PROXIMITY VEST

A design tool for the exploration of proxemic zones.

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Msc. Graduation Thesis

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ProximityVest

A design tool for the exploration of proxemic zones

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Thanks to

I would really like to thank my team of mentors for guiding me trough this difficult project. Thank you Himanshu for our kind lunches and research and data-processing knowledge. Thank you Aadjan for all the courage you gave me and your design and technology knowledge.

I would also like to thank all the TUDelft staff that helped me and informed me, all my friends and student-colleagues for the nice coffee moments and putting up with my user-tests, and my family for supporting me the last six months.

Executive summery

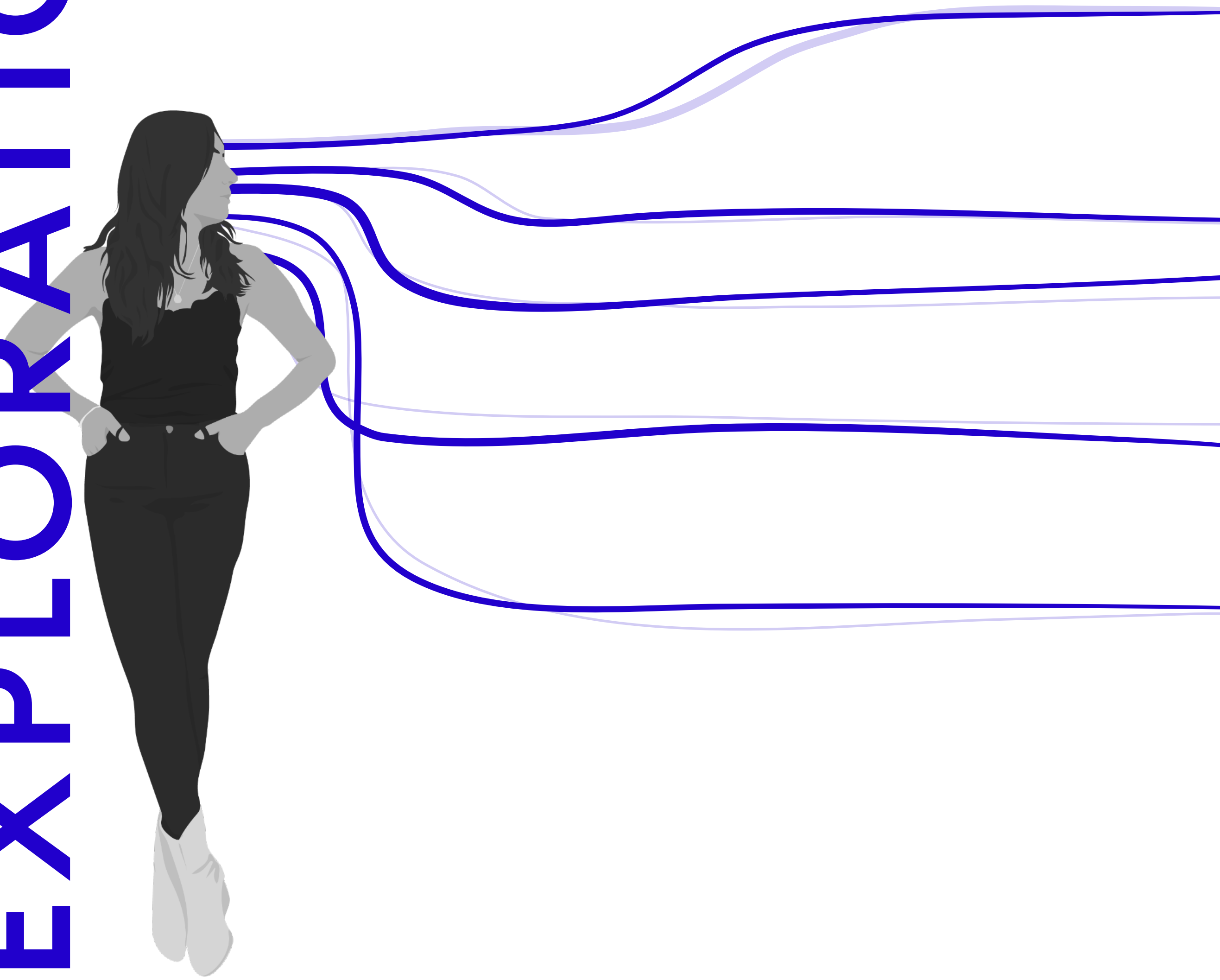
Everybody is different and it is impossible to know how people feel or think. We can however simulate similar scenarios to understand other people better. Personal space is, like the name says, different for everyone but it is not impossible to measure it and let somebody else know how you use it.

This project explored how to make a design tool that measures peoples personal space. The tool is a wearable called: ProximityVest. It uses a stereoscopic camera to detect people measure how far they are apart from you. It contains a big battery and processing unit that sends all the data wireless to the cloud.

The design started by reading upon different research that was already done in the field of human perception of proxemics. I discovered that their way of researching was done via interviews and observations. It was time to put a modern approach that uses proximity sensors to actually measure distances. A prototype needed to be made to verify if this whole idea could work. To achieve this prototype, I followed an iterative design process. Many prototypes were made and put to the test to see if they fitted the concept. When I finally found all correct subsystems of the concept, it was time to do a last verification test. That test proved that peoples specific personal space is very well measurable with technology.

Table of contents

EXPLORATION



Assignment statement

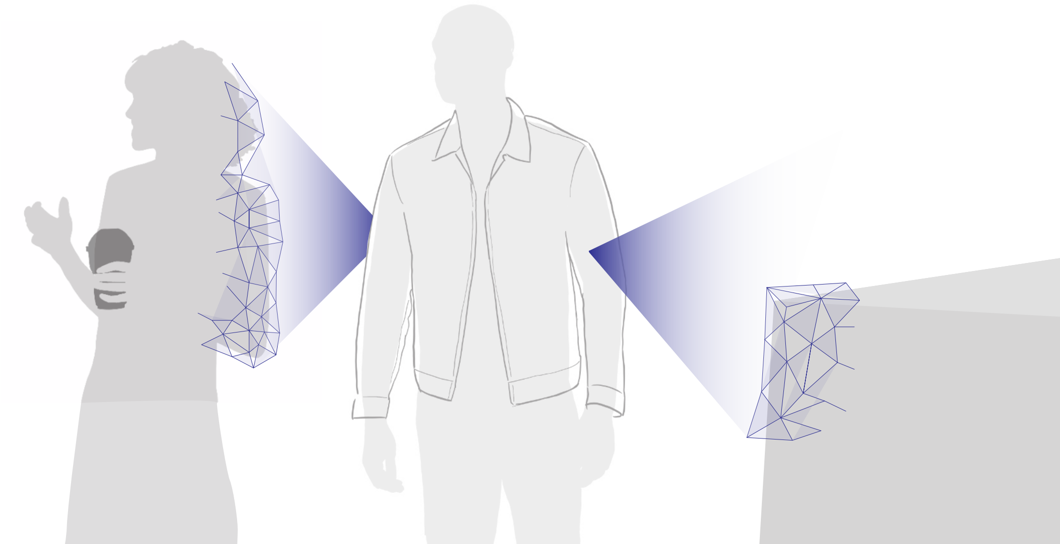
This project started out with the following statement:

“ The design of socially-aware technologies entails the sensing and interpretation of varied social and contextual indicators. Since our social interactions are highly complex and culture dependent, the sensing and interpretation of social context is not an easy task. Furthermore, the sensing of social context and social interactions in non-invasive and privacy-preserving manner entails the use of non-verbal indicators of social behaviour, such as proximity. So, can we design and prototype proxemic sensing capabilities embodied within cloths? „

The last sentence describes the project as an embodiment assignment to get depth sensors placed on clothing. To make that assignment work, a lot of other variables need to be researched and defined beforehand. Otherwise, things like: coverage, sensor placement, distance able to measure are very hard to develop right.

So it gets decided that the assignment gets shifted more towards an exploration of monitoring the context of a user in a wearable product, rather than measuring only data from the user itself. Read the project brief after this to get more information about this approach.

To make the project even more concrete, it also gets decided that it is best to go on a look-out for a nice application where this can be used.



Quick visualisation of how the project could turn out.

Project brief

Wearable technology is a fast-growing market. Technology is getting smaller and smaller and is more energy-efficient than ever before. This makes it more evident to fit it in wearable applications where it needs to be integrated into a small package with an unconventional shape. The most famous applications are smartwatches, smart glasses and fitness trackers.

The many benefits of wearable devices (also called smart wearable technology) become evident when you use them. When made right, it is a non-distractive way of assistive technology. It is very convenient because you can not forget using it. It blends in seamlessly with your day to day activities and it can disappear in your fashion style.

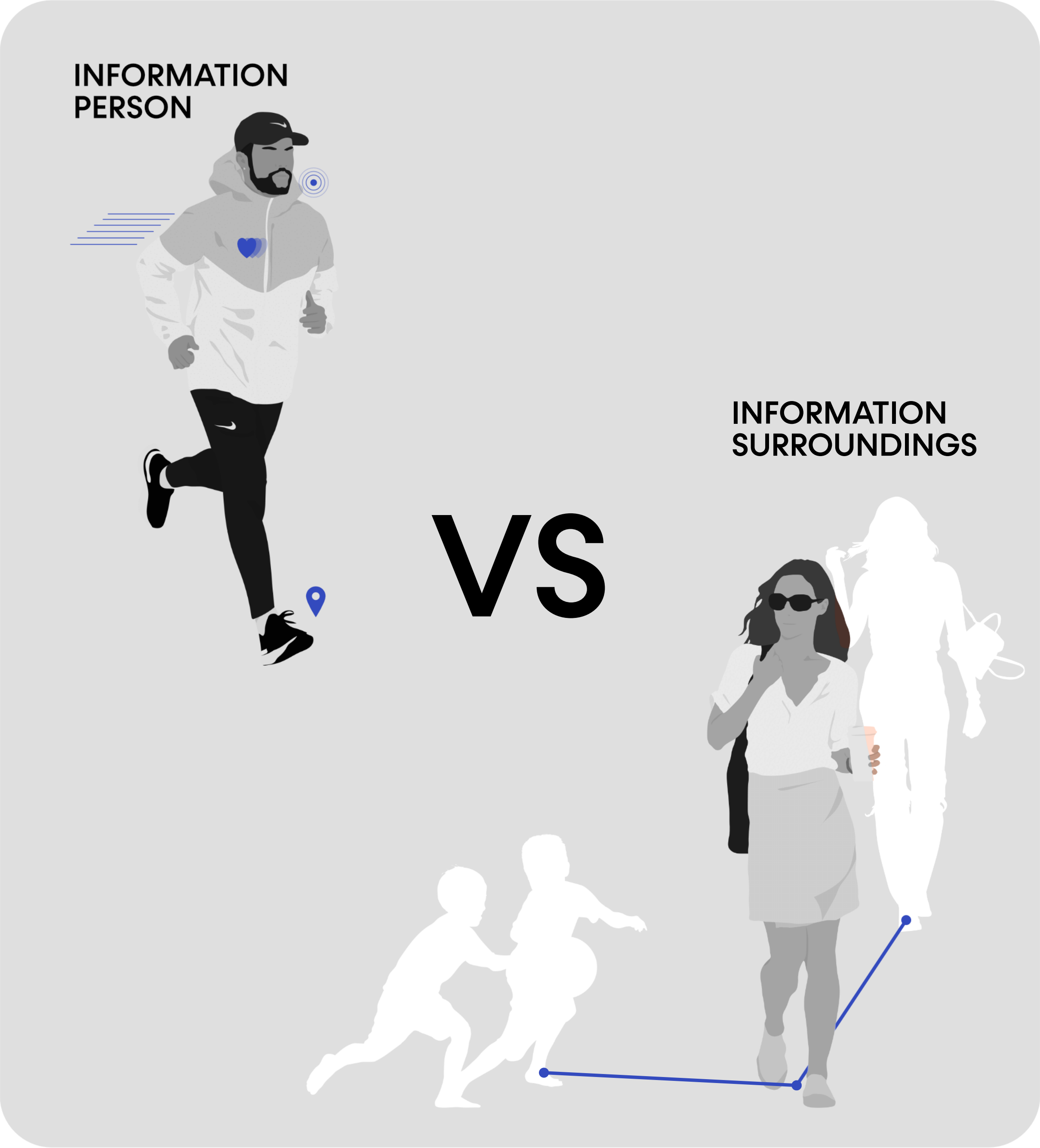
One group of those smart wearables is technology in clothing. Smart clothing is often used in sporting applications to monitor the vitals of a person. Most of these vitals need to be measured with close proximity or contact to the body and would otherwise require a separate skeleton to wear. Other than vitals, the movement or position of a person can also be measured with embedded sensors. Other applications of smart clothing are embedded key-cards, gesture inputs for seamless interaction with other devices and weather monitoring.

Almost all of these applications are about collecting data of the person itself, which makes a lot of sense because of the medium. Monitoring the context around the person is something that has not been explored. Knowing what happens around the person can be really useful. It can indicate interaction with other people or products.

Existing ways of doing this are via manual observations, video observations and surveys. You also have automated solutions, but those require a lot of infrastructure. Examples are the Estimote Bluetooth beacons that track where you are and systems like OptiTrack that use a lot of cameras and special suits to work.

This project is going to be focused on the embodiment of proxemic sensing technology in clothing. It will research which technology is needed to recognise people and objects in its surroundings in a privacy-preserving way. In addition to that, how can the information about surrounding objects and people be communicated to the user? Finally, it will explore different applications it can be used for.

In the long term, this product can also be used for researching the behaviour of people and societies at large scale to support sociological research (for example, computational social sciences). It can also be used as a tool to promote Research through Design.



Design path

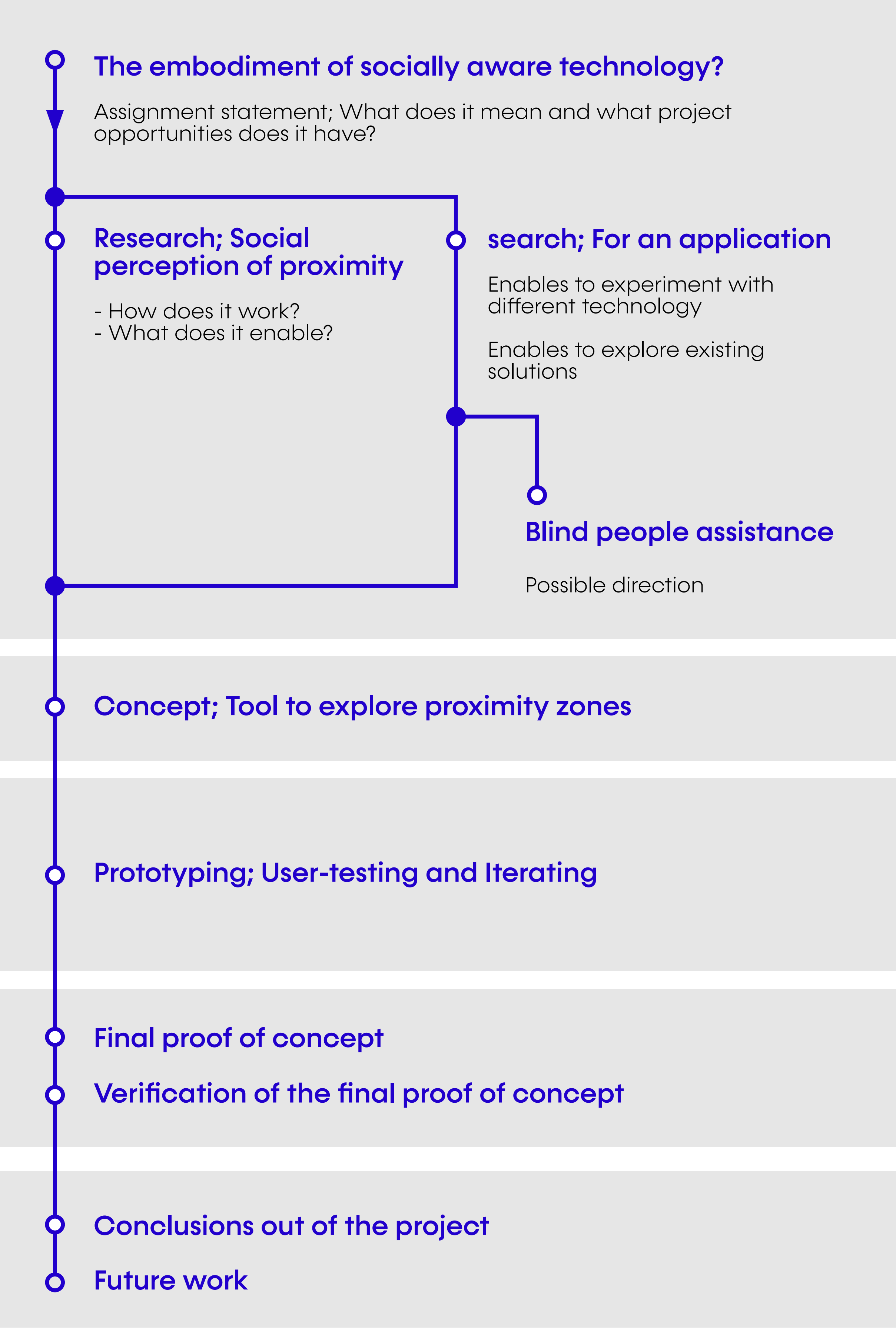
The project started with the previously already mentioned assignment statement: *Can we design and prototype proxemic sensing capabilities embodied within cloths?* Trying to understand socially aware technology and the social perception of proximity enabled me to contain this project in the six months deadline and choose a small part of this complex research and make a tool for it.

During the exploration phase of this project, the decision was made to look for an application when it comes to placing proximity sensors on clothing. This enabled to experiment with technology and look for already existing solutions, even though I was not finished yet researching the social perception of proximity. During the project, the direction to guide blind and visually impaired people was explored, but was not proceeded with.

Combining the knowledge of the research and the experiments done with many different sensors landed me on a concept to further embody: making a tool to explore proximity zones.

The next step was to prototype the concept. Different iterations were needed to come to the final proof of concept. Every iteration revealed the capabilities when it came to the exploration of proxemic zones and how to do it different or better with other technology.

When the final proof of concept was embodied, it got tested with one last verification test. The results of this test are discussed and future recommendations are made.



The embodiment of socially aware technology?

Assignment statement; What does it mean and what project opportunities does it have?

Research; Social perception of proximity

- How does it work?
- What does it enable?

search; For an application

Enables to experiment with different technology

Enables to explore existing solutions

Blind people assistance

Possible direction

Concept; Tool to explore proximity zones

Prototyping; User-testing and Iterating

Final proof of concept

Verification of the final proof of concept

Conclusions out of the project

Future work

PART: Social perception of proximity

The distance between people can tell a lot about their relation with each other. Fitting distance sensors on a human body asks for some research in the proximity interaction subject. This chapter will talk about past research done in this area and what they did with it.

Proxemics

by Edward T. Hall, 1968

Edward T. Hall was an American anthropologist and researcher. In the 1960s, he wrote an important work about the role of proxemics in culture and human behaviour. The research, evidently called 'Proxemics', contains many insides that can help us understand how distance plays a role in social interaction. The following chapter discusses all the insights Hall found in his research and what can be essential for this project.

Hall researched 'proxemics, the study of man's perception and use of space'. He states that it is vastly different from the study of space in physics. Therefore, he needed to approach it differently and used a variety of methods to do this. Using multiple methods assured him that he could verify his findings and, because this was a completely new research topic, find out what the best practices were. The chapter 'research methods and strategies' states that most test subjects were United States citizens. This was because he had quick access to them. Doing a study on such a brought topic needs to be done on as many people as possible and the more different cultures, the better. Hall says that the reason behind doing something is most of the time unknown by the person doing it. He states:

"Most individuals, try as they will, can specify few if any of the elements that enter into perfection. They can only describe the end product. Thus, the student of proxemics is faced with the problem of developing techniques to isolate and identify the elements of space perception. What he aims to achieve is a sense-data equivalent of the morphophonemic structure of language or the chemist's periodic table of the elements. His data should be verifiable and the elements capable of being combined with predictable results. Where does one look for procedural models when exploring a new field?"

I. Methods used

Identifying the elements of space perception is the goal here. Hall describes in his research some of the methods he used to do this. Looking at these methods can teach us more about his insights.

Observation

Hall observed people for longer periods of time and found patterns in peoples behaviour that way. Focused on their use of space in face-on-face conversations he used a camera to take still frames of the situation. In practice, when trying to read the pictures taken, it was hard to understand what actually was happening in them. Limitation of photography was that a single picture does not capture the whole situation.

Further in his observations, he also noticed that other things like subtle body language and use of speech give away how people feel about a particular distance to one another.

Experimental abstract situations

As an experiment, Hall asked people to put coins and pencils 'close', 'side by side' and 'far apart'. Different cultures put the coins and pencils further or closer together depending on the question. This is a more abstract way of understanding the meaning people give to terms like 'close'. But it does not really tell us anything about the distance between people.

Structured interviews

Another interesting method he used was interviewing people. This is a common design method for exploration. He asked people about their use of space. Things like: how do you arrange your house, where do you go to be alone. He also asked for the opinion on the spacial categories (see proxemic zones) he made and, for example, Arab people had lot of commends on it. This explains us that they have vastly different social zones.

Lexicon, Art and Literature

Very similar as the 'abstract situations' Hall analyses the Lexicon of people, the interpretation of different art and literature, as in, the perception of the writers.

These forms of communication describe often different proxemic situations and how people feel about them. A writer describing a tense situation in a close room with multiple people or analysing the dictionary and words related to space like: close, under, next to, ... This again is a more abstract approach of understanding people their use of space. It does not tell anything about concrete distance between people.

II. Concepts and measures found

Out of all this research, Hall made some groups and charts to try to find some logic or a system. He describes three categories of space, the difference between sociopetal and sociofugal space and a chart showing proxemic perception (of North-Americans).

Thee categories of space

There is fixed, semi-fixed and dynamic use of space. Walls for example are fixed features in space. Interpersonal distance is dynamic for most peoples of North European origin, says Hall. That means that in different situations that personal space differs.

Sociopetal and sociofugal space

Sociopetal space is a space that invites for communication. Different from sociofugal space, that not invites for communication. One sociopetal space for someone is sociofugal for someone else maybe. This is very apparent with different cultures.

Senses used to define distances

Interpersonal distances are not only defined with our sight. Our other senses indicate also how we feel about certain distances. They are also called: measuring rods.

THERMAL

When close enough, we can feel the heat coming of somebody. Also touch is related with heat.

