdwatchers/

Leica Pinmaster - Golf Sports - Lifestyle & Leisure - Sport Optics | Leica Camera AG. (n.d.). Leica Camera. https://leica-camera.com/en-int/sport-optics/lifestyle-leisure/golf-sports/leica-pinmaster

Find your birding community | U.S. Fish & Wildlife Service. (2022, April 13). FWS.gov. https://www.fws.gov/story/find-your-birding-community

LEICA Calonox 2.5x42mm Thermal Imaging Monocular (50502). (n.d.). GritrSports.com. https://gritrsports.com/leica-calonox-2-5x42mm-thermal-imaging-monocular-50502

Wikipedia contributors. (2023b). Ornithology. Wikipedia. https://en.wikipedia.org/wiki/Ornithology

Mid-priced Scopes Round-up 2009 - by Michael and Diane Porter. (n.d.). https://www.birdwatching.com/optics/2009scopes_mid/mid-priced_scopes2009.html

Leica Monovid 8x20, black | Leica Camera AG. (n.d.). Leica Camera. https://leica-camera.com/en-int/sport-optics/binoculars/monovid/monovid-8x20-black

Leica Noctivid 8x42 binoculars. (n.d.). https://www.aceoptics.co.uk/leica-noctivid-8x42-binoculars.html

Leica APO-Televid 65 W (Winkeleinblick 45°) | 65 | 3030582. (n.d.). Alljagd. https://www.alljagd.de/leica-apo-televid-65-w-winkeleinblick-450/3030582/

Admin, A. (2023b). Online bird guide, bird ID help, life history, bird sounds from Cornell. All About Birds. https://www.allaboutbirds.org/news/

Cooper, V. W. W. a. R. B. T. (2019). Birding for beginners. www.417mag.com. https://www.417mag.com/issues/april-2018/birding-for-beginners/

NHBS. (n.d.). Bird-Spot Laser Pointer. https://www.nhbs.com/bird-spot-laser-pointer.

Chente. (n.d.). Merlin Bird ID, Free Bird Id app is now available for southern Mexico! - aVerAves. eBird. https://ebird.org/averaves/news/merlin-bird-id-free-bird-id-app-is-now-available-for-southern-mexico

OpticsPlanet.com. (n.d.). Pulsar Merger LRF XP50 2.5-20x Thermal Imaging Binocular PL77465, Color: Black, $587.02 Off w/ Free Shipping. OpticsPlanet. https://www.opticsplanet.com/pulsar-merger-lrf-xp50-2-5-20x-thermal-imaging-binocular.html?sscid=81k7_p4slq&utm_source=shareasale&utm_medium=affiliate&utm_campaign=affiliate-2059122&sv1=affiliate&sv_campaign_id=2059122

Risoud, M., Hanson, J., Gauvrit, F., Renard, C., Lemesre, P., Bonne, N., & Vincent, C. (2018b). Sound source localization. European Annals of Otorhinolaryngology, Head and Neck Diseases, 135(4), 259–264. https://doi.org/10.1016/j.anorl.2018.04.009

A Beginner's Guide to Digital Signal Processing (DSP) | Design Center | Analog Devices. (n.d.). https://www.analog.com/en/design-center/landing-pages/001/beginners-guide-to-dsp.html

Andéol, G., Macpherson, E. A., & Sabin, A. T. (2013). Sound localization in noise and sensitivity to spectral shape. Hearing Research, 304, 20–27. https://doi.org/10.1016/j.heares.2013.06.001

Night Vision Binoculars, 300m vision range 960P Video 7-Level Infra. . . (n.d.). Fruugo. https://www.fruugo.de/night-vision-binoculars-300m-vision-range-960p-video-7-level-infrared-lighting-4x-digital-zoom-hd-digital-infrared-night-vision-goggles-for-spotting-huntingblack/p-61160231-122799701?language=en

Redirect notice. (2023, April 23). https://www.google.com/url?q=https://badgerlandbirding.com/2023/04/23/whats-the-difference-between-birding-and-bird-watching/?utm_content%3Dcmp-true&sa=D&source=docs&ust=1692795669140758&usg=AOvVaw2oKrgIiDsWiqOs-54-kwfW

Admin. (2021b). What are Sport Optics? Sector Optics. https://sectoroptics.com/uncategorized/what-are-sport-optics/

Admin. (2021a). What are Sport Optics? Sector Optics. https://sectoroptics.com/uncategorized/what-are-sport-optics/#:~:text=The%20phrase%20%E2%80%9Csport%20optic%E2%80%9D%20is,home%20defense%2C%20or%20even%20astronomy.

The European market potential for birdwatching tourism | CBI. (2021, June 23). https://www.cbi.eu/market-information/tourism/birdwatching-tourism/market-potential

Wikipedia contributors. (2023e). Digital audio. Wikipedia. https://en.wikipedia.org/wiki/Digital_audio#:~:text=In%20a%20digital%20audio%20system,%2Dcode%20modulation%20(PCM).

Birdwatchers of the world – unite and take environmental action. (n.d.). Horizon Magazine. https://ec.europa.eu/research-and-innovation/en/horizon-magazine/birdwatchers-world-unite-and-take-environmental-action

The European market potential for birdwatching tourism | CBI. (2021b, June 23). https://www.cbi.eu/market-information/tourism/birdwatching-tourism/market-potential#:~:text=The%20average%20birder%20is%2050,or%20organised%20activities%20involving%20birdwatching

Wikipedia contributors. (2023). 3D sound localization. Wikipedia. https://en.wikipedia.org/wiki/3D_sound_localization#:~:text=3D%20sound%20localization%20refers%20to,between%20the%20source%20and%20sensors.

Grondin, F., Létourneau, D., Godin, C., Lauzon, J., Vincent, J., Michaud, S., Faucher, S., & Michaud, F. (2022). ODAS: Open EmbeddeD Audition System. Frontiers in Robotics and AI, 9. https://doi.org/10.3389/frobt.2022.854444

hark. (n.d.). http://library.isr.ist.utl.pt/docs/roswiki/hark.html

Risoud, M., Hanson, J., Gauvrit, F., Renard, C., Lemesre, P., Bonne, N., & Vincent, C. (2018). Sound source localization. European Annals of Otorhinolaryngology, Head and Neck Diseases, 135(4), 259–264. https://doi.org/10.1016/j.anorl.2018.04.009

Wikipedia contributors. (2023c). Acoustic camera. Wikipedia. https://en.wikipedia.org/wiki/Acoustic_camera

Hear tiny sounds with a Super Sound Cone! | NASA Space Place – NASA Science for Kids. (n.d.). https://spaceplace.nasa.gov/sound-cone/en/

Boyle, E. (2021, June 22). Best Nintendo Switch accessories: pro controllers to storage. British GQ. https://www.gq-magazine.co.uk/culture/article/best-nintendo-switch-accessories

Yuan Tian | 2023

Y.Tian-16@student.tudelft.nl
yuan.tian.0911@gmail.com