ORAL

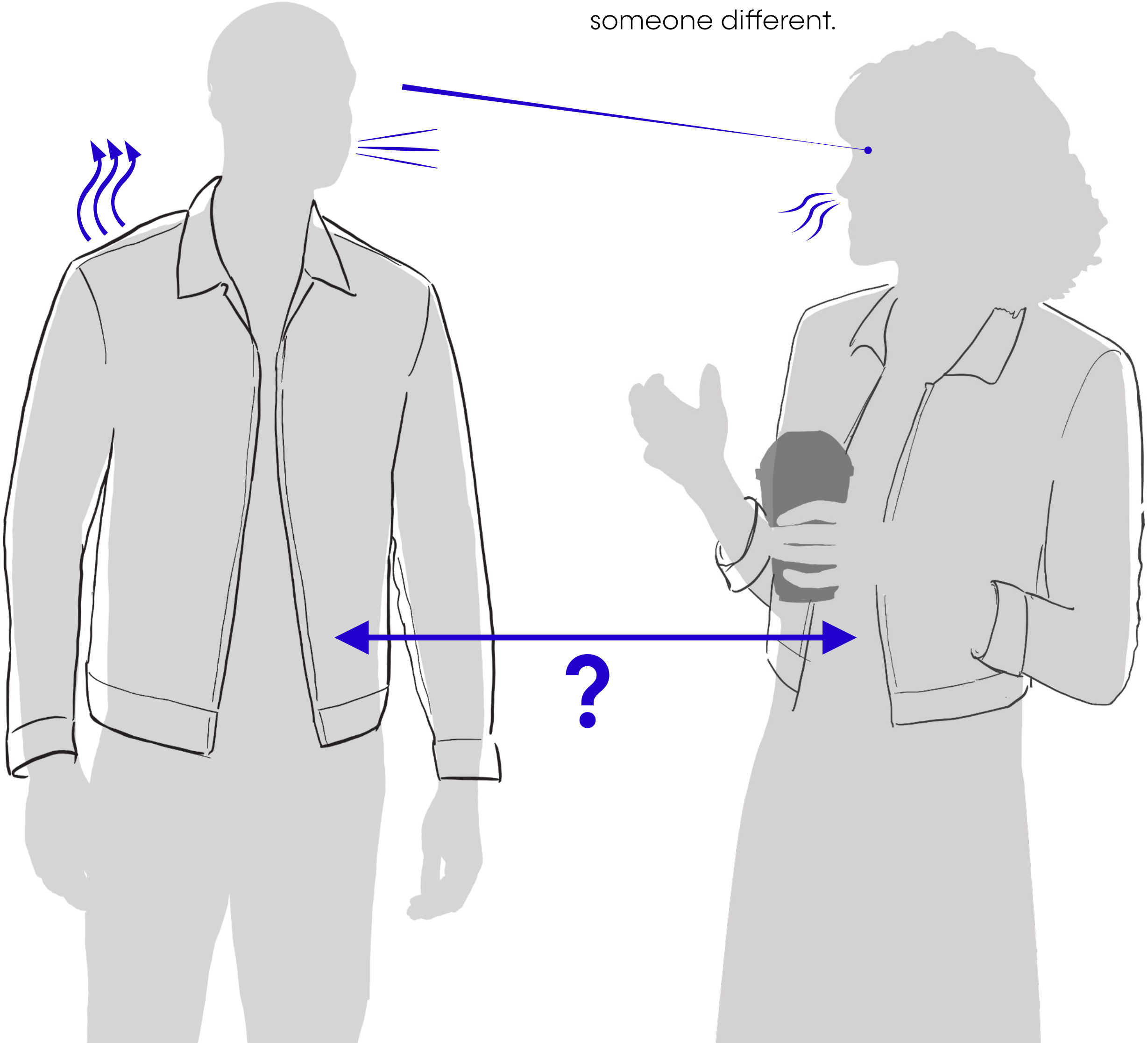
The amplitude of someone speaking can also change your experience. Think about whispering, shouting, ..

OLFACTION

We can smell various smells associated with someone, and that way experience someone different.

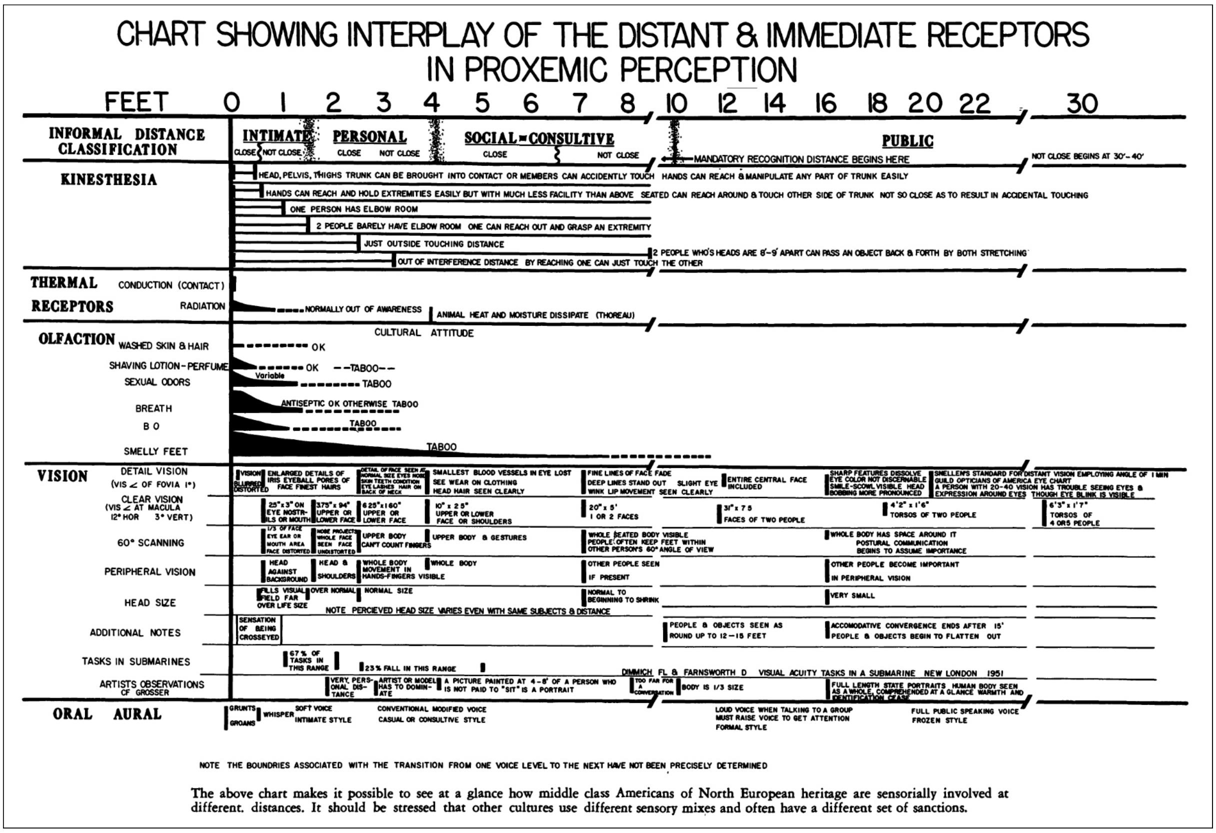
VISION

Our vision has depth perception so we can experience very precise distances from each other.



Proxemic zones

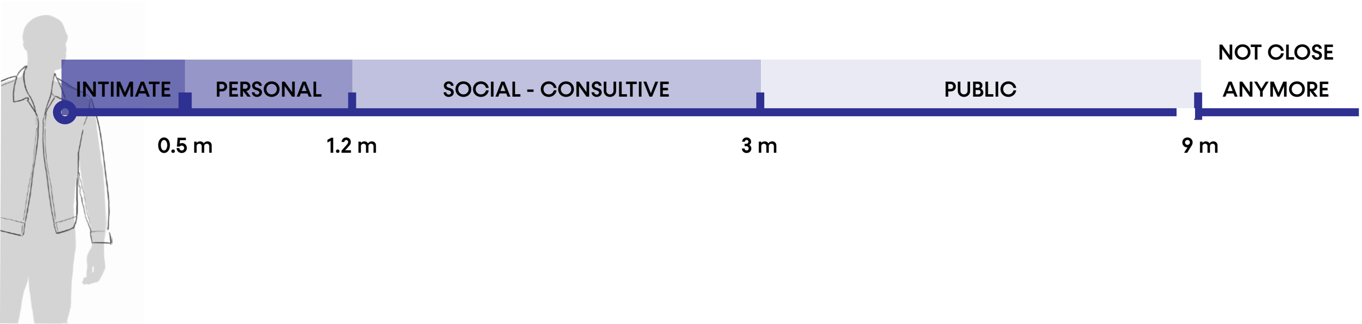
Hall made a chart, following his research, showing interplay of the distant & immediate receptors in proxemic perception (for Americans and North Europeans). It is illustrated underneath here.



NOTE THE BOUNDRIES ASSOCIATED WITH THE TRANSITION FROM ONE VOICE LEVEL TO THE NEXT HAVE NOT BEEN PRECISELY DETERMINED

The above chart makes it possible to see at a glance how middle class Americans of North European heritage are sensorially involved at different. distances. It should be stressed that other cultures use different sensory mixes and often have a different set of sanctions.

Chart showing interplay of the distant & immediate receptors in proxemic perception, Edward T. Hall, Proxemics, 1968



III. Conclusion 'Proximity paper'

Hall concludes with saying that there is no such things as a 'universal distance-setting mechanism'. "What is taken for granted in one culture may not exist in another" he says.

"One of the complexities of proxemic research is the fact that not only are people unable to describe how they set distances, but each ethic group sets distances in their own way. In fact, their measuring rods are different."

This raises the question if it would be possible to brute-force collect a lot of data on the interpersonal distances to one another and find a more precise distance-setting mechanism? If the problem of: 'why do people do something' is taken out of the equation by measuring distances with a technical solution, and measuring the experience of the person with vitals or surveys.

This can show some potential in the research on how to make people more comfortable. Or a way to experience how other people divide their distance-setting mechanism. In a growing international world it is important to think about designing for a variety of cultures instead of just the one that you live in.

Hall's first attempt on dividing different proxemic zones is a very helpful step towards a first prototype. Although it might seem like obvious divisions, from intimate to personal to social to public, it makes a whole lot clear for a first exploration.

PART: Application search and technology exploration

Application

The following chapter is an exploration for an interesting application that can use this technology. As described in the previous chapter is this chosen to have more grip on how to develop this solution, rather than having to work with a lot of unknown variables.

The ideas were generated via a few different methods. It is a combination of paper research, brainstorming, internet inspiration and derivatives of other ideas.

Help socially awkward people reading the situation

Firefighters in smoke

Walking in the dark

Interactive learning experience

People recognition

Forced behaviour jacket

Social distancing tracking

Prisoners tracking

Close contact counter

Warning for pickpockets

Safety clothing

Digital recreation of your live

Blind people assistance

Making music with proximity

Research surrounding of people

Mapping a room

Military night vision

Having eyes on your back

Findings

The first thing that occurs is that it is very hard to think of a nice application that is standing on itself. Looking for an application from the perspective of a technology is never ideal to do. This in itself already brought a lot of hurdles during this project. This probably has to do with the state of the concept:

" Proximity sensing in clothing „

This is already a very specific way of using technology. A lot of applications are better solved in ways other than depth sensors mapped on the body. That there is no direct commercial solution does not mean that it can not have a nice application.

Making music with proximity

Using proximity sensors mapped on your body to make music is an interesting idea. It invites to explore the sensors mapped on the body because with different values come different sounds. A first exploration in this category can maybe bring more ideas on the table.

This application invites more towards an art-project based solution. I personally think it is nice to use the distances measured and give them meaning for the person. For example in a tense situation with a lot happening close to you, you will get also a tense soundscape. That does ask for a better understanding of how humans experience distance and space.

Looking a bit further

Understanding interpersonal distances and how people set those is something described in Hall his work 'proxemics' from 1968. This could be a good start to get a better understanding.

I do not choose a direction yet, because I first want to verify if interpersonal distances and proxemic zones are an interesting topic to work with.

Technology exploration & existing solutions

Sensors

During the project, I had access to a lot of technology. Understanding the technology I wanted to use and the ones that were available to me really helped me with scope of this project. Even before I had a fixed concept, I explored different sensors and software packages during prototyping. This whole journey is described in the 'embodiment' chapter to keep consistency in the whole story of my design process.

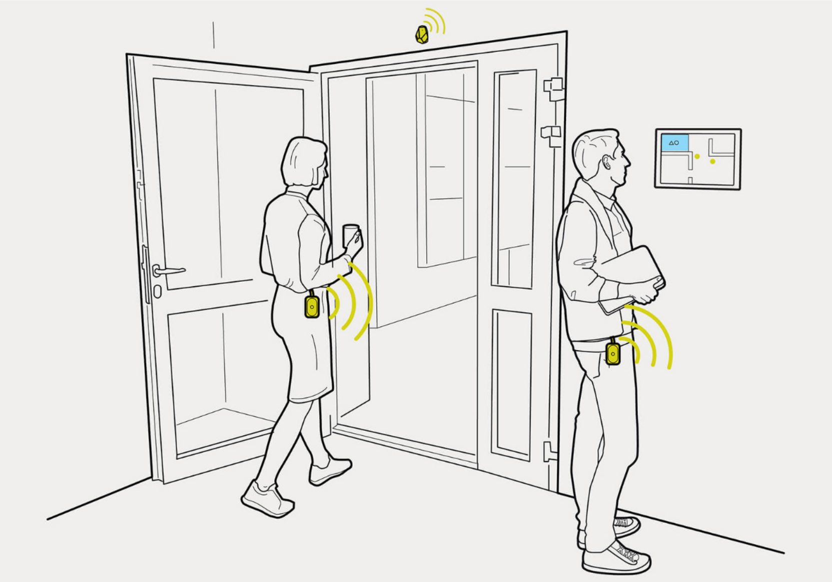
Some pictures of explored technology that can measure proximity in some way.

Existing products

Today, you can find commercial products that deal with analysing the movement of humans. They get used in different sectors other than just pure research of the human perception of proximity. I will discuss two products: Estimote Bluetooth beacons and Optitrack cameras.

I. Estimote

Estimote is a company focused on proximity and location solutions. It uses mainly Bluetooth beacons and GPS trackers to track where people and goods are. Their infrastructure enables to make more efficient workflows for companies. It can be really valuable to know how things in practice move.



Experiment

At the campus are several Estimote sensors available to test out. I ran some experiments with them to see what they were capable of and if they could be useful to work with in the future of this project.

Bluetooth beacons are very efficient technology. They sends Bluetooth low energy pulses with a certain interval and detect if there is another Bluetooth device nearby. When another device, like a phone or another beacon, is in range it registers its presence. It can all do this while using almost no power. A single beacon can run for two full years on a single button cell. This however gives only the indication if someone is close or in the same room, it does not tell anything about an exact distance. I tried to get an exact distance from beacon to beacon, because that is a crucial data point for this graduation project.

It is possible to detect the strength of the Bluetooth signals and theoretically link a certain distance to it by calibrating it. In practice was this very inaccurate and unusable for a distance measurement.

The Estimote Bluetooth beacons I used for the experiment.

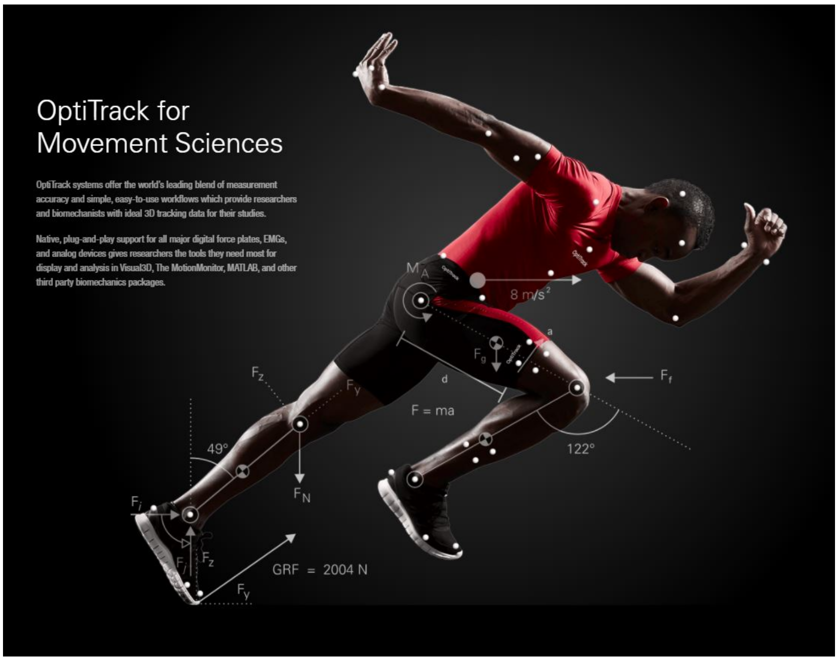
Another method was to place 3 beacons on the wall and let them calculate the moving object in the middle via triangulation. This was very inconvenient to calibrate. By placing beacons on the wall, you rely on a certain location to be able to measure distance.

Findings

While being very efficient, easy to deploy and easy to operate, the Bluetooth beacons are only good for indicating proximity and not for an exact measurement. This project is going to be focused on more exact measurements. This is no wonder, Estimote sensors were not designed to research exact distances from human to human.

II. Optitrack

The Optitrack system is a solution for precise body tracking. It uses a very advanced camera solution with multiple cameras and tracking points placed on a human body. It is used in movement science, virtual production and robotics.



OptiTrack for
Movement Sciences

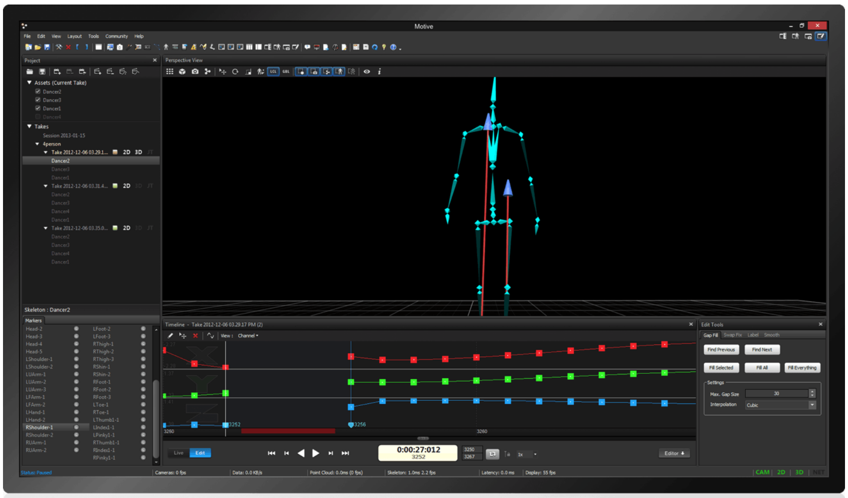
OptiTrack systems offer the world's leading blend of measurement accuracy and simple, easy-to-use workflows which provide researchers and biomechanists with ideal 3D tracking data for their studies.

Native, plug-and-play support for all major digital force plates, EMGs, and analog devices gives researchers the tools they need most for display and analysis in Visual3D, The MotionMonitor, MATLAB, and other third party biomechanics packages.

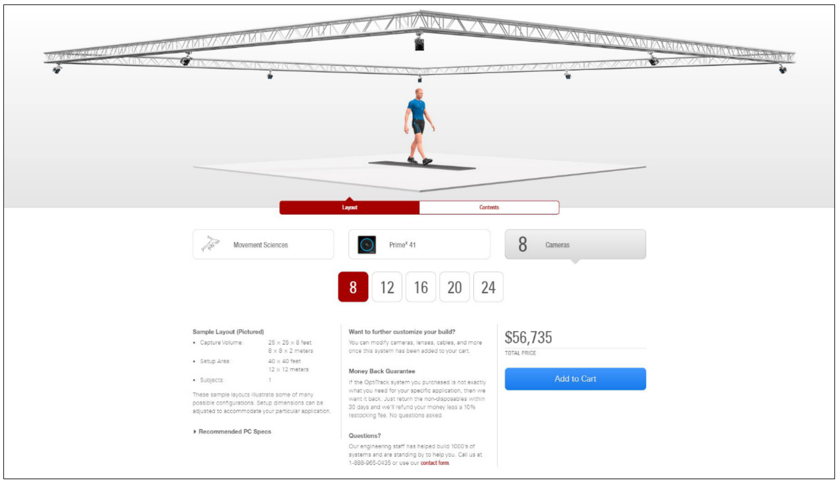
A screenshot from the Optitrack website.

Optitrack.com

Optitrack claims to be the most advanced tracking and measuring system in the world. It can digitise the whole movement of the body with extreme accuracy and at a very high frame-rate. That data can then be used for all sorts of things like analysing the body posture and the speed of a person.



The Optitrack solution could easily measure the distance two people have from each other, but it would be an overkill solution. The whole system cost around 50 000 euro - 150 000 euro depending on the configuration you choose. This is partly because it is a commercialised solution, but also because it is so complex to make.



Sample Layout (Pictured)
- Capture Volume: 25 x 25 x 8 feet, 8 x 8 x 2 meters
- Setup Area: 40 x 40 feet, 12 x 12 meters
- Subjects: 1

These sample layouts illustrate some of many possible configurations. Setup dimensions can be adjusted to accommodate your particular application.

Want to further customize your build?

You can modify cameras, lenses, cables, and more once this system has been added to your cart.

Money Back Guarantee

If the OptiTrack system you purchased is not exactly what you need for your specific application, then we want it back. Just return the non-disposables within 30 days and we'll refund your money less a 10% restocking fee. No questions asked.

Questions?

Our engineering staff has helped build 1000's of systems and are standing by to help you. Call us at 1-888-965-0435 or use our contact form.

$56,735
TOTAL PRICE

Price configuration for the Optitrack system on their website.

Findings

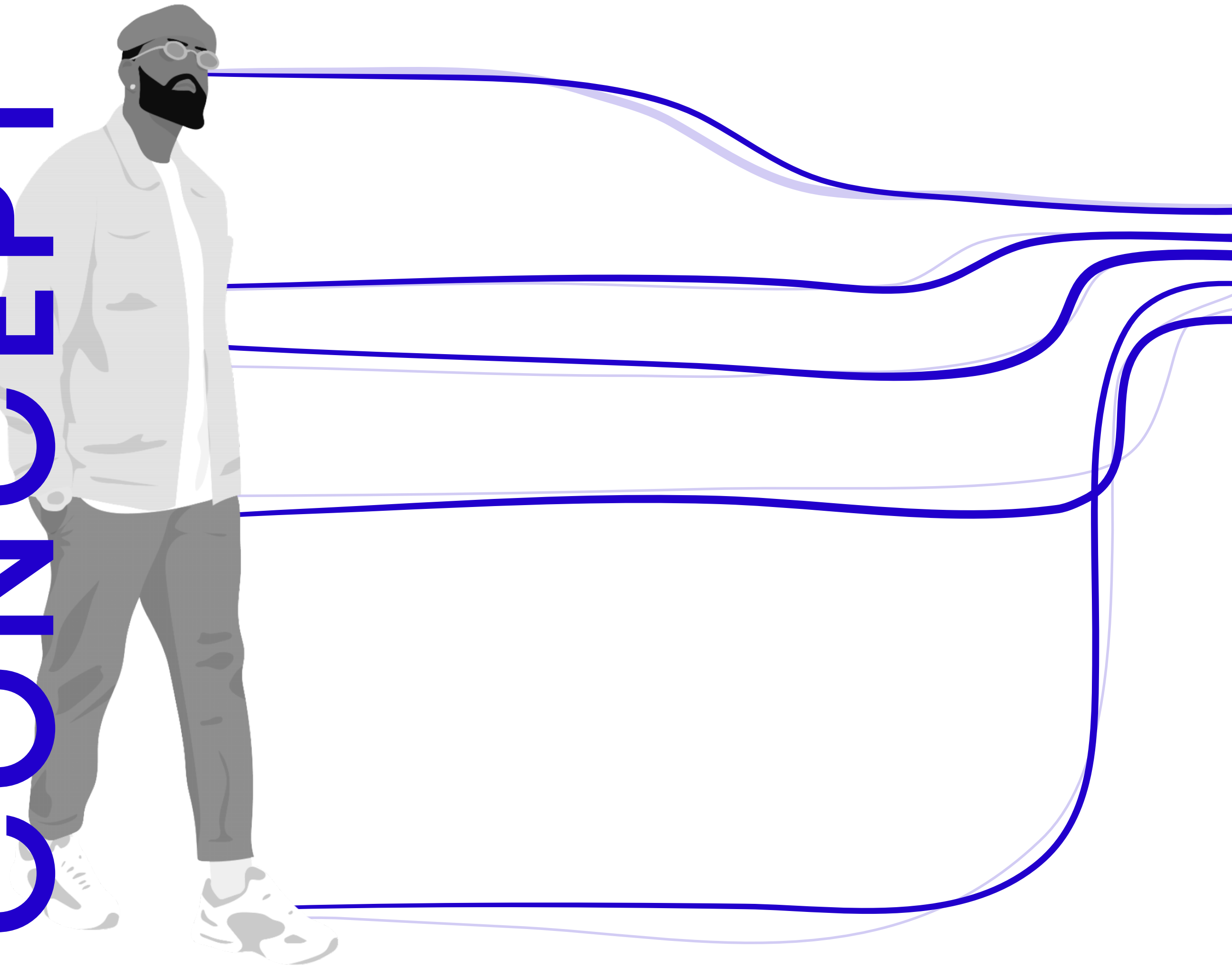
Measuring the people around you is possible with a tracking solution like this, but it would ultimately be very unpractical. A lot of infrastructure, money and calibration is needed to make system like this work. Maybe there is a simplified solution possible with the tracking technology that they use.

III. Discussion existing products

The Estimote and Optitrack are both very different solutions for very different applications. They do however both measure proximity in some way and analyse the data of it.

Making a tool for the exploration of proxemic zones is not done before. For this project, the solution will be somewhere in the middle of course. The challenge is to find the essence of the perception of proximity for humans and use the best technology for researching that. As seen in this chapter, the solution can be very complex (Optitrack) or just not precise enough (Estimote) for this project and in that case useless. Finding a solution that is not depending on a certain location is also a must if it needs to be easily employable at many locations.

CONCEPT



My research question

Hall did very insightful research on how people define distances from each other. His methods did however stay very analogue because of the lack of technology back then. Nowadays, we have many distance sensors and wearable technology to make a prototype that will be able to measure how far people are apart from each other. I want to tackle this project with the use of modern sensors.

Hall divides four different proximity zones. He does not indicate that these zones are fixed, but he found general trends for American and West-Europeans. One of the more interesting distance setting is the personal space of people. Personal space is a very individualistic thing, it is different for everybody. It tells how comfortable people are with close contact.

The question asked in this project is:

" Can we make a tool to find peoples personal (and interpersonal) space? „

That makes the design of this project:

" A design tool for the exploration of proxemic zones „

Although this is a research focused project, this question will be solved with a lot of iterative prototyping and testing. This method is called research through design and is in line with the focus of this project: use technology to answer our question.

“ a **Design tool** for the **exploration of proxemic zones** „

The personal space is something everybody has and subconsciously uses to set distances from other people. This tool is to explore when somebody is in that personal space.

A wearable of some sorts to put on. It measures the distance people have from you and how comfortable you are.

Goal/ why this tool?

Everybody is different and it is impossible to know how people feel or think. We can however simulate similar scenarios to understand other people better. Personal space is, like the name says, different for everyone but it is not impossible to measure it and let somebody else know how you use it.

That’s why this tool can be handy. Down here are a few scenarios summed up of different use of personal space and space in general.

I. Different cultures

Hall studied mostly people from North-America and a small part of West-Europe. He ended up with specific proxemic zones, but those do not apply for other cultures in, for example, the Middle-East or Africa.

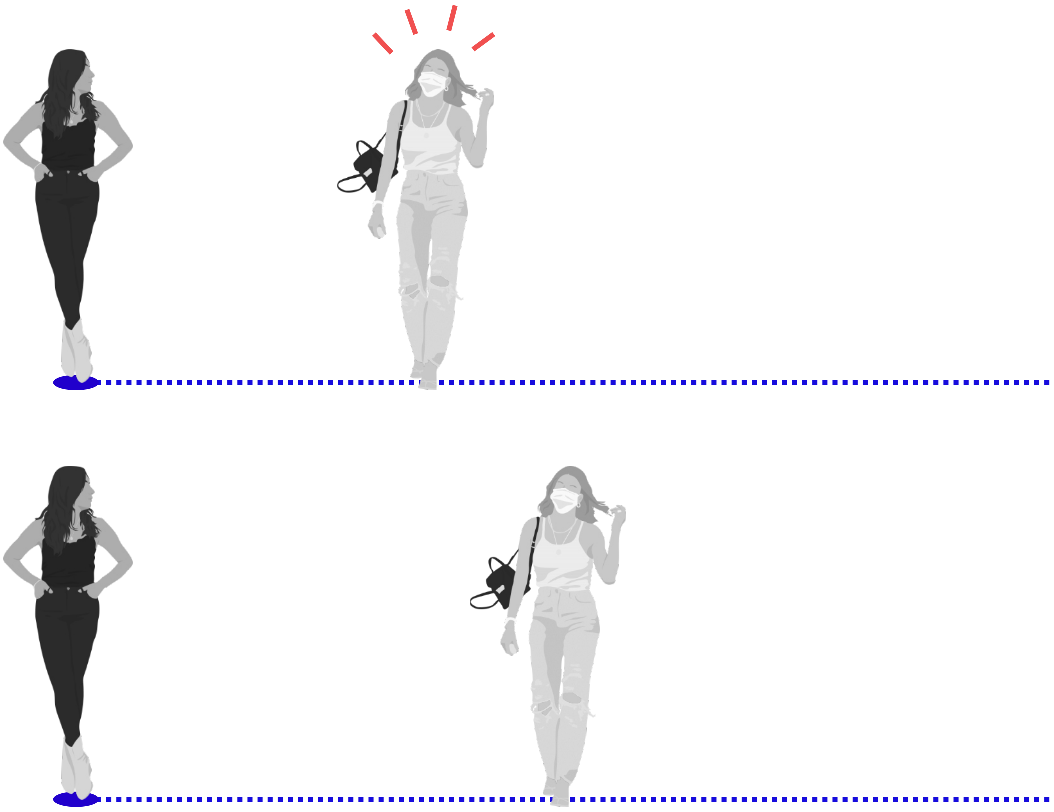
II. Individuals

Defining zones for a whole geographic area or culture is a good idea to simplify things, but it does not tell anything about individuals their experience. For designing a hyper-personal product, data from that individual is much more valuable.

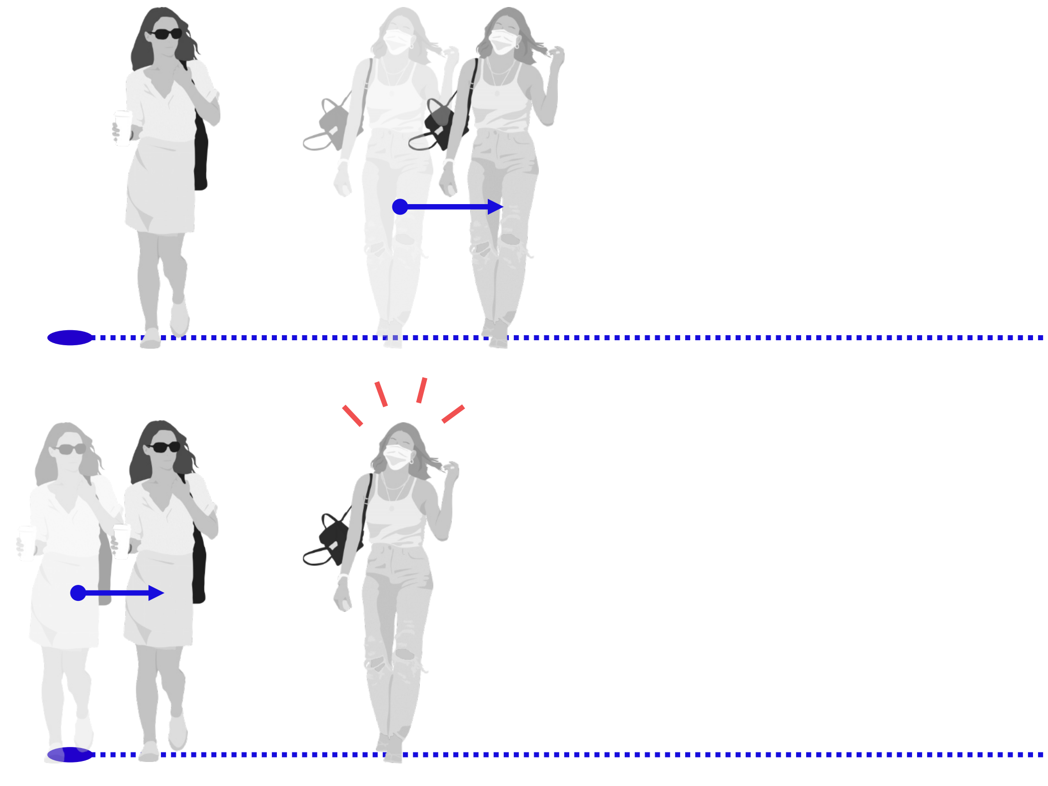
When we look at individuals, some people have vaslty different personal zones than others. This is could be connected to certain fairs they have. People with agoraphobia, for example, can experience panic attacks with too many people around them, or also absolutely nobody around them. Claustrofobia is the fear of confined spaces. So, having almost no proximic space around them can make them extremely uncomfortable. Calling these examples does not mean everybody has the same amount of fear. So, understanding individual proximic comfort can really help these people.

Hall also talks about the different senses we use to set our proxemic zones. In Europe it is mostly based on visual feedback. In this case, blind or visually impaired have to experience it in a different way. People with anosmia can not use smell and deaf people can not use sound. All these people have to set their own zones and the question is how they are different from fully abled people.

SITUATION 1 : THE GIRL ON THE LEFT GETS UNCOMFORTABLE FROM THE OTHER GIRL CLOSE TO HER, BUT IS OKAY WITH THE LADY A BIT FURTHER



SITUATION 2 : ANOTHER PERSON MIGHT ONLY GET UNCOMFORTABLE WITH A MUCH CLOSER DISTANCE



What to measure?

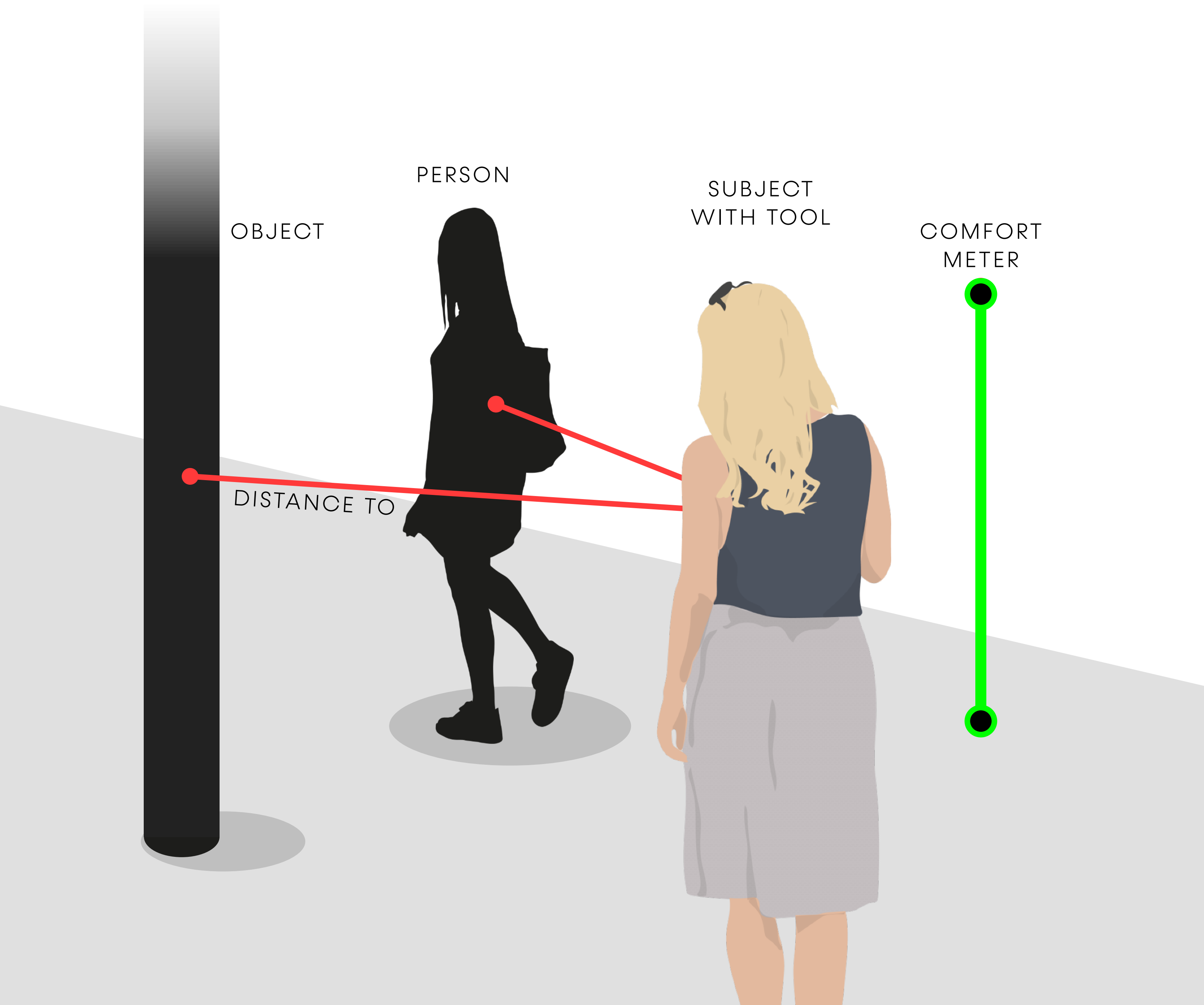
This tool needs input to work. This includes:

- Distance measuring from the person to the other person or environment
- Difference between a person and the environment
- An indication of how how people experience that particular distance.

How exactly these things will be measured is going to be decided via research through design in the *embodiment* chapter.

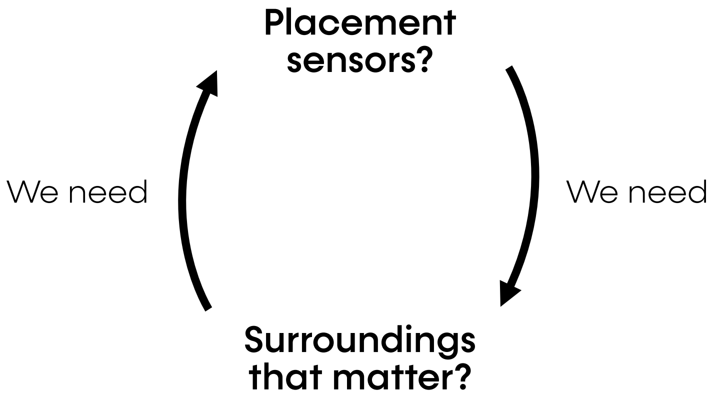
Research question: **what is the best way to measure an indication of discomfort?**

Research question: **is discomfort connected to certain distances people have from each other?**


PERSON
OBJECT
SUBJECT
WITH TOOL
COMFORT
METER
DISTANCE TO

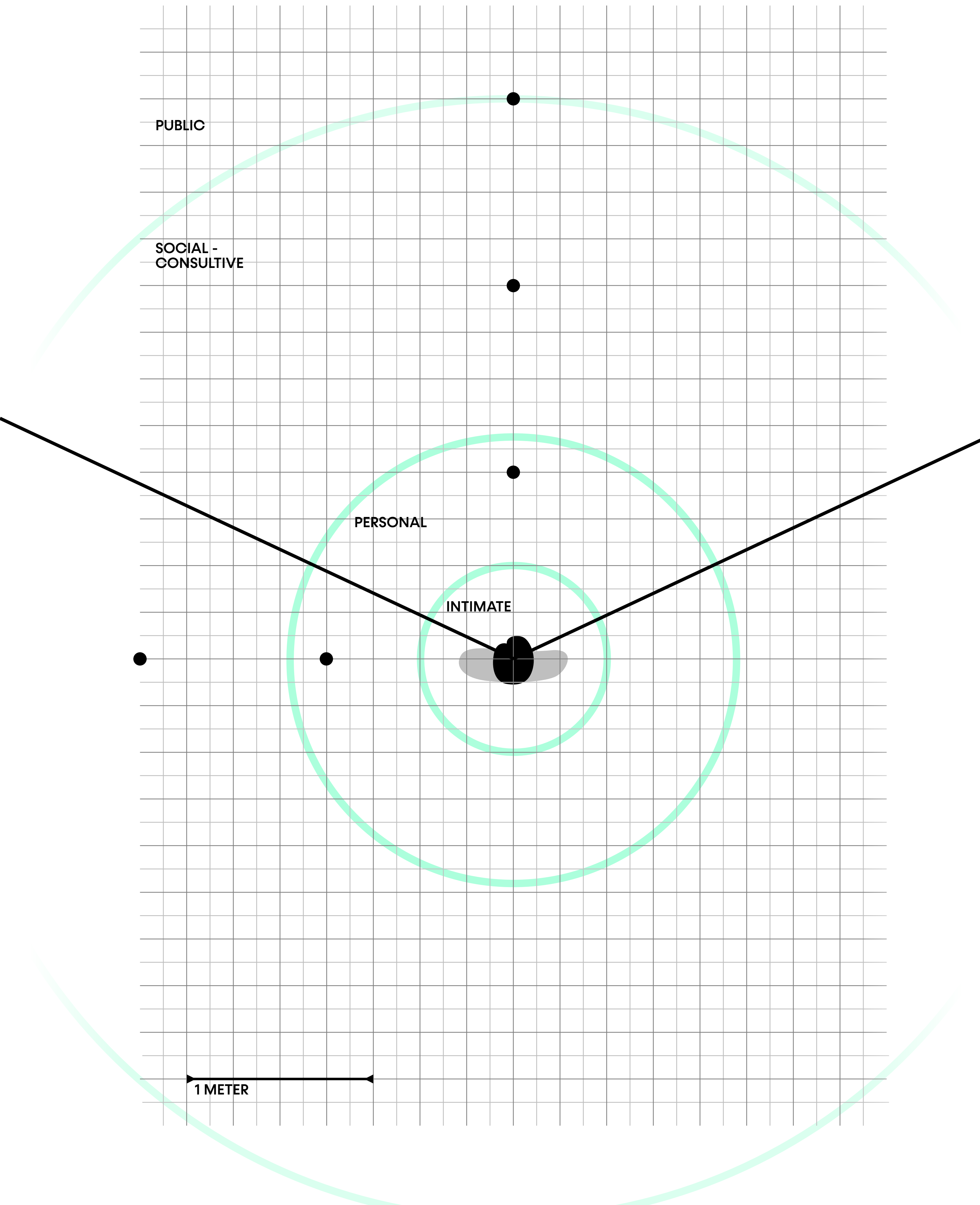
Coverage

This is an aspect that loops in on itself. We would like to know how much around the person matters that influences his/her personal space so we can put sensors on those places. But we don't know how much surrounding influences the personal space, and in order to know that, we need to test that with placing sensors at those places.



To get started, it is the best idea to assume that the persons field of view is going to have the biggest impact on their personal zone. It is safe to start there and see what the technology enables us to measure.

Research question: **what technology enables to measures the distance from people around you?**

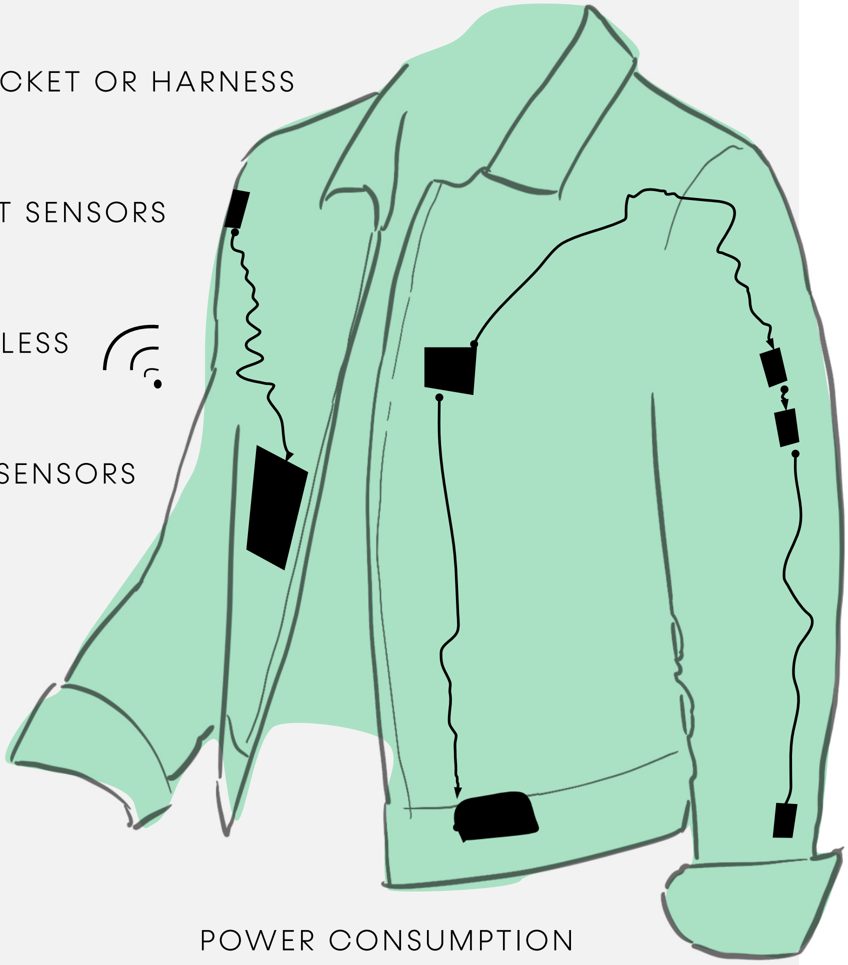

PUBLIC
SOCIAL -
CONSULTIVE
PERSONAL
INTIMATE
1 METER

Wearable solution

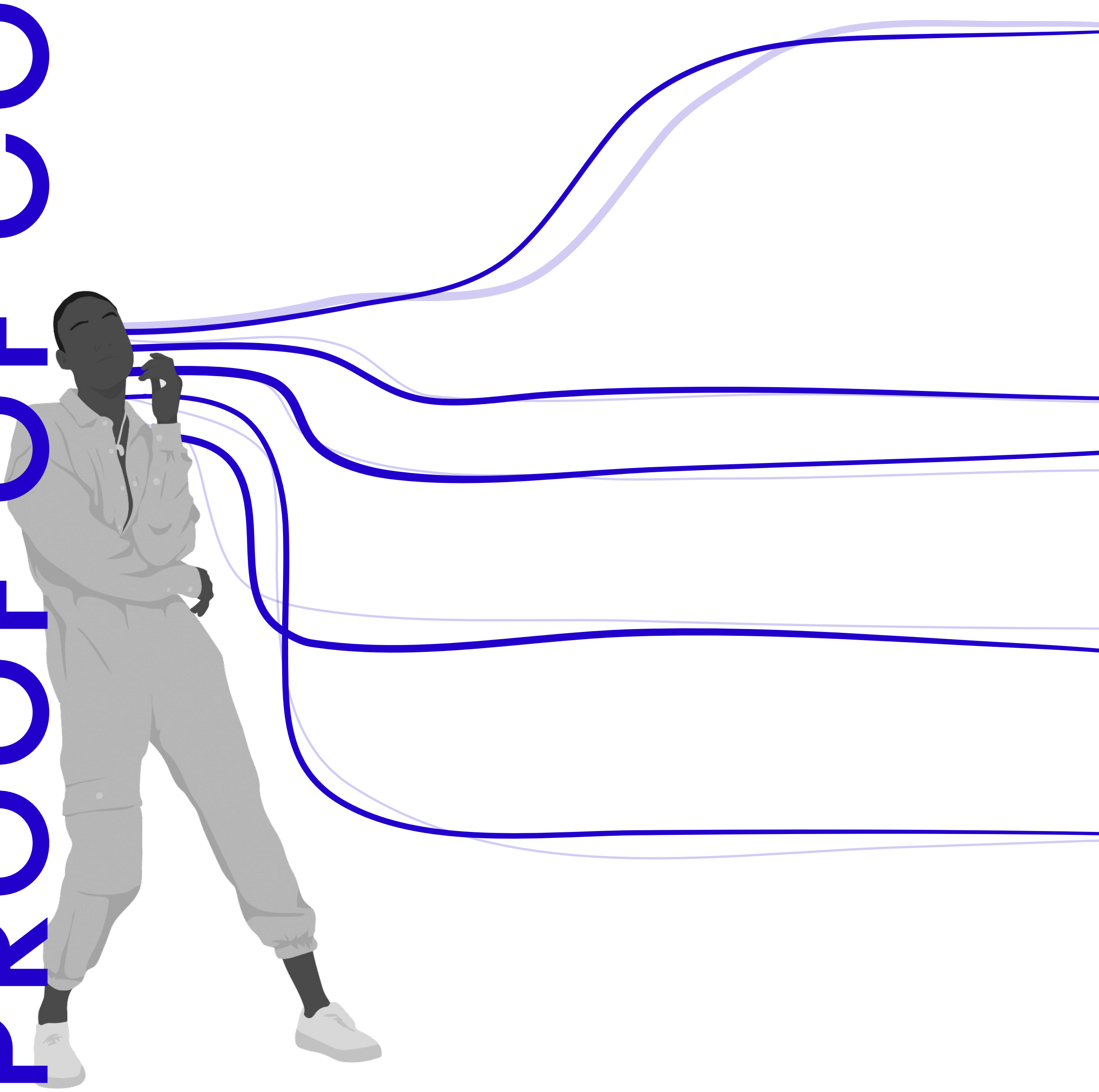
The embodied solution is still to be decided and researched. But there are several aspects that are already known to be included. Some parts are decided, but need verification.

- The solution needs to be in the **form of a jacket or harness** of some sorts, and needs to be easily in use on different sizes of people. It needs to be tested what the more elegant solution is.
- An array of sensors will be placed on the wearable. The **types of sensors** are still to be decided based on which one will work and which are the best suited.
- The **placement of each of these sensors** needs to be researched. The proximity sensors can not be blocked for example and the placement of them also decides how much of the surroundings they can cover.
- The **data of the sensors needs to be send to a database**

Research question: **what garment is the best solution for this concept?**


SOUND PRODUCING
JACKET OR HARNESS
PLACEMENT SENSORS
WIRELESS
TYPE OF SENSORS
POWER CONSUMPTION

PROOF OF CONCEPT



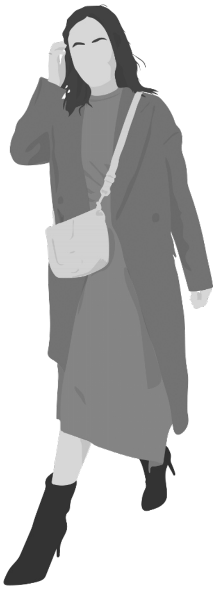
Approach

In this project is chosen for the **research trough design** approach. By making a lot of prototypes and every time iterating on them, you get a better and better insight on how the final product should look. This is a good design method because of the exploratory nature of this project. It is not certain yet what kind of systems are possible and what the best solution will be in the end.

In this chapter, I will describe the different prototypes I made to come closer to a solution. With every prototype, you get a **decription of the problem** that needs to be solved, the **approach to solve it** and, of course, a page with all the things I learned from it.

The **insights page** is a blue page at the end of every prototype. It quickly goes over the things learned on the left side. On the right side, there is a **Harris profile**. This describes the status of the prototype worked on. During this project, I verify different aspects of the design and see if they need to be improved or are developed well enough. On the right page here, you can find a description of this Harris profile and all the categories that are getting verified.

Under the Harris profile is a **things to do for the next iteration**. That is a quick sum-up of suggested improvements.

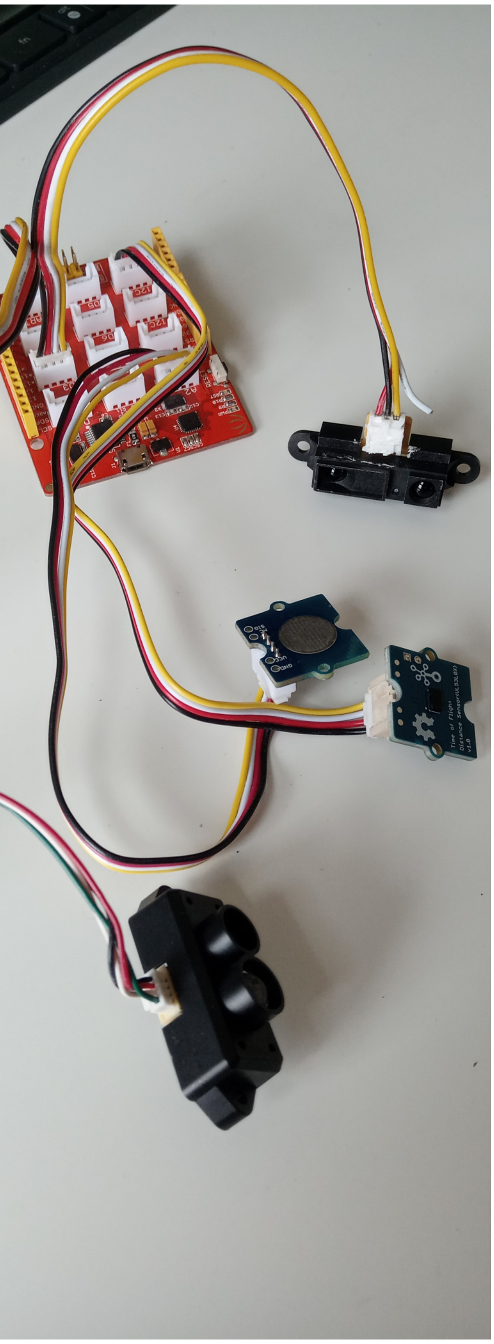


Harris profile

The 4 categories indicate how developed that piece of the prototype is. ++ means it is good to go. - - means it needs more development.

		--	-	+	++
How much of the surroundings of the person can the prototype measure? More is better.	FIELD OF VIEW	■			
How much of the proxemic zones can the prototype measure? More is better.	# PROXEMIC ZONES			■	
Can the prototype see the difference between a human and the rest of the environment?	HUMAN & OBJECT	■			
Does the solution ask for a lot of processing power? Less is better.	LOW CPU POWER				■
How accurate are the distance sensors? More accurate is better.	ACCURACY				■
How easy is it to use the data the prototype generates, for something else like a data base.	VALUE OF DATA-POINTS				■
Does it intrude the privacy of the person wearing it an the people around them? Less is better.	PRIVACY				■
How portable is the solution? Smallest form factor is the best.	PORTABILITY				■
How stigmatic is the solution to wear?	STIGMA				
How much power does it consume? Less is better	POWER CONSUMPTION			■	■
How much does it cost in total?	PRICE			■	
Is the sound developed and does it create a nice soundscape?	~~SOUND~~				

If the category is striked trough, it means the prototype did not develop that part.



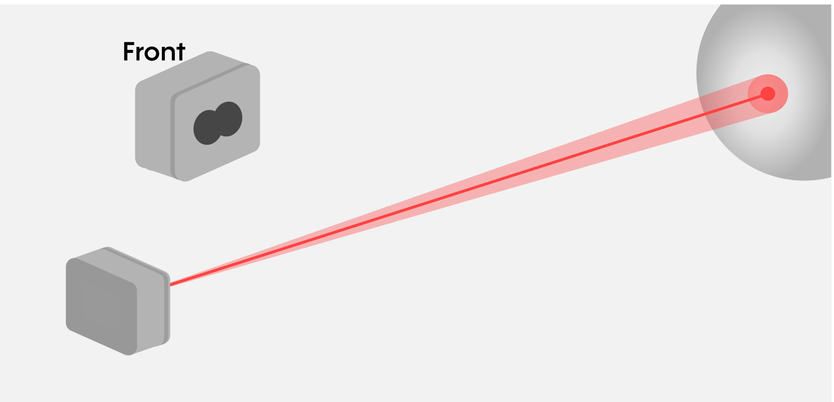
Seeduino with a (from top to bottom) infrared proximity sensor, touch sensor, Time of flight sensor and mini LiDAR sensor

Prototype 1 • Exploration

Single range proximity sensors

With access to a verity of proximity sensors it was decided to start there and see what they can do. In these tests was looked at the capabilities of the different sensors, the ease of use and limitations.

These sensors can only measure the distance to the object that comes in its single beam path. Solutions convenient enough to wear use three different technologies: Time of Flight principle, Ultrasonic distance measuring and infrared triangulation.

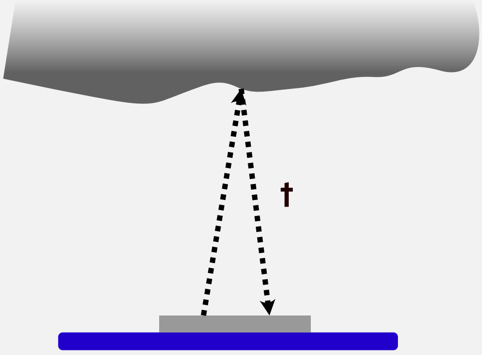


Capability of a single ranging solution

I. Technology/ How does it work

TIME OF FLIGHT

This sensor measures the time the infrared light-beam takes to fire out of the sensor, bounces of the distant surface and comes back at the sensor. Dividing this number with the speed of light gives the distance the beam made. By dividing this by two, we get the measured distance.

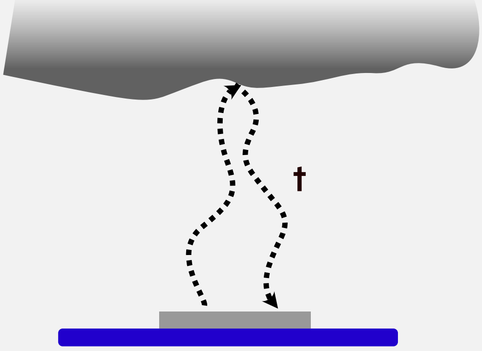


PROS: very accurate, super fast, works in darkness and bright conditions, small package

CONS: Needs a sufficient reflective surface to bounce off, does not work in too bright ambient light

ULTRASONIC

The sensor sends out a beam of sound, unnoticed by the human ear (40kHz). The same calculation is done as the ToF principle, but with the speed of sound.

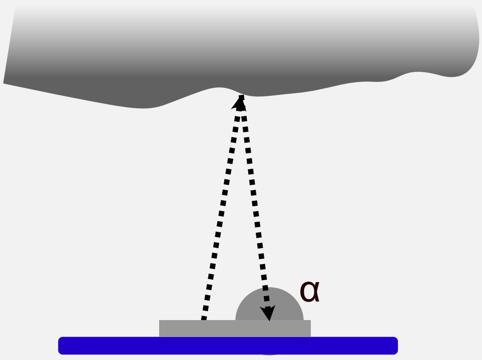


PROS: easy to operate, low energy, good close to far range

CONS: is influenced by wind and too fast moving bodies, more on the bulky side

INFRARED TRIANGULATION

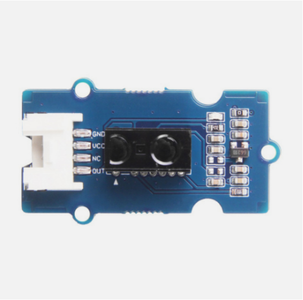
This sensor sends a infrared light beam to the distant surface. The beam bounces back to the other lens of the sensor and this one measures the angle at which the beam arrives at the sensor. The bigger the angle, the shorter the distance.



PROS: easy to operate, low power

CONS: short range distance, bulky package

II. Type of sensors



DISTANCE INTERRUPTER

Range: 0.5 - 5 cm
Technology: Infrared triangulation
Resolution: in range = 1, out of range = 0
Low energy, cheap, easy to use
Size: Small, but 5mm thick

INFRARED PROXIMITY SENSOR

Range: 0.1 - 0.8 m
Technology: Infrared triangulation
Resolution: +- 1cm
Low energy, cheap, easy to use
Size: medium, but 5mm thick

TOF SENSOR, VL53L0X/VL53L1X

Range: 0.2 - 2 m / 0.4 - 4 m
Technology: Time of flight
Resolution: +- 1cm (2%)
Low energy, 10 euro
Size: small, but 2mm thick

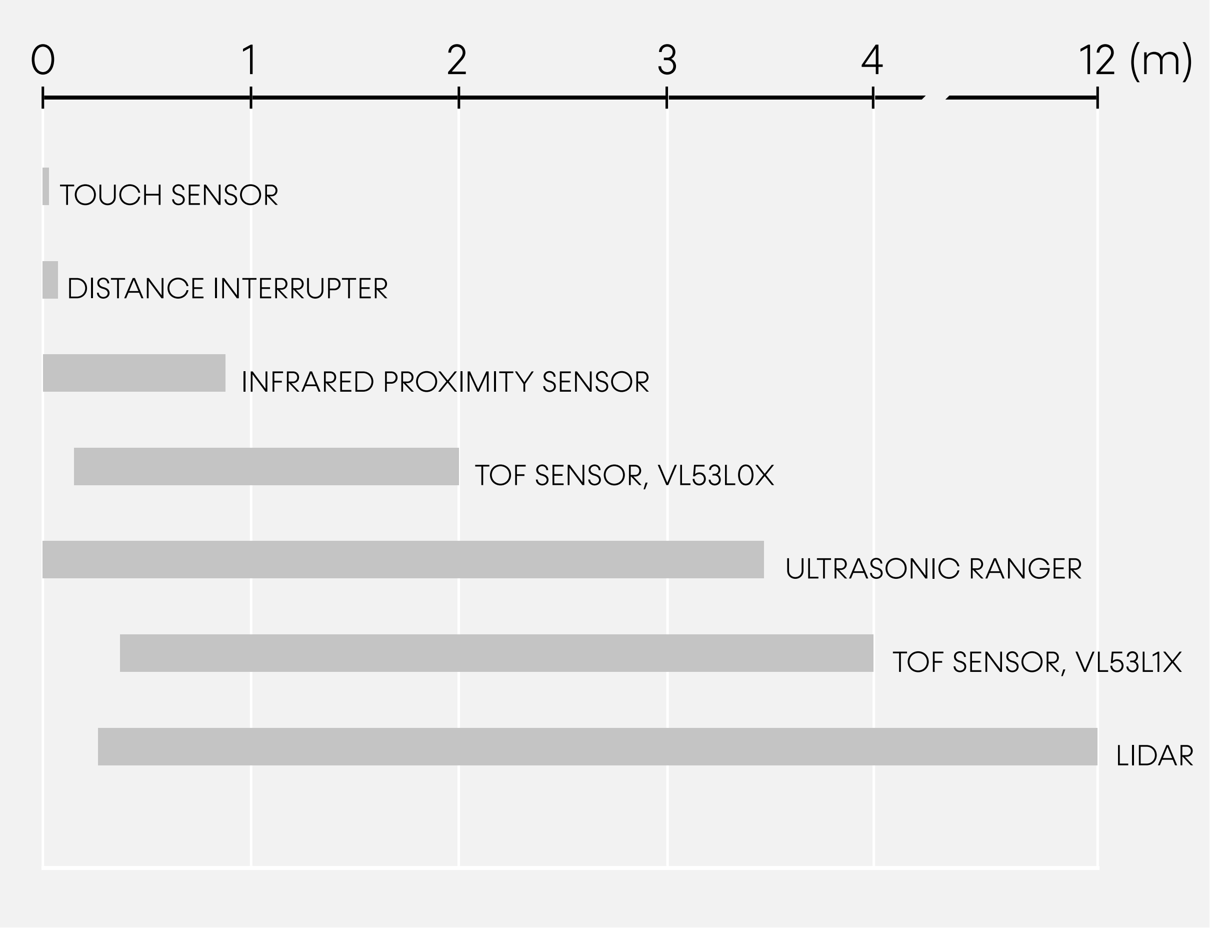
ULTRASONIC RANGER

Range: 0.02 - 3.5 m
Technology: Ultrasonic
Resolution: +- 1cm
Low energy, 10 euro
Size: Big, 12 mm thick

MINI LIDAR

Range: 0.3 - 12 m
Technology: Time of flight
Resolution: +- 1cm
Medium energy, expensive (40 euro)
Size: medium, 8 mm thick

III. Ranges & coverage



While most sensors are only capable to measure up to a few meters. The LiDAR can get up to 12 meters. Now, for this application, it probably suffices to measure around 3-4 meters. So, these time of flight and ultrasonic ranger are usable candidates.

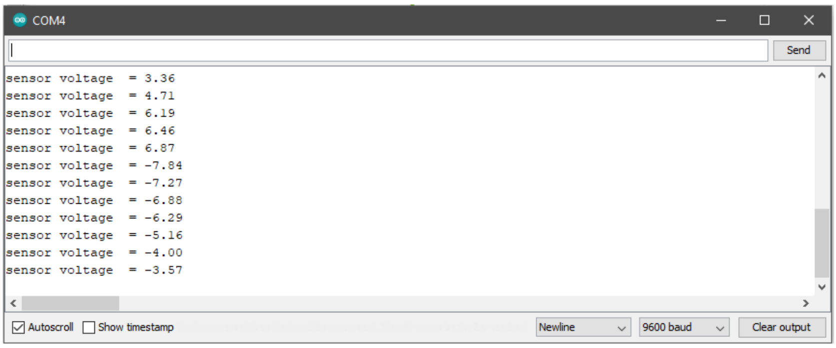
When talked about the field of view of these sensors, all of them are the same. These types see only around 2-3 degrees of view. The sensor needs to be pointed at the object or person. This is the obvious disadvantage of all of them. Next prototypes need to explore what is possible in terms of coverage. Maybe stacking a lot of sensors together, or pointing them strategically?

IV. Arduino prototyping

All sensors are low in processing and barely take any memory of the microcontroller. The refresh rate of all of them is more than enough for constant measuring.

The analogue sensors are just plug and play. Adding a analogRead on the right pin and the values come out as a voltage that changes according to the distance the sensor measures. A little calculation to convert it to an actual distance and the processing is done.

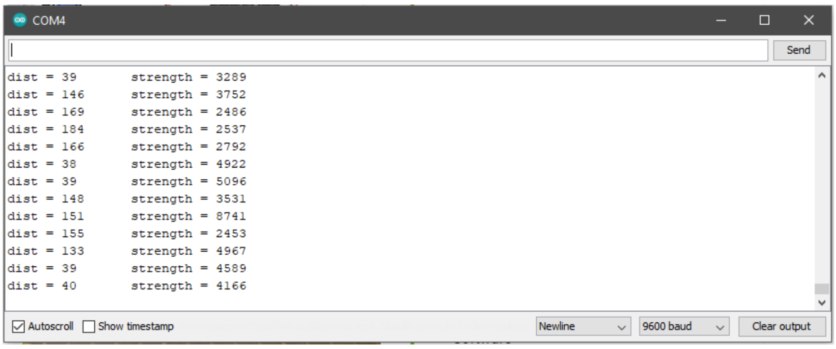
Values you get from an analogue sensor, specifically infrared proximity sensor



```
sensor voltage  = 3.36
sensor voltage  = 4.71
sensor voltage  = 6.19
sensor voltage  = 6.46
sensor voltage  = 6.87
sensor voltage  = -7.84
sensor voltage  = -7.27
sensor voltage  = -6.88
sensor voltage  = -6.29
sensor voltage  = -5.16
sensor voltage  = -4.00
sensor voltage  = -3.57
```

The digital sensors like the TOF and LIDAR need an Arduino library to work because they work via a I2C protocol. This takes more processing for the microcontroller, but gives a better result in the end.

Values you get from a digital sensor, specifically LiDAR



```
dist = 39       strength = 3289
dist = 146      strength = 3752
dist = 169      strength = 2486
dist = 184      strength = 2537
dist = 166      strength = 2792
dist = 38       strength = 4922
dist = 39       strength = 5096
dist = 148      strength = 3531
dist = 151      strength = 8741
dist = 155      strength = 2453
dist = 133      strength = 4967
dist = 39       strength = 4589
dist = 40       strength = 4166
```

A distance interrupter and touch sensor give just a 0 when out of range and a 1 for in the range. As far as distance measuring goes, that is not usable. The only thinkable scenario is to see if something/somebody is touching the subject.

Insights
Proximity sensors

Distance measuring

Single range sensors are very accurate in the measuring for depth. The worst of them all still has an accuracy rate of around 5%. When it comes to their range, a solution like LiDAR can go up to 12m in ideal conditions.

Coverage

The biggest problem is that they just measure 1 point in space, and it needs to be right in front of it. Researching if this will be sufficient for a final prototype is essential.

Portability

All the sensors are small, don't weigh much and consume little power. Putting these on a wearable will not be a problem at all.

Multiple sensors

The sensors that measure the light can be used with multiple at the time. The sound sensor is more tricky, because they interfere with each other quite quickly.

Harris profile

	--	-	+	++
FIELD OF VIEW	■			
# PROXEMIC ZONES			■	
HUMAN & OBJECT	■			
LOW CPU POWER				■
ACCURACY				■
VALUE OF DATA-POINTS				■
PRIVACY				■
PORTABILITY				■
~~STIGMA~~				
POWER CONSUMPTION			■	■
PRICE			■	

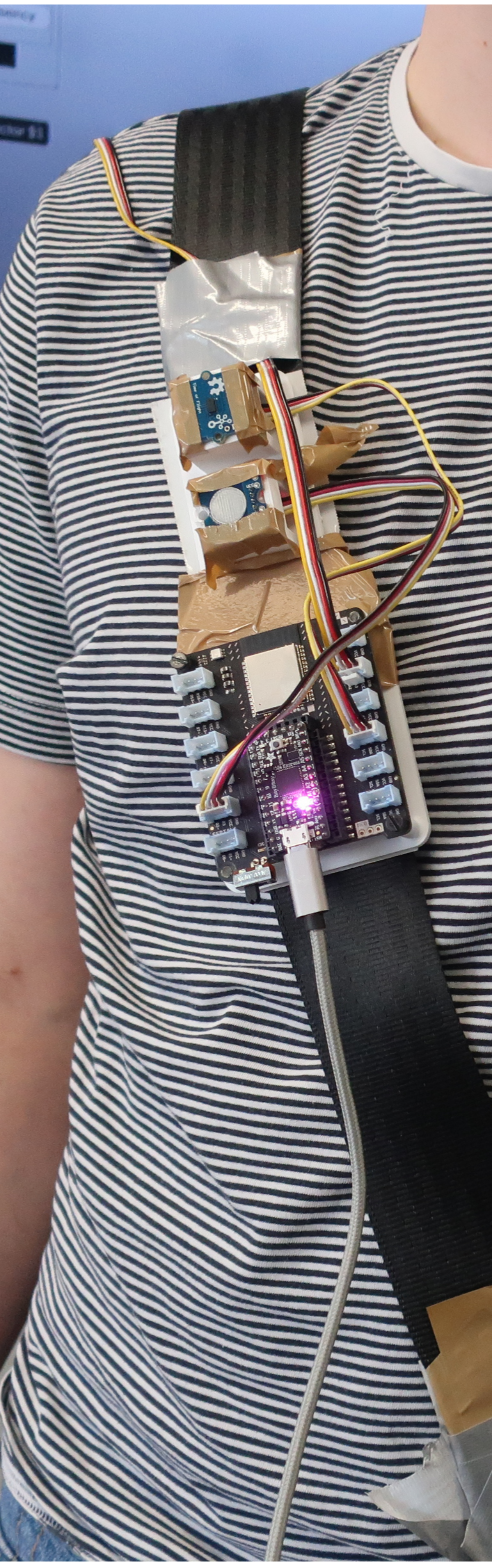
~~SOUND~~				

Things to do for next iterations:

- Test the sensors on a wearable vest
- Test if sensors can take enough coverage

Belt wearable

Connecting to max



Prototype no. 1, attached to a seat belt for easy putting on and off.

This first prototype was made to get familiar with the different sensors and the MAX MSP software. The goal was to make a prototype that uses the Arduino TOF sensors and live manipulates sounds made in MAX.

I. Sensors

Here, a combination of three sensors was used. More exactly:

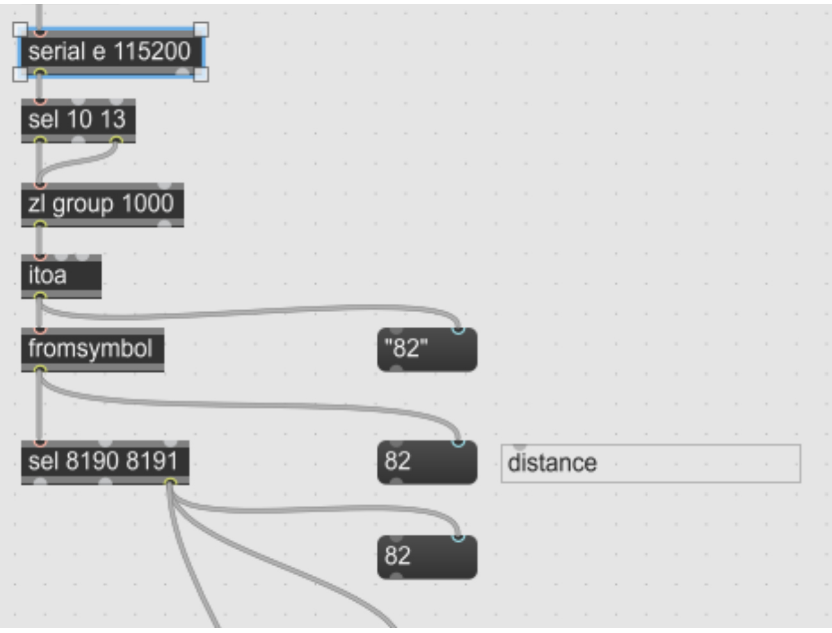
- **Touch sensor**, on the front for imitating a distance of 0 meter.
- **VL53L0X sensor**, on the front for measuring distances up to 1,2 meter.
- **Infrared proximity sensor**, on the back for measuring 0,8 meter.

These specific types were chosen because they all use different ways of outputting their data. The touch sensor gave a 0 or a 1 indicating if it was touched or not, while the ToF sensor gave an exact distance outputted in mm. Both of them updated 10 times per second because the arduino program was written that way. The infraRed sensor gave an analogue signal in the form of a voltage. The more voltage, the closer the measured object. In the arduino sketch was also a conversion provided to an actual distance (in cm). Because of this method of measuring, the distance was far less accurate than the other two.

II. MAX patch

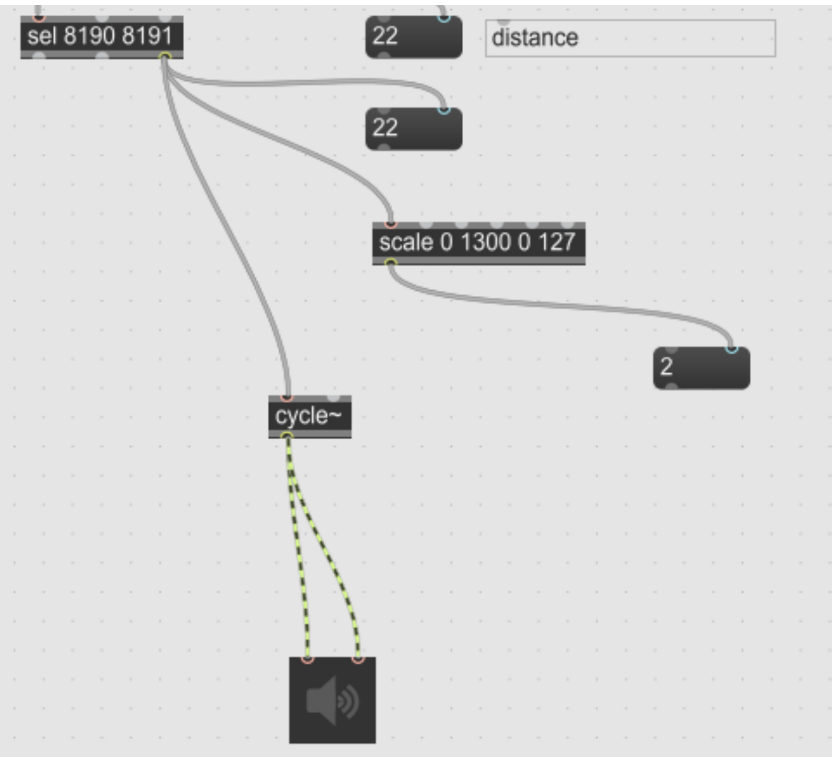
On the MAX side of things, it was essential to figure out how to get the Arduino-data into the MAX patch and use it as a variable for changing sound. Making a nice sound was not the objective.

The idea is to make a bridge of communication over a defined serial port. If the micro-controller is plugged in COM8 for example, the MAX patch can use a serial object and define it so it reads the data from COM8. Out of that object will come the RAW microcontroller data. After translating that back to mm-values via some other MAX object, you are good to go and use that data to manipulate sound.



Beginning of MAX patch that handles the translation of the sensor values.

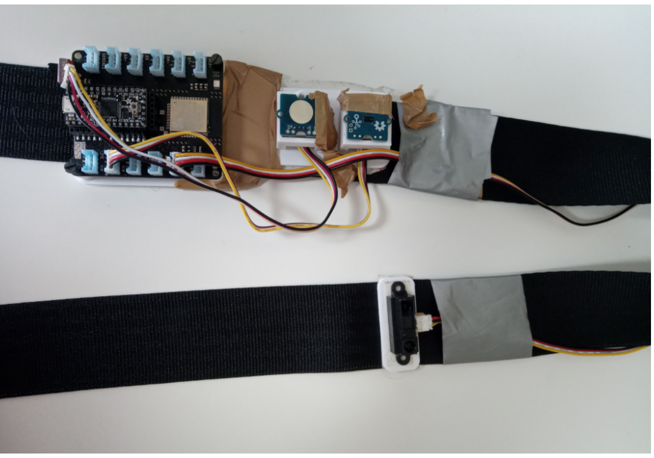
Now, after all this set-up, the patch is ready to use the sensor as ‘an instrument’ so to speak. In the image above, a distance of 82mm is measured in that moment. Linking that to a ‘cycle’ object gives a 1:1 conversion from mm to Hz. The closer the sensor measures, the higher pitched the sound.



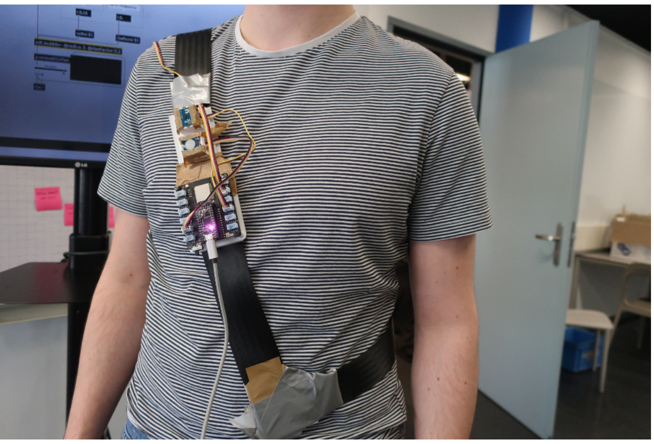
MAX patch using the sensor mm data and converting it to a Hz signal sound.

III. wearable

On this belt are multiple and different sensors attached. One in the front and one on the back. Also a touch sensor is added to simulate someone touching the subject. The sensors need to be attached on the body in some way.



Belt prototype with sensor on the front and back



Front with heavy 3D print

Back sensor is hanging too much to the ground

In this case was chosen for a seat-belt as body. The electronics are attached with 3D prints, and the prints are attached with double sided tape. Decisions were made so it could be tested as soon as possible.

In terms of portability and quick access, this was a nice first iteration. So, it is high in usability, but the actual quality of the measurements was not so great. The belt needed to hang quite high for the front sensors to point straight but when done that, the back sensor started pointing too much to the ground. Only when the area of the sensors was quite heavy, the sensors would stay in place.

The wires of the prototype sometimes got in front of the sensor, and that gives wrong results. And the long wire connected to the computer restricted the movement a bit. Altough it was still 3 meters long, the fear to step on it is there. To make a future prototype wireless is a good idea but it will also depend on the time and problems that come with it. A plug and play solution (like it is now) is still the best scenario.

Insights
Belt wearable

Sensors

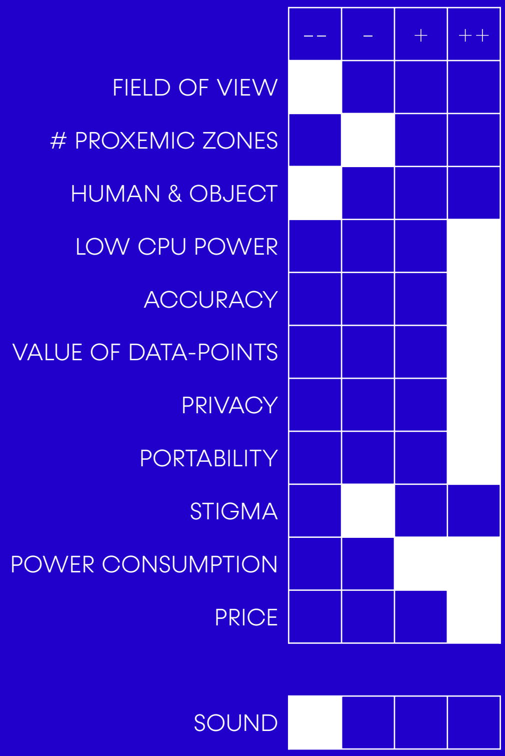
Sensors used here are only able to measure 1 meter. Also just on the front and the back.

MAX MSP integration

The program has 2 sides to it for this project. Getting the Arduino-data to work with the program and using those values to manipulate sound.

And the second one is to make an interesting soundscape. This one can be much more work than anticipated. It seems to be wise to get an external partner who knows already a lot about sound so I do not have to figure out that out on myself. That also gives me the opportunity to focus on other things.

Harris profile



	--	-	+	++
FIELD OF VIEW	■			
# PROXEMIC ZONES		■		
HUMAN & OBJECT	■			
LOW CPU POWER				■
ACCURACY				■
VALUE OF DATA-POINTS				■
PRIVACY				■
PORTABILITY				■
STIGMA		■		
POWER CONSUMPTION			■	■
PRICE				■

SOUND	■			

Things to do for next iterations:

- Wireless iteration at some point
- Other wearable that covers more of the body
- Make the sensors point at the right orientation
- Nice sound integration

Prototype 2 • Proxemic zones

Experimental set-up

The idea is to link peoples level of comfort to the distance they are to another person. We do not know yet if a correlation exist there, so to check that a quick prototype was made that measures the distance to one another and the 'level of comfort'.

I. Level of comfort

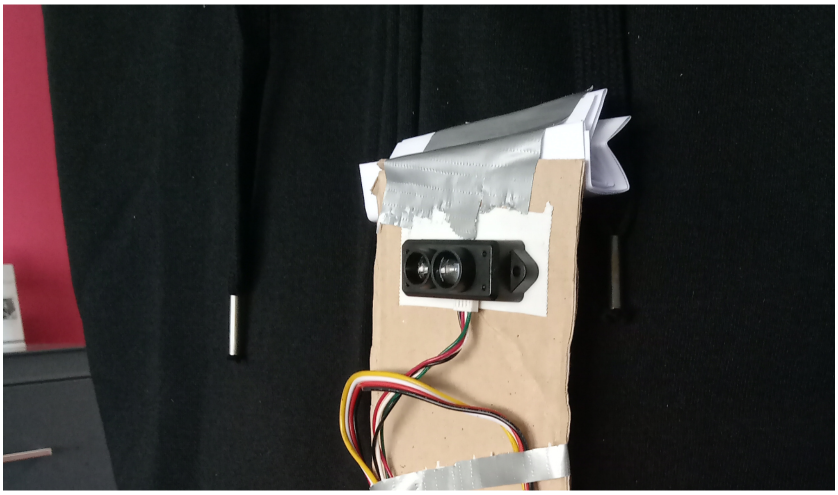
Measuring this can be done with a variety of sensors that measure the heartbeat and the amount of moist on the skin, but that is far to complicated for this set-up. It was decided to just use a potentiometer slider. This is given to the user and they indicate themselves how comfortable they are.

Indication slider the user gets to express their comfort level. Currently on the highest stand.

II. Distance measuring

The sensor used to measure the distance is a mini LiDAR for

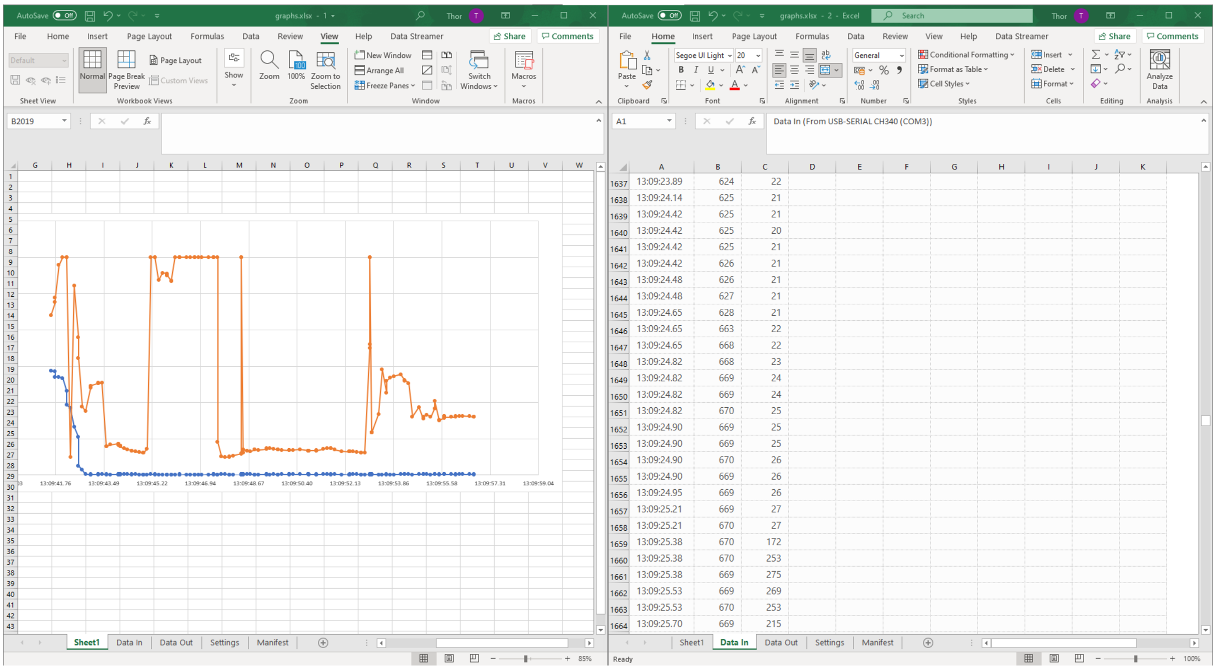
Mini LiDAR attached on a vest of the subject.



micro-controllers. It measures the furthers of them all and is very accurate.

III. Plotting

On the software side of things is an arduino sketch that reads the data from the LiDAR (in cm) and the potentiometer (from 0 - 1024). Those values can be plotted in Arduino itself, but does not offer enough flexibility. A solution of linking excel with the arduino sketch enabled more options for visualising the data in the form of a skatter chart.



Data In (From USB-SERIAL CH340 (COM3))

	A	B	C
1637	13:09:23.89	624	22
1638	13:09:24.14	625	21
1639	13:09:24.42	625	21
1640	13:09:24.42	625	20
1641	13:09:24.42	625	21
1642	13:09:24.42	626	21
1643	13:09:24.48	626	21
1644	13:09:24.48	627	21
1645	13:09:24.65	628	21
1646	13:09:24.65	663	22
1647	13:09:24.65	668	22
1648	13:09:24.82	668	23
1649	13:09:24.82	669	24
1650	13:09:24.82	669	24
1651	13:09:24.82	670	25
1652	13:09:24.90	669	25
1653	13:09:24.90	669	25
1654	13:09:24.90	670	26
1655	13:09:24.90	669	26
1656	13:09:24.95	669	26
1657	13:09:25.21	669	27
1658	13:09:25.21	670	27
1659	13:09:25.38	670	172
1660	13:09:25.38	670	253
1661	13:09:25.38	669	275
1662	13:09:25.53	669	269
1663	13:09:25.53	670	253
1664	13:09:25.70	669	215

IV. Pilot test

An initial test is done to see how the prototype behaves. Participant were me and a friend of mine. The relation between us is going to be very important when the results are analysed.

The focus was on:

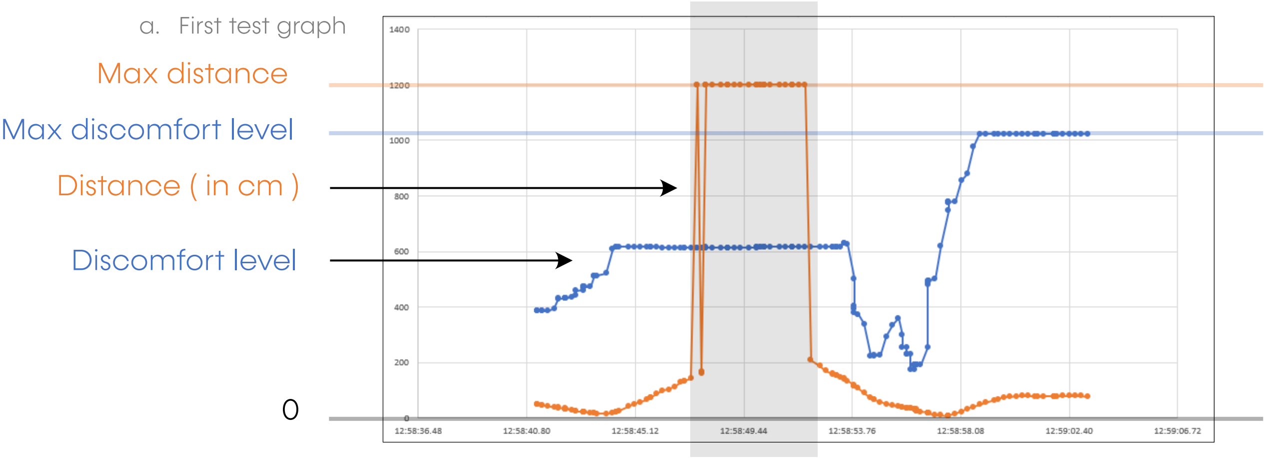
- Does the sensor always point at the other subject?
- What is the relation between the distance measurement and the comfort meter?
- Is the discomfort slider a good idea?

My friend, the test subject. The test was done in the studioLabs, a familiar place for the both of us. There was also nobody around.

Results 1

My friend had the prototype on and I was walking away and towards him. I started from about 1 meters away. The first run gave these results:

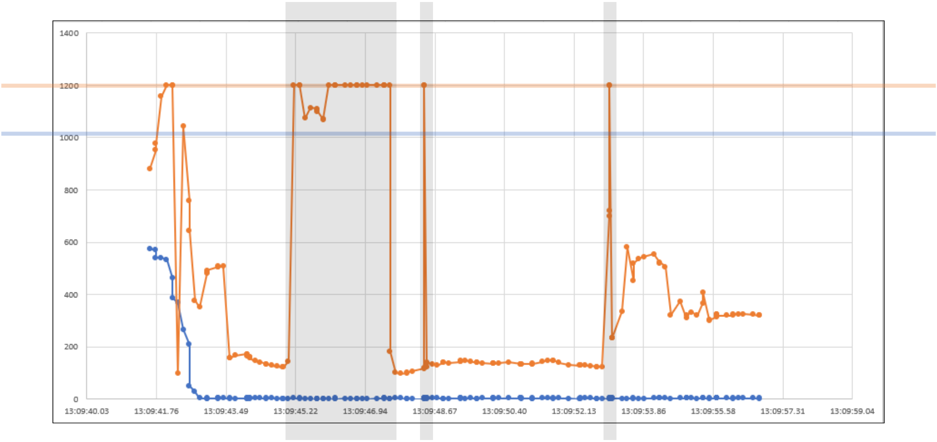
a. First test graph



- In the grey zone did the sensor point next to the person, resulting in the maximum distance. It is really hard to point the sensor exactly.
- Everytime I came close, the discomfort goes up by a lot and it stays there. It not going down when I back off explaines that discomfort is something that stays for a while.
- The discomfort meter was only used when I came closer than 1.5 meter or so.

Result 2

This time, I had the prototype on and controlled the discomfort slider.



- The grey zones are again moments that the sensor pointed wrong.
- In the beginning, my friend is coming close and the discomfort is quite high, but after that the comfort is always good. This has to do with the fact that he only was 1 meter as the closest and we know each other well enough to be comfortable

Evaluation

Pointing a single beam at a subject is going to give a lot of errors in the measurements. A wider coverage should be used to solve this problem.

At first glance, we do see a correlation between comfort and distance, but it is not a prominent one. Making a set-up like this can unravel this phenomenon more. It does give interesting results and should be verified with another couple of tests. This time it has to include 2 strangers, because it will definitely give different results.

Another test will be conducted with a newer prototype that also solves the issue of missing the target.

Insights

Prototype 2 • Proximic zones

LiDAR

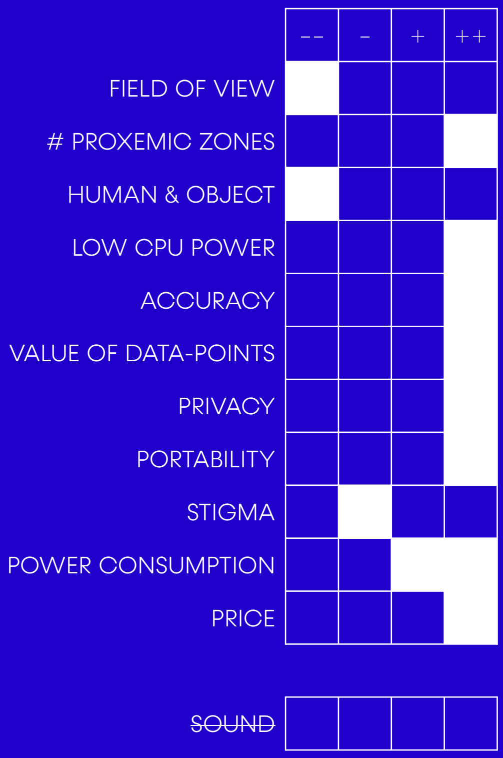
The mini LiDAR sensor is very powerful when it comes to measuring far and close distances. It does however only have a very small coverage to point at something.

Comfort slider

The comfort slider did gave us some insights on how the person wearing the prototype felt, it is still a very arbitrary method to really know how somebody feels. The levels from 0 to 1024 do not say anything useful other than: lower or higher than a few moments ago. A moment at discomfort level 1024 compared to a moment of level 800 (half a minute before that) does not mean it was more uncomfortable. Replacing this with a button concept where every click means another proximity zone or actually measuring discomfort via the vitals of a person could be better alternatives.

A correlation between discomfort and distance from other people is proven on some level in this test. To get more definite results, a follow-up test with a better prototype needs to be done.

Harris profile



	--	-	+	++
FIELD OF VIEW	■			
# PROXEMIC ZONES				■
HUMAN & OBJECT	■			
LOW CPU POWER				■
ACCURACY				■
VALUE OF DATA-POINTS				■
PRIVACY				■
PORTABILITY				■
STIGMA		■		
POWER CONSUMPTION			■	■
PRICE				■
~~SOUND~~				

Things to do for next iterations:

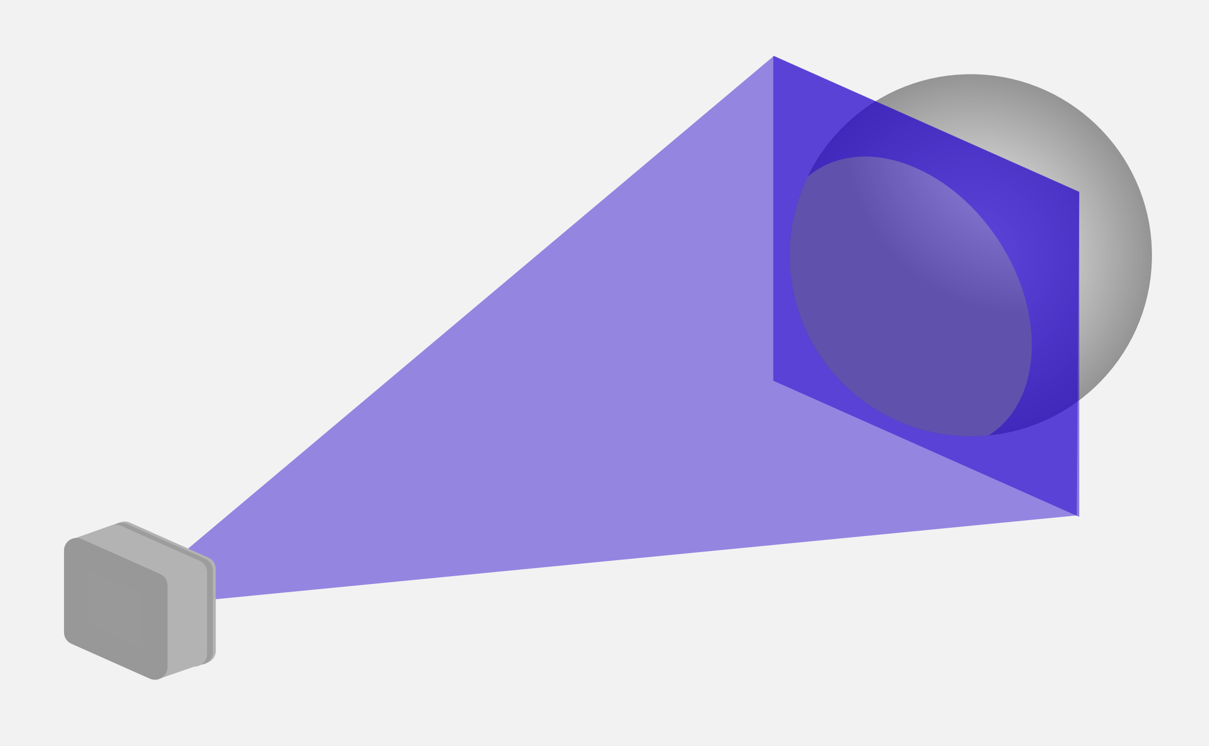
- Finding a better alternative for the comfort slider
- Looking into using more sensors or better sensors to solve the problem of missing the target.

Prototype 3 • Proxemic coverage

Until now, one of the biggest problems is the amount of area that can be 'scanned' around the person. The idea of stacking a lot of single range sensors the get a better view only brings you so far. A different solution is needed to get a better prototype. This chapter will go over different possible solutions.

Multi ranging solutions

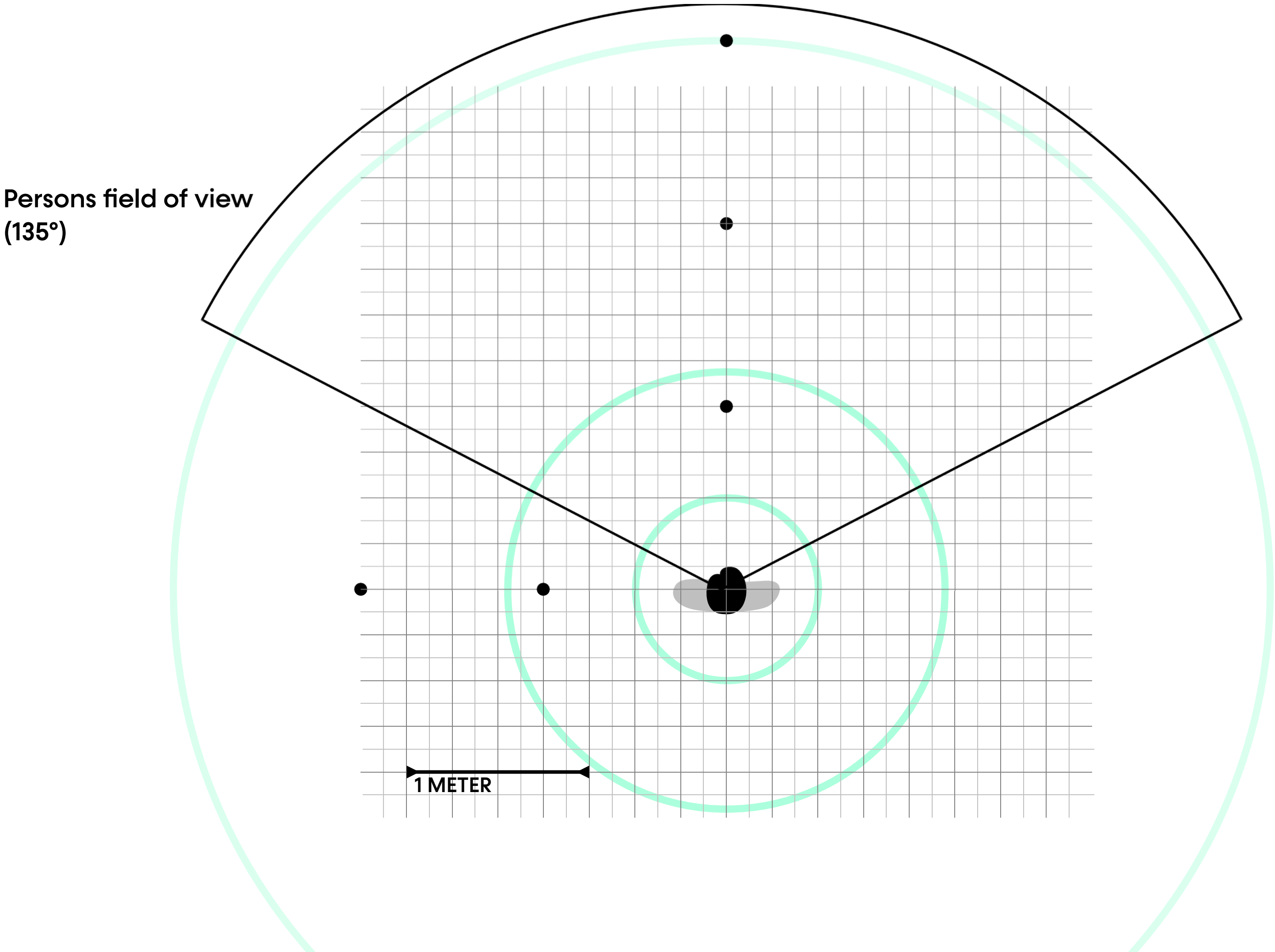
These 'sensors' are able to capture a certain field of view of distance compared to the single point in the previous chapter. These are really powerful solutions as they enable us to have a much better idea of the context and even do some light person v object recognition.



Human vision

To have an indication on how much coverage the prototype actually need, it is best to look at what humans can actually perceive with their vision.

A person's field of view is around 135° in front of him/her. Having a technical solution that would cover this whole range would be an ideal situation. But with the limited prototyping capabilities, something that comes close will also suffice for now.

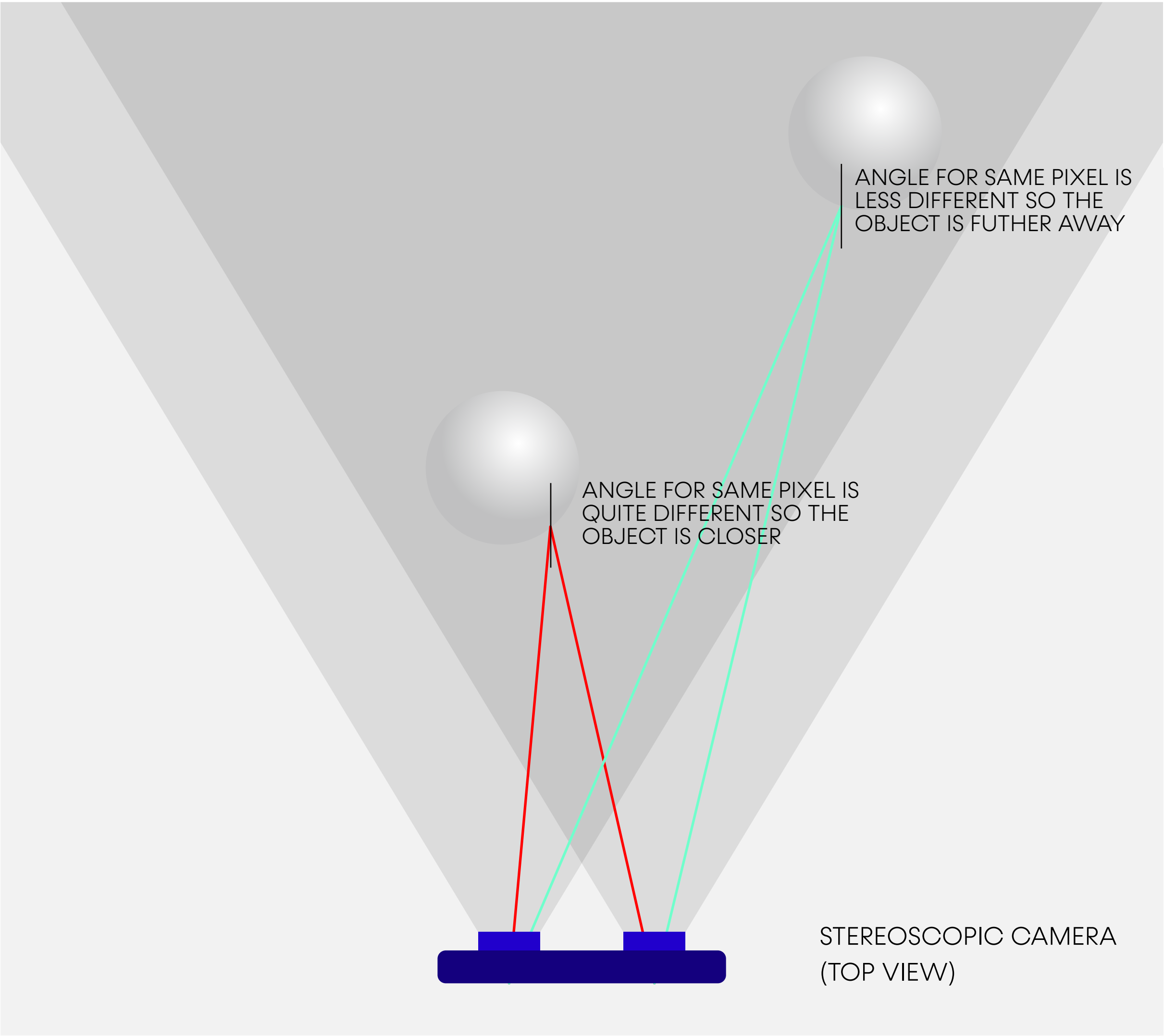


Stereoscopic camera

A stereoscopic camera is an easy way to capture 3D images. It exists in all shapes and forms and is used in a variety of applications like AR, 3D movies and stereo images.

I. Working principle

The idea of a stereoscopic camera comes from the same principles of why we humans see in 3D. By having two cameras spaced in the same orientation but a certain distances apart, it creates two overlapping images. The images are slightly different and by calculating the displacement of the pixels in the images the distance from the camera can be calculated. The further away, the similar the pixels are.



II. Prototype

Camera model

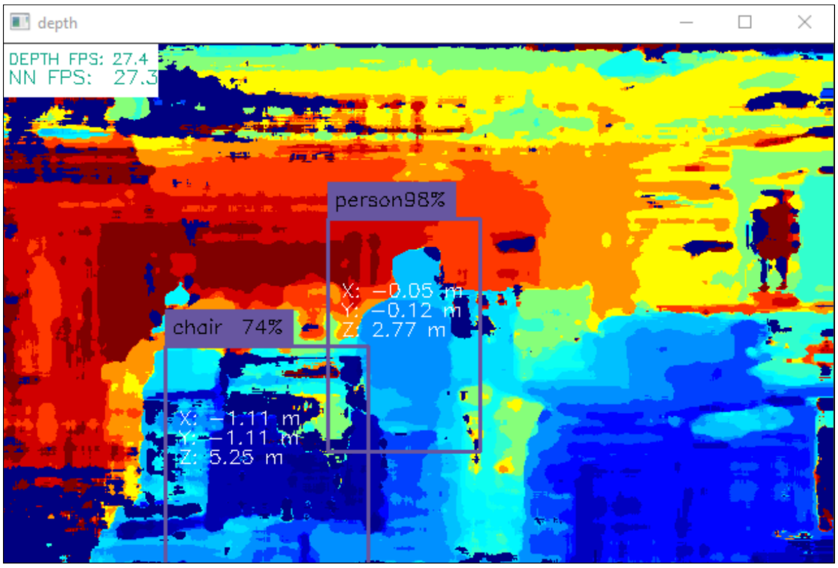
The tool used for this test is a DepthAI OAK-D camera. It has a central colour camera and two monochrome cameras on the side for the depth vision. It can be used for depth sensing and also image recognition. It has a Python API that calculates all this stuff for us. It can be used connected to PC or a RaspberryPi.

OAK-D camera connected to a windows laptop.

In this case, a PC was used with Windows Powershell to operate the camera. The demo code already provided some very powerful features and showed the potential of the camera for my prototype.

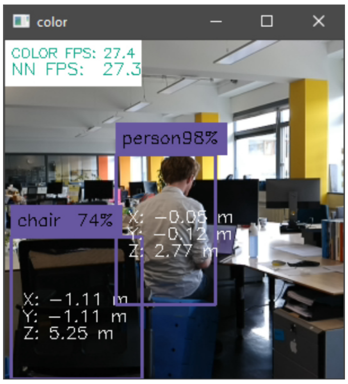
Demo results

The demo code provides a depth view in the shape of a coloured image and some light subject recognition like humans, chairs and cups.



Coloured depth map output of the OAK-D camera

Lightblue indicates the surfaces that are the most close and red are surfaces that are the furthest away.



```
COLOR FPS: 27.4
NN FPS:  27.3
person98%
chair  74%
X: -0.05 m
Y: -0.12 m
Z: 2.77 m
X: -1.11 m
Y: -1.11 m
Z: 5.25 m
```

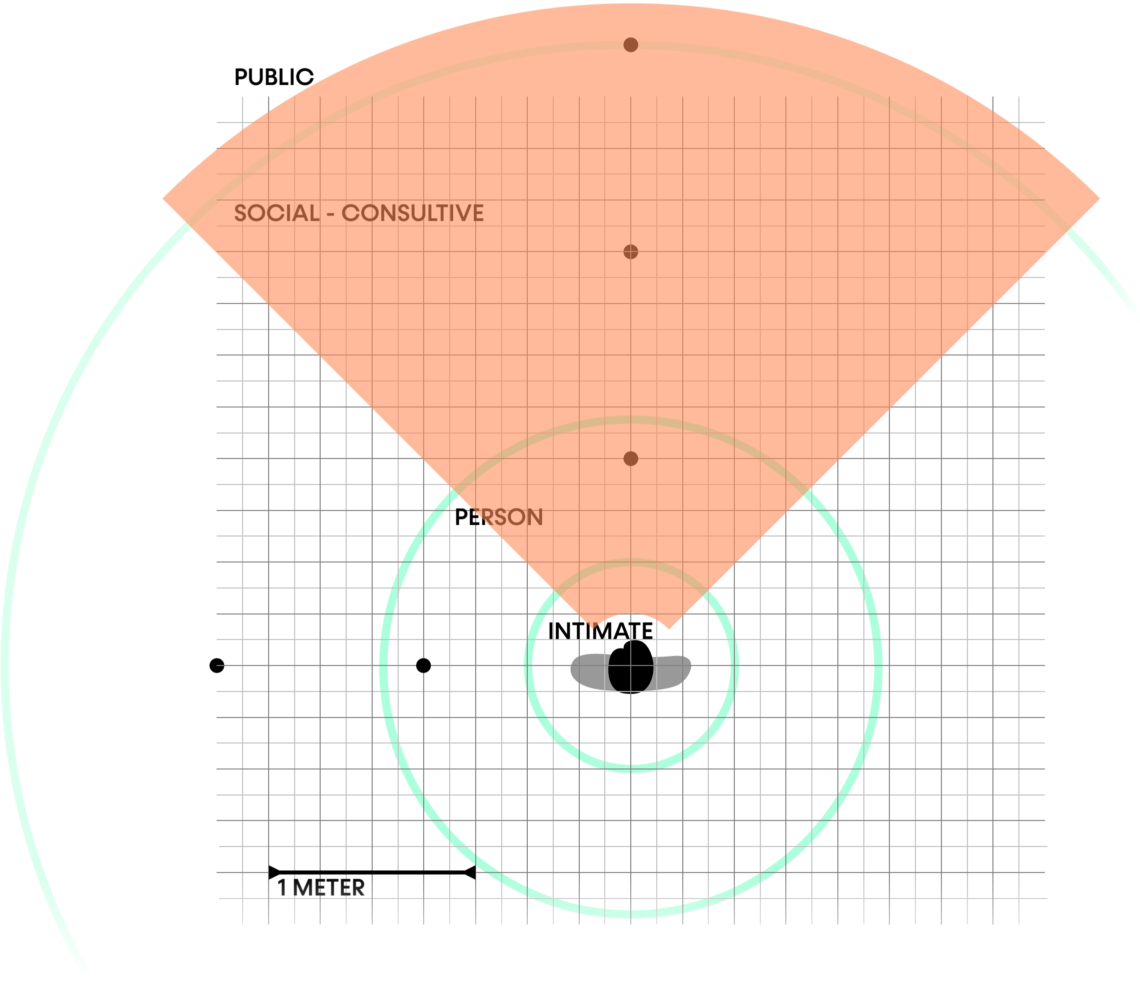
The depth map shows more than enough detail for our application. The accuracy is not perfect, but still good enough. The person in the picture for example is indicated at 2,77 meter from the camera, but when I measured the actual distance, it was more like 2,40 meter. In this example, that is an accuracy of around 85%. If we think about the proxemic zones (intimate 0-0,5 m, personal 0,5 - 1,2 m) this kind of accuracy is still more than enough the differentiate these zones.

The coloured camera shows all the objects that are recognised. My colleague got recognised as 98% person, and his chair as 74% chair. This is all very accurate. The chair is indicated as 5,25 meters away, while in reality it is 2 meters from the camera. This is because the fine grid of the chair is hard to measure. Not all surfaces are good enough for the stereoscopic camera.

III. Coverage

The camera measures as much as **81 degrees field of view** from the person. This is around the same field of view of what a person looks at when he or she is looking straight in front of them. The camera can accurately measure distances as far as 10 meter, but it has a blind spot in the first 25 cm. If this blind spot needs to be covered by other sensors is to be tested.

A visualisation of the coverage can be found on the next page.



IV. Verdict

A stereoscopic camera turns out to be a very approachable solution to depth measurement. It requires just 2 identical cameras with around 8 cm distance and widely available software.

The big advantage is the wide range of coverage, 90 degrees field of view in this case, that can be measured and the accuracy of it is about 90%. The field of view does have a limitation: the wider, the more distorted, the less depth perception the camera can capture. Commercial solutions of 120 degrees of view do exist though.

The method uses CMOS sensors and is that way also able to do person recognition. This is an essential feature for the prototype.

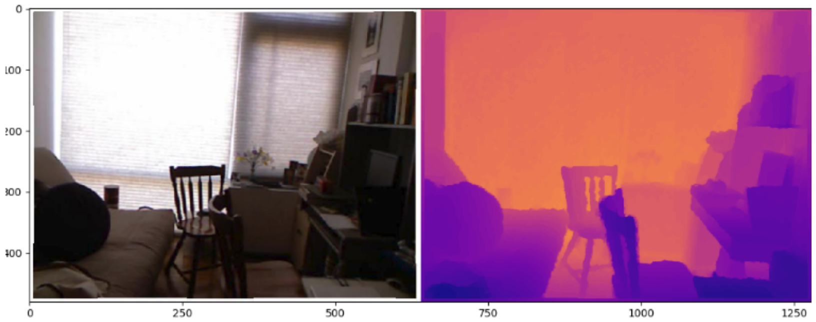
	--	-	+	++
FIELD OF VIEW				■
# PROXEMIC ZONES				■
HUMAN & OBJECT				■
LOW CPU POWER		■		
ACCURACY			■	
VALUE OF DATA-POINTS			■	
PRIVACY	■			
PORTABILITY		■		
STIGMA				
POWER CONSUMPTION		■		
PRICE		■		
~~SOUND~~				

Depth estimation

As 'paperwithcode' describes it: Depth Estimation is a crucial step towards inferring scene geometry from 2D images. The goal in monocular Depth Estimation is to predict the depth value of each pixel, given only a single RGB image as input.

I. Working principle

By using the power of machine learning and a lot of reference images, a depth estimation can done from just a single image.



A depth-map generated via a depth estimation algorithm.

The database consist of pictures with just RGB data and pictures of a depth-map (captured with a stereoscopic camera) of the exact same scene. The algorithm looks for queues to estimate the depth captured in the scenes. A problem with this method is that most of the time it is only able to measure relative depth. That means it can recognise what is closer compared to other things in the scene, but not the actual distance (absolute depth) to the camera. New training models are trying to solve this limitation.

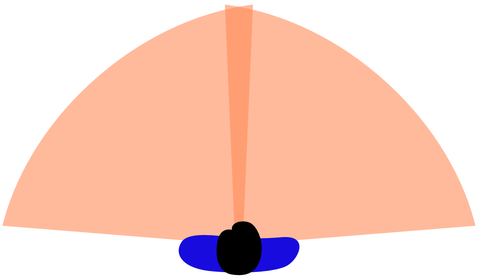
II. Prototype

Nowadays, depth estimation can be done quite accurately. The training of these models is mostly done in an open-source environment. The models were available to me, but making a prototype with it was too advanced for my abilities. But the lack of absolute depth measurement keeps this technique from actually be useful for this concept.

III. coverage

The coverage of the depth measurement can be as wide as the lens of the camera allows. When using a too wide angle lens (more than 120 degrees) , the image does get distorted a lot and may be hard to recognise.

The big advantage about depth estimation is that it can be done with just a small camera sensor and a bit of processing power. Because of this advantage, placing multiple cameras on a garment is a valid solution.



IV. Verdict

The technology is not quite there yet, but has a lot of potential for improvement over the coming years. The lack of absolute depth measurement is a deal-breaker at the moment and that is why it can not be used for this prototype.

	--	-	+	++
FIELD OF VIEW				■
# PROXEMIC ZONES			■	
HUMAN & OBJECT				■
LOW CPU POWER		■		
ACCURACY	■			
VALUE OF DATA-POINTS	■			
PRIVACY	■			
PORTABILITY				■
STIGMA				
POWER CONSUMPTION		■		
PRICE			■	

~~SOUND~~				

Advanced LiDAR sensors

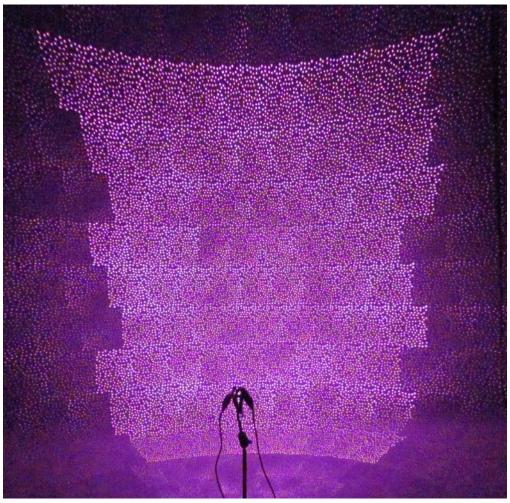
This chapter talks about the LiDAR sensors that are able to measure multiple points in space compared to just one.

LiDAR is not new technology, but it is mostly used in the very innovative and wealthy car industry. It is only recently that we see usable compact solutions appear on the smartphone market and in open-source products to experiment with.

A LiDAR sensor on the back of an iphone. It is used for camera focusing and AR applications.

I. Working principle

It uses the same TOF principle as described in chapter: prototype 0. Instead of sending only one light beam, an array of light-beams get send and measured individually on how fast they come back. The first picture is the LiDAR of an Ipad Pro. It displays around 400 dots per measurement. The second picture is from the Google Tango project. It contains a lot more points and also covers a much wider area than the apple device.

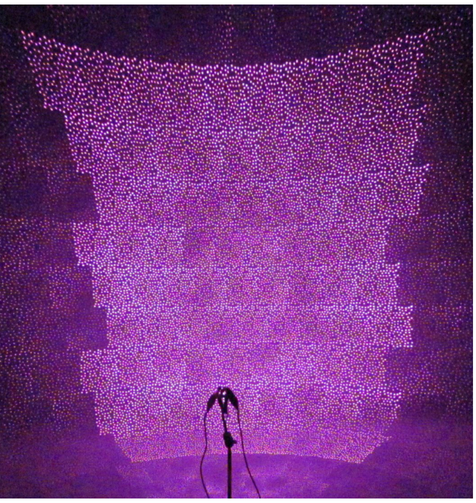


Measuring the dots alone is not enough though to get a nice output. A complicated algorithm written by the companies makes sure that a lot of cleanup happens before it displays the actual 3D image. This keeps it from being accessible to little developers and also this project.

II. Prototype

The fact that the sensors are not for sale makes it very hard to do a proof of concept prototype with this technology. The only option is to use an Apple device that has a LiDAR sensor and a pre-made app from the App store to see how it preforms. I did not have access to such an apple device, so there is no prototype with this technology.

III. Coverage



Google Tango phone LiDAR projection.

Depending on the optics in front of the sensor, a big field of view can be measured. The Tango phone is an example of a very wide view. When using more than 1 optics element the coverage is as much as you want it to be.

IV. Verdict

While easily the best technology in this list, it is not developed enough and thus not accessible enough for us to use in this concept.

	--	-	+	++
FIELD OF VIEW				■
# PROXEMIC ZONES				■
HUMAN & OBJECT				■
LOW CPU POWER		■		
ACCURACY				■
VALUE OF DATA-POINTS				■
PRIVACY				■
PORTABILITY				■
STIGMA				
POWER CONSUMPTION			■	
PRICE	■			

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Insights
Proxemic coverage

Which sensor

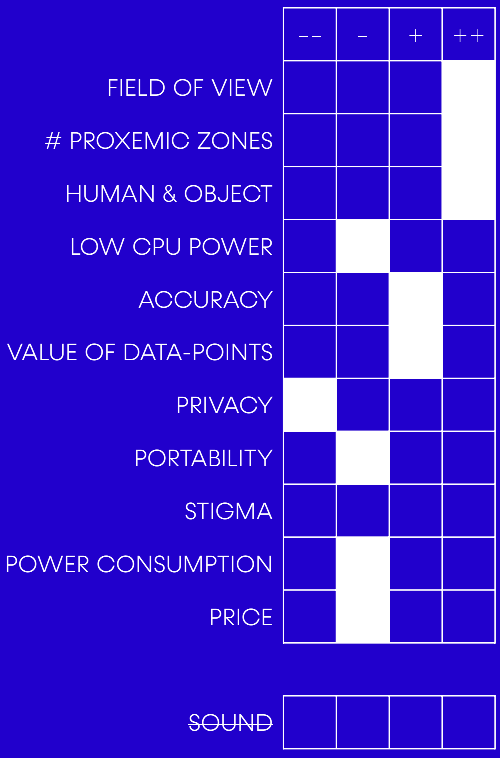
Really only one sensor is a suitable solution for this prototype: the stereoscopic camera.

It provides enough capabilities for the concept and is easy enough to work with.

Future variations

When the LiDAR sensors become more affordable and accessible to work with, they are easily the best option for the concept.

Harris profile



	--	-	+	++
FIELD OF VIEW				■
# PROXEMIC ZONES				■
HUMAN & OBJECT				■
LOW CPU POWER		■		
ACCURACY			■	
VALUE OF DATA-POINTS			■	
PRIVACY	■			
PORTABILITY		■		
STIGMA				
POWER CONSUMPTION		■		
PRICE		■		
~~SOUND~~				

Things to do for next iterations:

- Use stereoscopic camera

Prototype 4 • Proximity vest

From the 3 previous prototypes various things were learned that are going to be useful to make this 4th prototype.

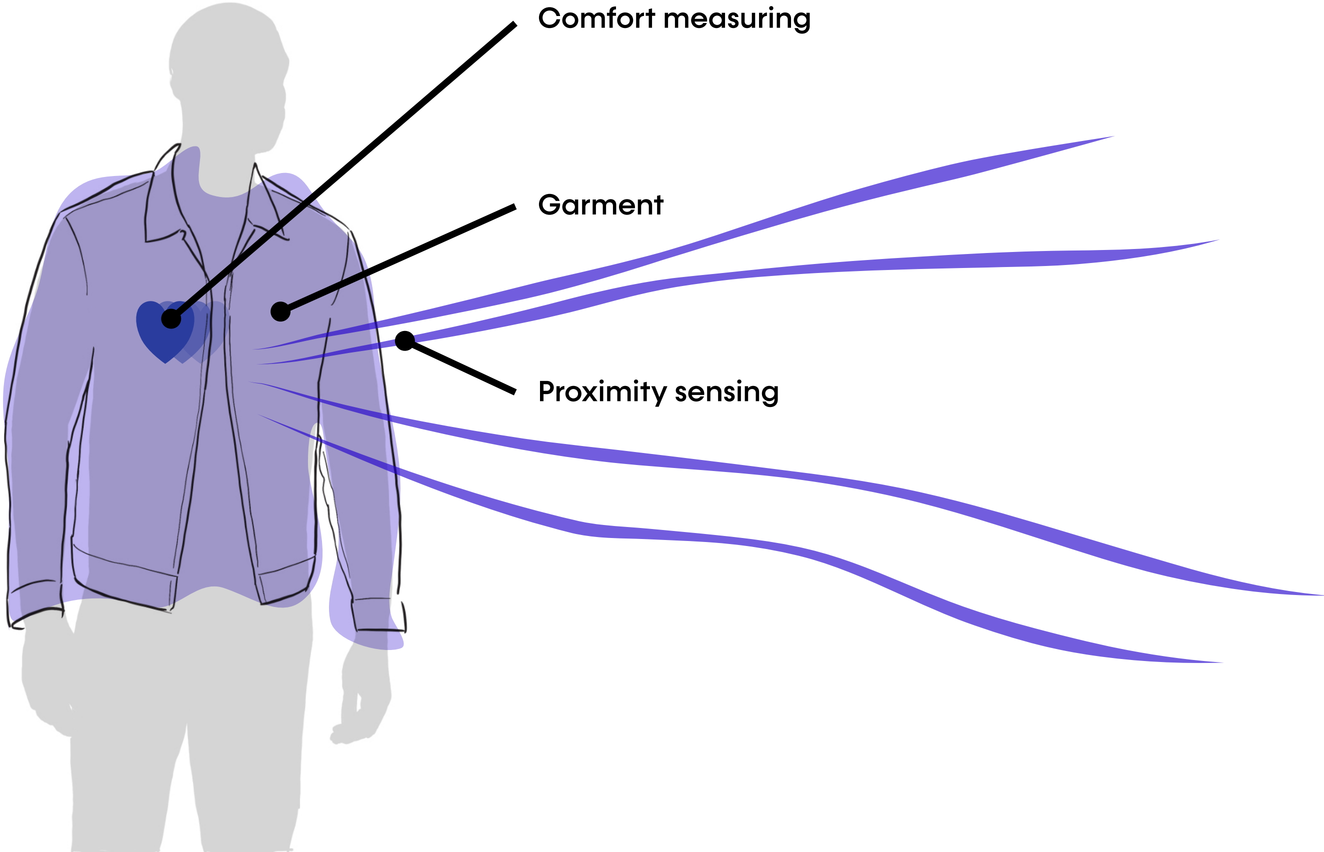
Previous iteration had a focus on one specific subject or research question. It is time to combine all these insights and result in a prototype that can be used for a valid first pilot test.

We learned from previous prototypes:

- A stereoscopic camera is nice for human recognition and covering multiple proximity zones.
- Comfort slider is too rough for usable measurements
- Belt as garment is not sturdy enough
- Single range sensors could be nice for additional measurements, but are not versatile enough to use on itself

Proposed architecture of prototype 5

This prototype got development in the following three areas.



I. Proximity sensing

Using the DepthAI stereoscopic camera from prototype 4 saves a lot of time during the programming phase. It already contains a lot of written code that detects people and measures the distance they are away from the camera.

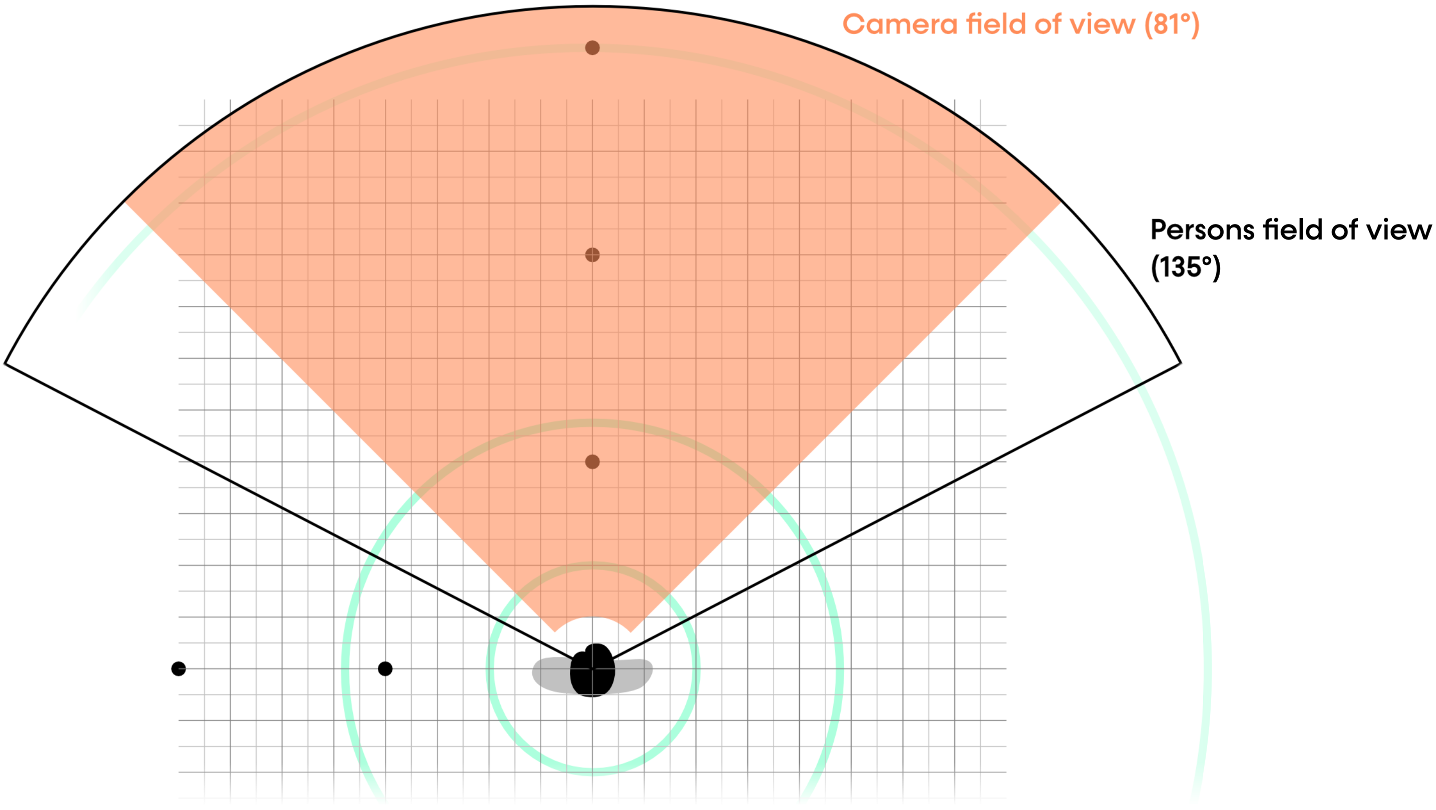
Synchronized Global Shutter

Image Sensor:	OV9282
Max Framerate:	120fps
Pixel Size:	3um x 3um
Resolution:	1280 x 800 pixels
Field of View:	81 DFOV° - 71.8 HFOV°
Lens Size:	1/2.3 inch
Focus (Fixed):	19.6 cm - ∞
F-number:	2.2

Luxonis OAK-D stereo camera. The model I use for this prototype.

Placement

Using a single unit of this camera will be enough for our proof of concept. A central mounting position that looks right in front of the person is ideal as it covers a big part of the field of view a person has.



II. Garment

The prototype does have, in the end, only one sensor: the OAK-D camera. It needs a reliable way to be mounted to the body of a person. That means as centred as possible and parallel with the ground.

Clothing is very wrinkly, so there needs to be searched for a way to overcome this. Ideally, the garment is usable for different sizes of people. It should be easy to put on and off and needs to be safe of course. Additional to the camera, there needs to be a battery and a processing unit stored somewhere in there.

Good fit

I bought online an oversized fisherman-jacket. It contains a lot of pockets and this comes in handy to hide electronics. It also does not have sleeves and a zipper in the front for easy comfort.

Because it is oversized, a belt with a click system is sewed to the back so it can be tightened for everybody their fit. In the right picture, a friend of mine is wearing the vest and she is only 155 cm tall.

Sensor embedding

I printed a case for the OAK-D camera to fit in. This way, it did not have to be disassembled out of its case and can be easily removed when needed.

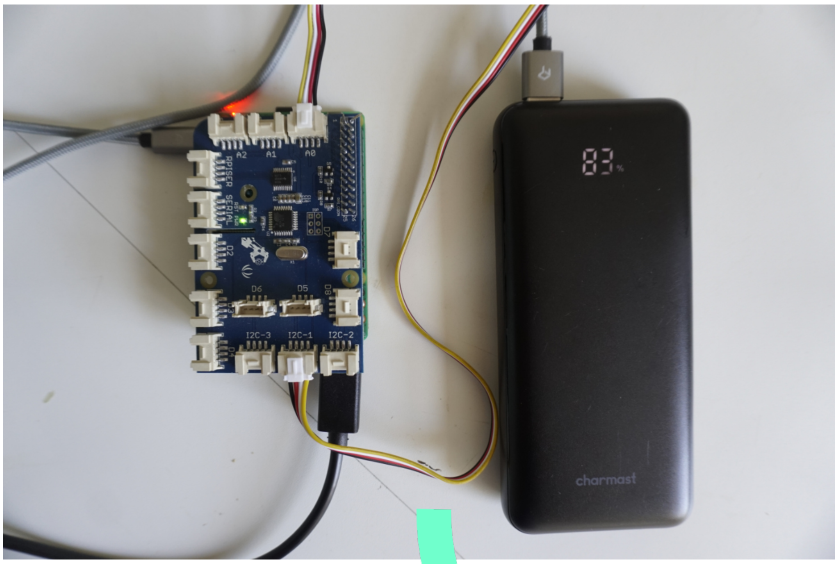
Casing for the Luxonis OAK-D stereo camera. Easy plug and play.

To keep the vest from wrinkling too much and the camera from pointing to the wrong direction, I attached cardboard cutouts in the lining of the vest. When somebody puts it on, the front will stay straight.

This picture indicates where the cardboard cutouts are located to keep the sensor from pointing in the wrong direction..

To power the camera, a battery (24000 mAh powerback) and a RaspberryPi (model 3B+) are needed. These can be hided in one of the many pockets that the vest contains.

The battery has a small display to show how much battery is still left. This is a handy feature when the prototype needs to be passed to a lot of people.



A raspberry pi connected to a powerbank. The raspberry pi has a grove shield attached to it so grove sensors can be easily tested.

III. Comfort measuring

In a previous prototype, comfort was indicated by the user with just a slider. Here, a more advanced solution is used to measure an indication of the comfort of the user via body vitals.

Specifically used here is:

- Grove Heart rate sensor. This will measure the heart rate of the person, sudden peaks in the measurements can indicate discomfort.
- Grove GSR sensor. This will measure the galvanic skin response, the conductance of the skin. Sweat is correlated with your nervous system and can indicate discomfort.

Both sensors together can give an indication if the comfort of the user changed. It is however again not perfect and that should be kept in mind when analysing the data.

A heart rate sensor and a GSR sensor packaged together.

IV. Total prototype

Connecting this all together gives us the prototype to be seen on the right page here.

Code

A code is written to make all these parts work together and output data. The RaspberryPi is running RaspberryPi OS and the code is written in Python. The camera is using the DepthAI API to run. The grove sensors have their own Python libraries that can be used.

Pilot test

The next step is to set-up a pilot test and see if we could get any useful correlation between the comfort and the distance towards other people.

The whole prototype with all its components.

Pilot test

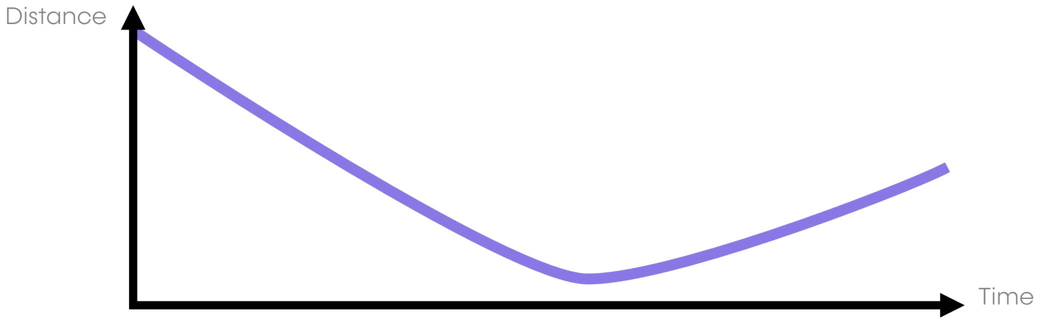
In this set-up, the assumption is made that by measuring the heart rate and the galvanic skin response we can detect if the person is in discomfort. Measuring active body signs is not done before in this project and it is important to see if this could be a direction to move into.

The sensors attached to the hand that measure the GSR and heart-rate of the person.

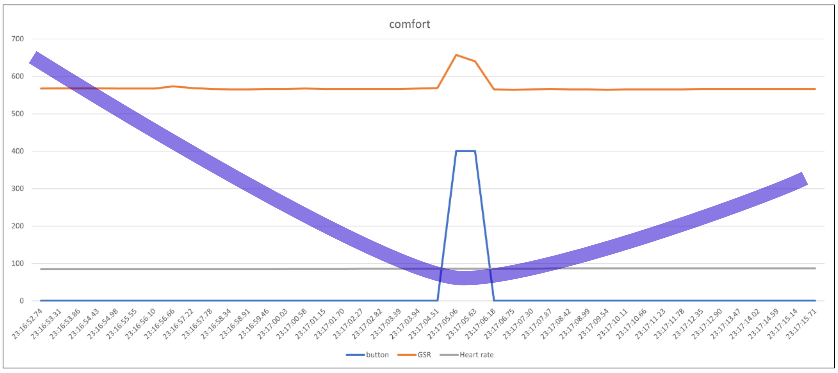
Test set-up

This test has a quick set-up because it is mainly about verifying the sensor-measurements of the heart-rate and GSR sensor.

I asked a friend to approach me, and someone else I didn't knew. So this test has 2 data-points. My heart-rate and GSR are monitored while the other person is approaching me. The person will come as close as 0.5m and then go back for a few meters. I would also indicate with the press of a button when the person came to close in my opinion.



The heart rate sensor does absolutely nothing for the test and the GSR sensor gives mild response, but while testing this turned out to be more correlated with me pressing the button than getting uncomfortable.



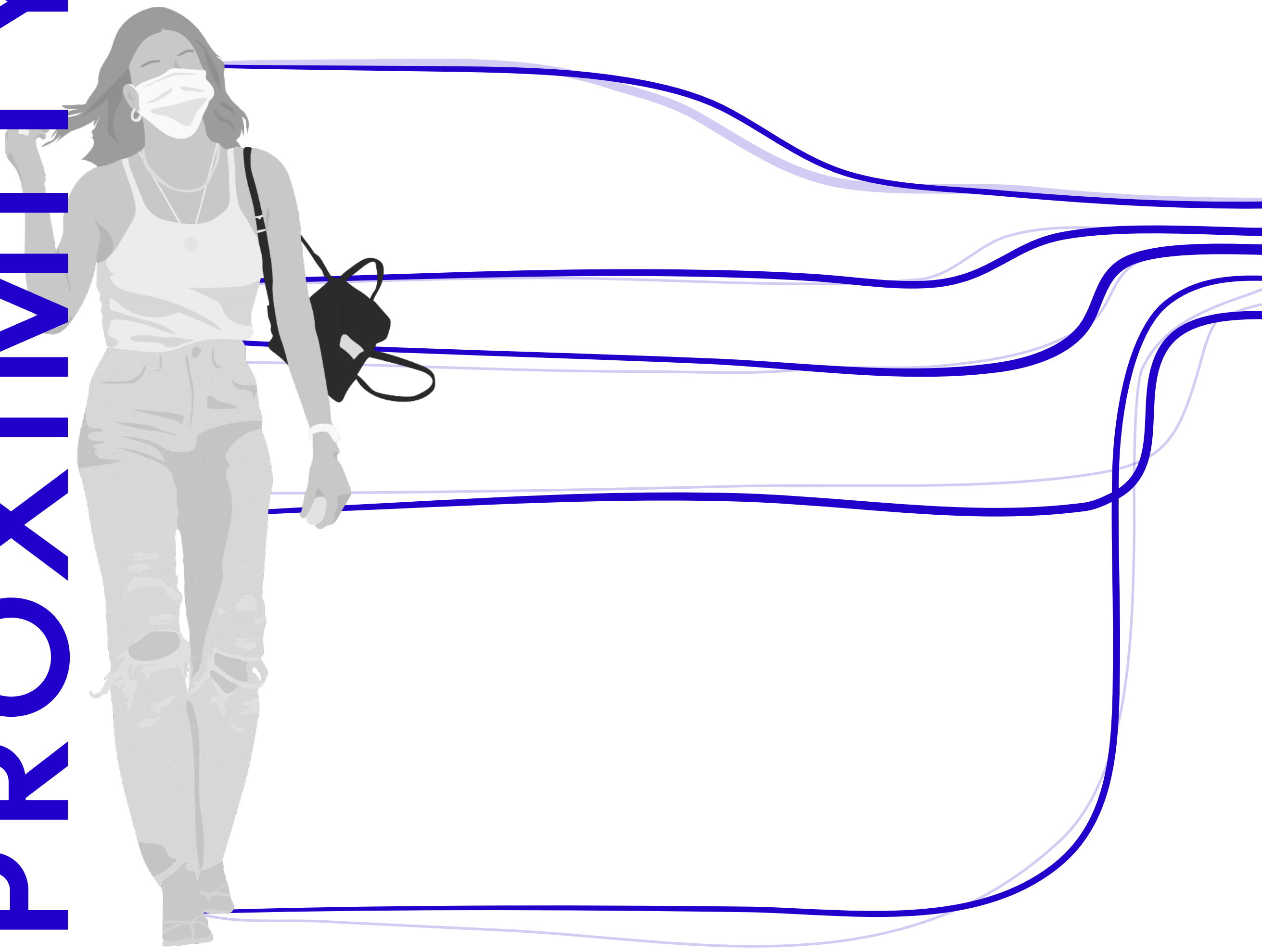
The results of the sensors is not very promising for a future solution. Maybe a correlation between body-vitals and the mild discomfort a person might get when somebody is too close was too good to be true. It could be that the sensors I was using were not good enough. In that case better equipment would be worth checking out, but it is just not worth following up on.

Discussion previous tests

The two previous tests done both rely on active placement of the participant to see how he or she feels in a particular situation. Maybe this is not the right way to tackle this experiment.

The next test will use a passive way of collecting data. In real life, people automatically preserve their personal space. When they feel uncomfortable, they will automatically move away until the discomfort disappears. Via measuring how much distance they naturally preserve, you have a pretty good indication of how big their personal space actually is.

PROXIMITY VEST



Showcase

The ProximityVest is a tool to measure your personal space. It uses a stereoscopic camera to recognise people and measures the distance towards them.

It contains a battery-pack and local processing unit that is connected to the cloud, so all your data is accessible there.

Because of it’s wireless functionality, it is easily deployable at any location. You are not restricted to a certain test-space.


Stereoscopic camera
Battery
Processing unit +
wireless connectivity

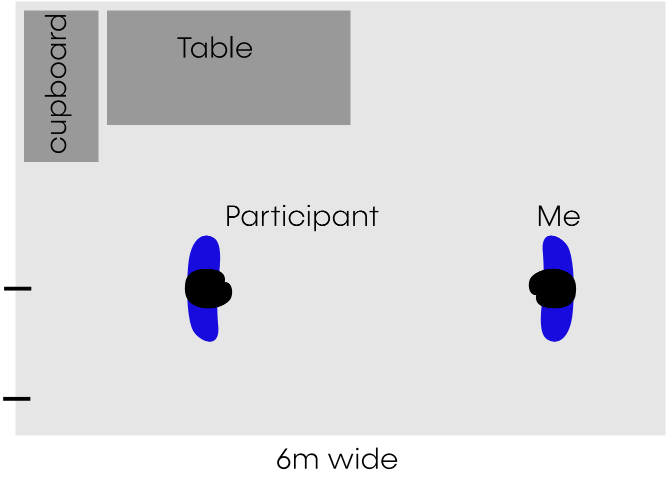
Verification test

A last verification test will find place with the ProximityVest. The last proof of concept showed us that people naturally preserve their personal space if you let them. They will stop at the distance they feel comfortable or will step back when they feel you are too close. To see if this prototype can capture this behaviour a scripted scenario will be played with different participants.

Test set-up

The concept is meant to be worn in different scenarios and with the people around you unaware of an experiment, but this prototype is not ready enough to do this. The verification test results are also harder to analysed in a random scenario. That's why is chosen for a fixed location with no other distractions.

Room (approx. 4m x 6m) chosen to conduct the test.



Top view of the room

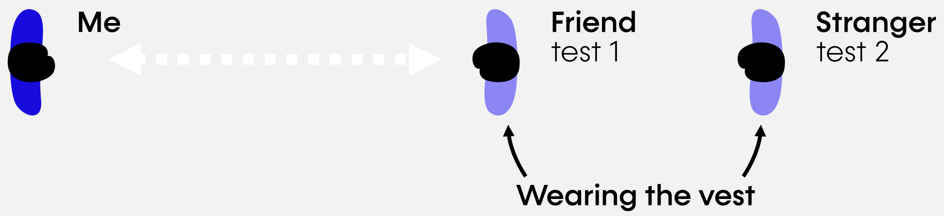
Factors of influence

There are a few variables that we know will influence the personal space of a person.

- The relation between the two people that interact. If they are friends or family, they will certainly come closer than two people who never met each other for example.
- The other one is the intent of the interaction. Is the person just walking by? Does he offer something? Or does he just want to make a chat?
- Who is approaching who? Will the other person come too close or stop in time to not invade your personal zone.

I picked some scenarios and ran the experiment with two different people. One person was a close friend of mine, the other one was a friend of a friend and I had never met before. That way, the test would go about a scenario with two strangers and two friends.

***I do realise that with the current corona situation people might behave differently than normal, but there is no way around this, unfortunately.**



Scenarios

Me, just asking something

Me, with mouth-mask

Me, Handing some food

Me, with scary mask

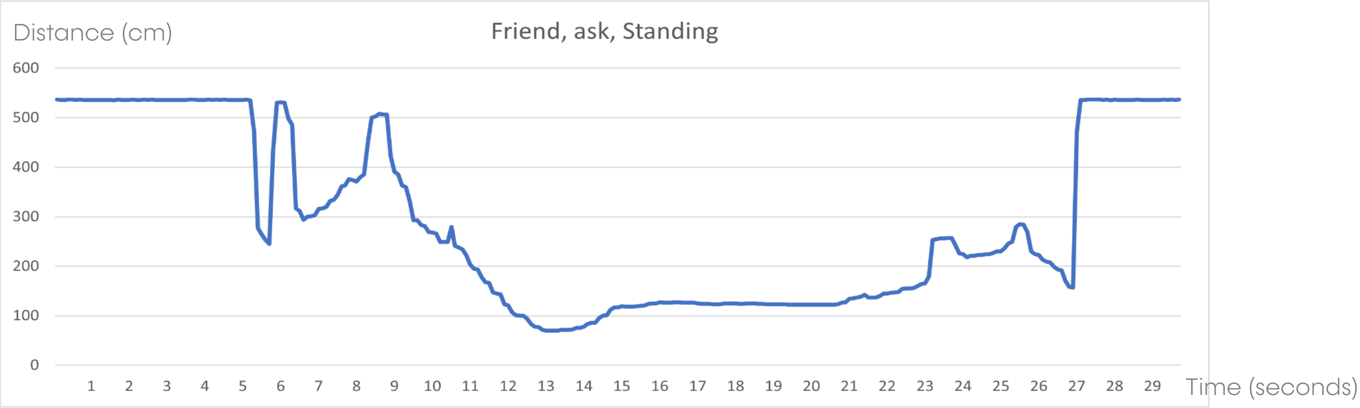
All interactions were done twice, one with me approaching, and one with the participant approaching

Test results

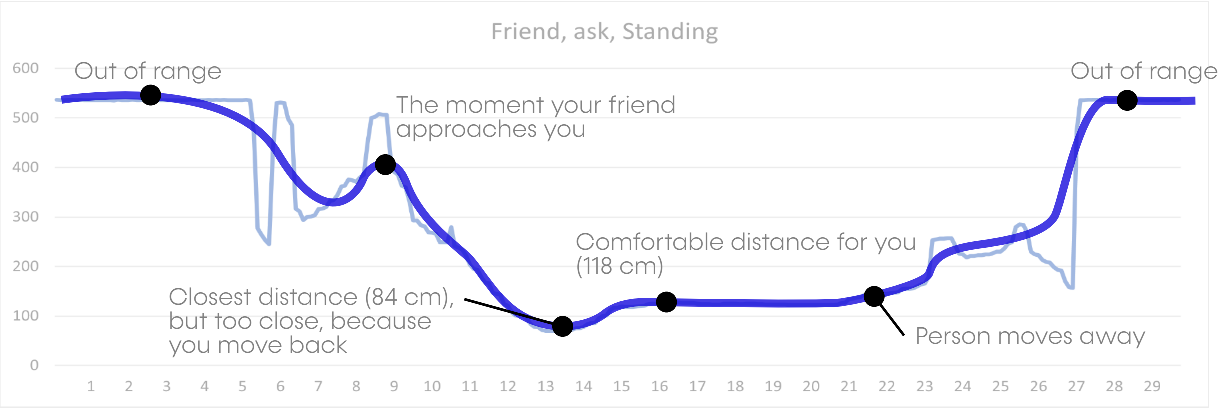
A total of 16 measurements were taking in the different scenarios described in the previous chapter. The vest measures the distance to the other person many times per second, and this way a graph can be plotted with the distance the people have from each other in correlation with time.

I. Detailed motion analysis

The first example is shown underneath. It is the interaction between two friends, the other one is coming towards you to ask something and you are standing still.



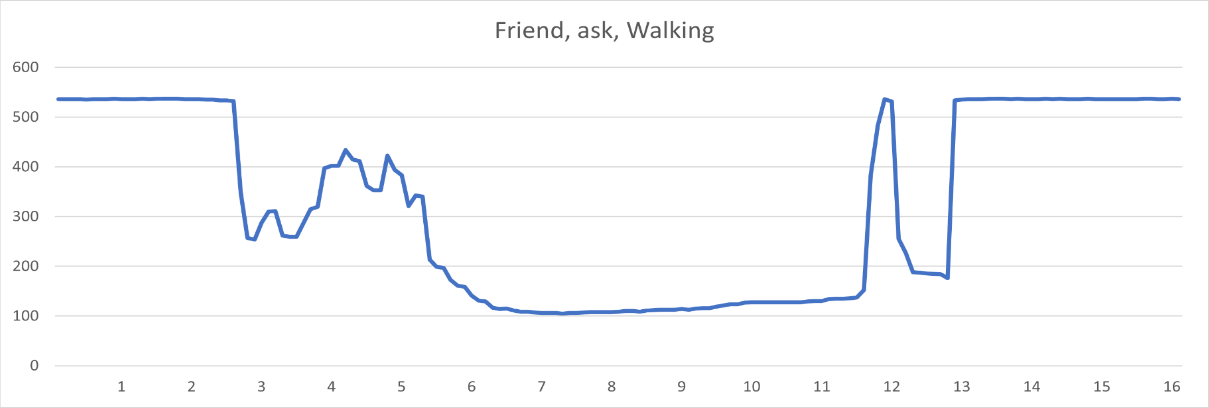
The graph contains a lot of useful information. If it gets analysed, it can be seen that:



Most valuable data is the distance you move until you are comfortable to have a conversation. This is easy to recognise, because it was asked to hold that position for at least a few seconds. Let's do this for a couple more data-charts.

Friend, ProximityVest walking

The RAW measurement from two friends, one asks a question and the one with the proximityVest is walking towards the other one.



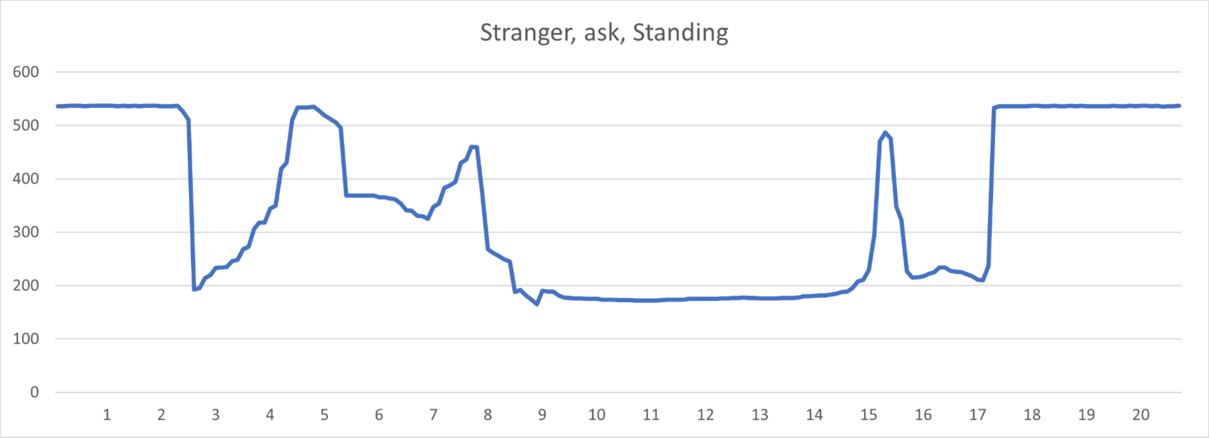
Analysed, we get:

Comparing the two data charts where the only difference is: is the person with the vest approaching someone, or is he/she being approached? The difference looks to be that an approached person will move back if the other person comes to close. When he himself approaches someone, he immediately chooses the right distance.

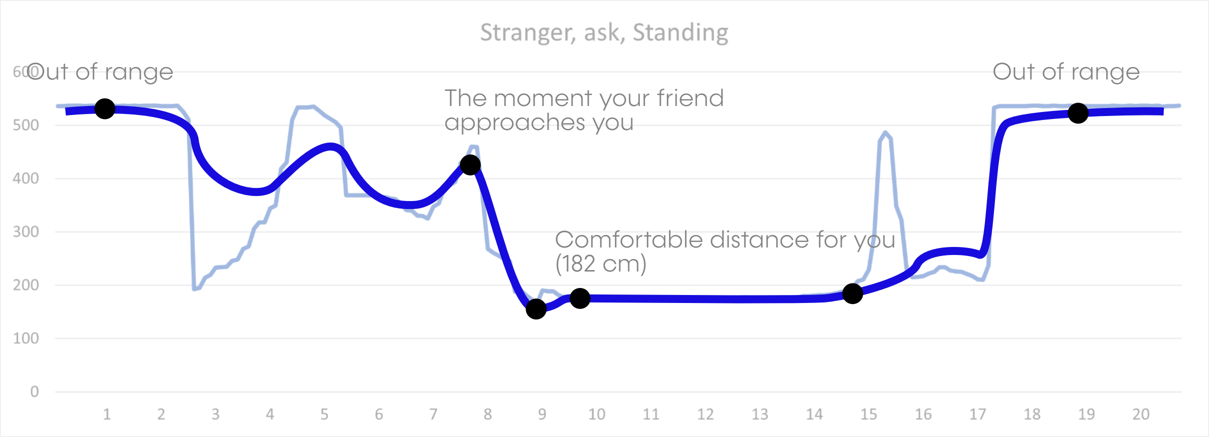
Before and after the interaction, the measurements go all up and sometimes go to maximum. This is probably because the prototype loses the target for a bit. These technical errors can easily be spotted by eye.

Stranger, ProximityVest standing still

This is a chart with two stranger interacting. Immediately a different result is created.



Analysed, we get:

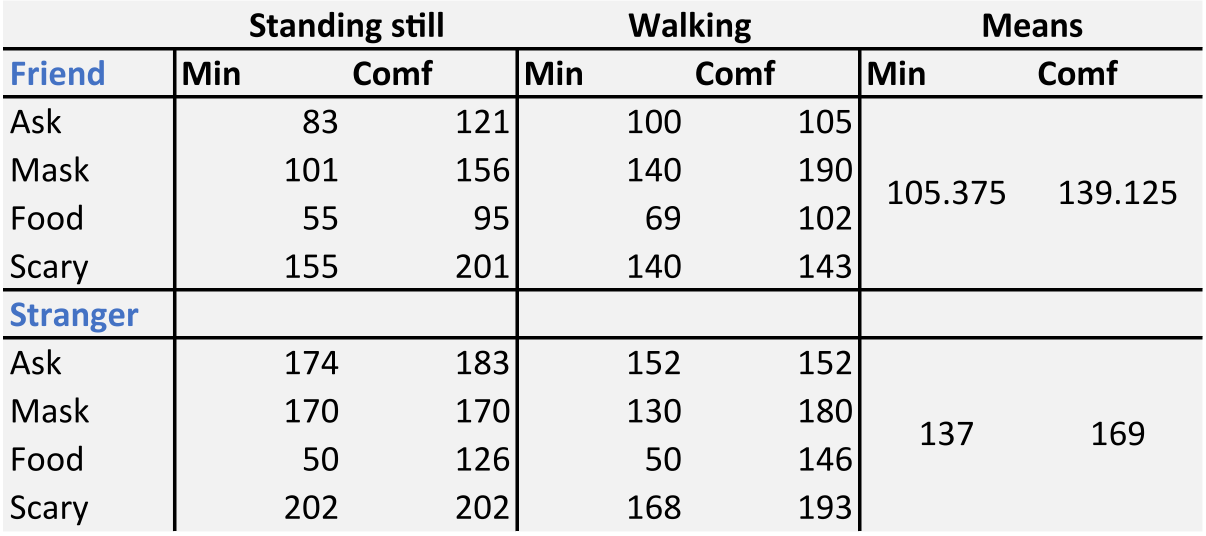


In comparison with the friends interacting, the distances are much higher here. This makes a lot of sense because you are less comfortable around strangers. We also see that the minimum distances is closer to the comfort distances. The participants probably don't want to invade someones personal space.

II. Overall comparison

The test contains 16 graphs of data, but not all are shown here in the result chapter. For all the graphs, look in the appendix.

The next table contains all the minimum distances and distances that people felt comfortable. This is an easy way to see the differences and correlation of the data.



	Standing still		Walking		Means	
Friend	**Min**	**Comf**	**Min**	**Comf**	**Min**	**Comf**
Ask	83	121	100	105	105.375	139.125
Mask	101	156	140	190		
Food	55	95	69	102		
Scary	155	201	140	143		
Stranger						
Ask	174	183	152	152	137	169
Mask	170	170	130	180		
Food	50	126	50	146		
Scary	202	202	168	193		

- When calculating the average values of the minimum and comfortable distance, a strong difference can be seen between the stranger and the friend.
- Strangers tend to set their comfortable distance fast and don't change after that. They probably choose a save distance from the beginning rather than going close and then backing off.
- When the minimum and comfortable distance are different, it seems to be a difference of 30 cm. This is the distance you make when setting a small step back.
- When there is food offered, the stranger and friend both come quite close and then back away around 0.5m to 1m.

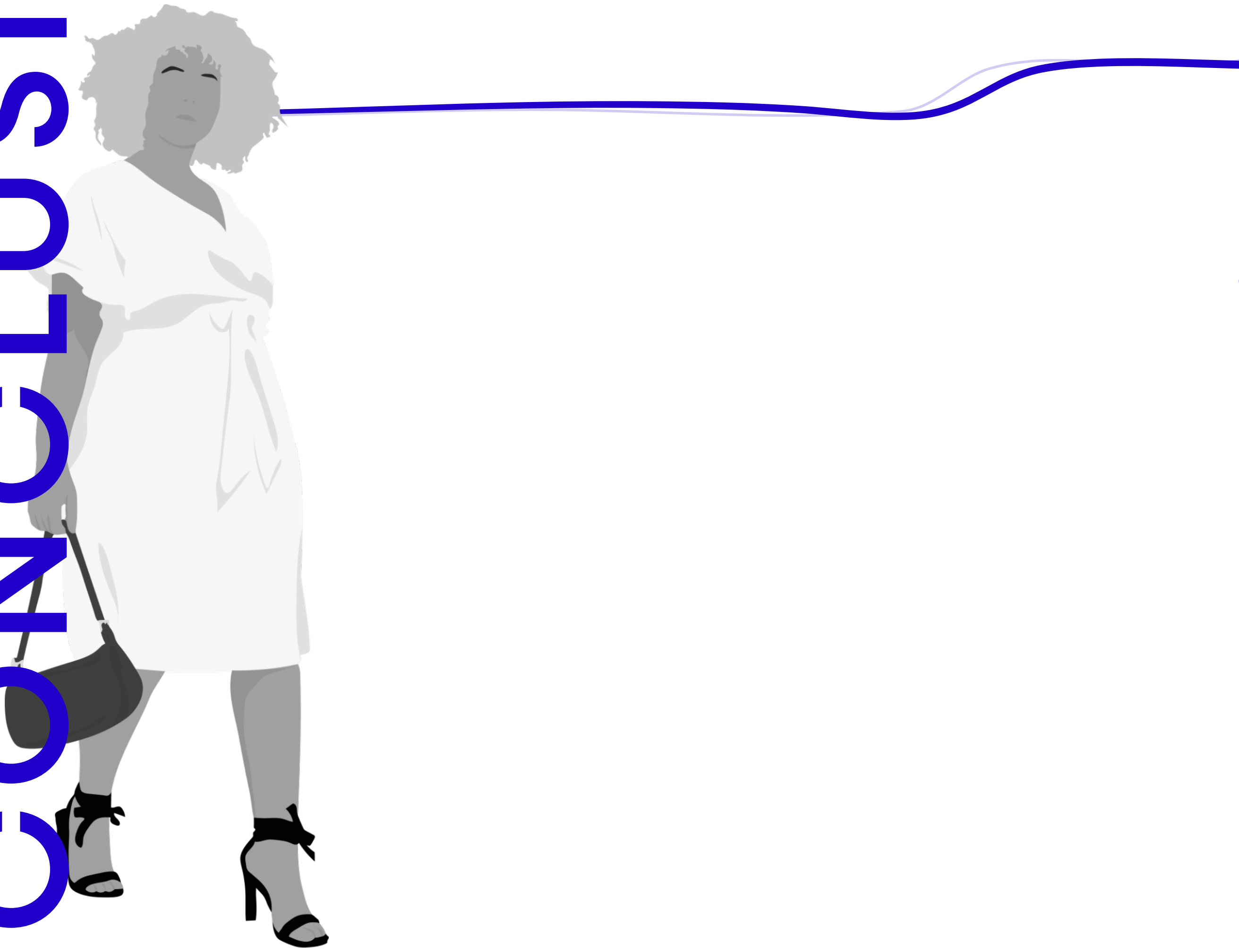
Results discussion

The results are promising. This verification test proofs that the personal space is flexible concept and is worth researching further to get even more detailed data out of it. This approach of precisely measuring the distance between two people reveals even slight differences in preferred distance. If in the future a test would be conducted, it might be a good idea to repeatably measure the same person in the same scenario to see how constant the distances stay.

When evaluating the measured distances, a lot of the results are quite obvious. Two strangers keep more distance than two friends, for example. But the power of this tool lays in the fact that we can actually know how much exact. These obvious results also verify that this tool works at least as expected.

In this proof of concept is only a proximity sensor embedded and the rest of the verification test was scripted. What if the prototype was able to recognise different scenarios and that way also be deployable anywhere you want?

CONCLUSION



Concept discussion

The current state of the proof of concept has proven valuable in the development of the technical research towards proximity and the human perception of it.

Researching proximity and the human perception of it is a difficult task. I chose for the personal space, because I believe that it can uncover some social clues of people, but also because it is a concept I was already familiar with. Using technical solutions to unravel this phenomenon is something new in that particular research sphere, but it counts several advantages compared to the analogue way of observing and interviewing people.

A thorough development process has been done, with prototyping and testing, to get this to a working concept. Technology was bench-marked to see what would fit this concept best. It was also taken into account that this was going to be an iterative design process and prototypes were needed to verify every iteration before taking the next step. The current ProximityVest is also a working prototype and all the user tests were done it.

It does however only measure the distance to other people at the moment and so much potential of this concept is left on the table this way.

Recommendations

- Do several more tests like the last verification test. It will enable the researcher to get more data points and make more conclusive conclusions.
- Add other sensors to the vest that reveal more about the interaction finding place. Sensors like an accelerometer or a microphone.
- Adding the function of facial recognition can help the tool to recognise friends and strangers. This is an interesting data point to link to the proximity values.
- The current prototype is very ugly and obvious looking. A next step of integration would be welcome to overcome this problem.

Conclusion

This project was focused on making a tool to explore proxemic zones. More specific: to measure the personal space of people. In order to do this, I had to research what was already done in the field of proxemics and how they solve problems.

I read the paper 'proxemics' from Edward Hall and saw how he in a very analogue way tried to understand and explore the way humans perceive proximity. This inspired me to follow his search, but with all the modern technology that is available today. An array of proximity sensors and distance sensors enabled me to build multiple prototypes.

The goals was to make a tool that can be easily deployed everywhere, with the people around you not aware of the experiment that is going on. It needed to be embedded in a convenient wearable in order for this to be possible.

I landed on a proof of concept that has all the proximity measuring figured out. I used that proximity data-point and several user tests to unravel how people set their personal space. Although the proximity sensor gives a lot of information, the prototype can use more sensors that reveal more about the interaction happening between the people. It is also my recommendation that the next iteration explores more in the human distance setting mechanism.

All by all did we learn a lot about proximity technology and how to use it properly in order for it to be useful in the exploration of the human perception of proximity.

[redacted]

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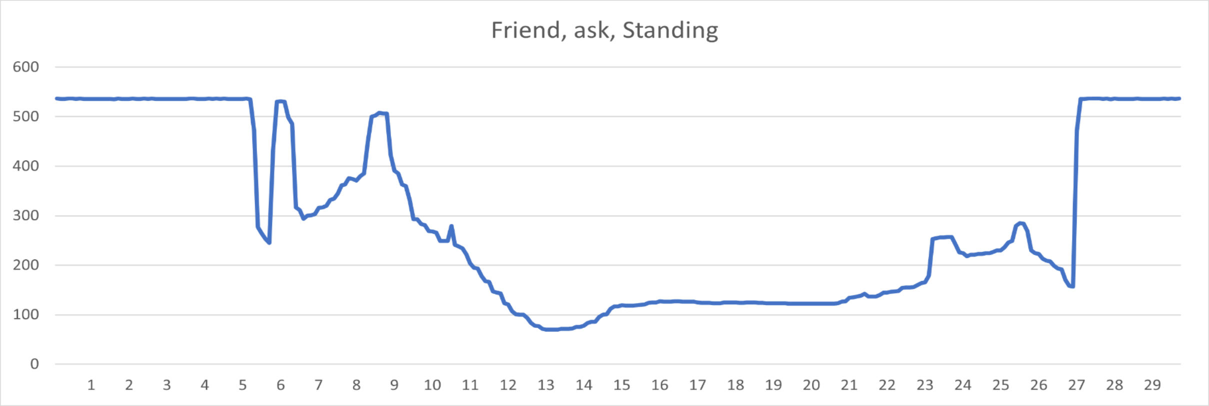
Appendix

I. Data verification test



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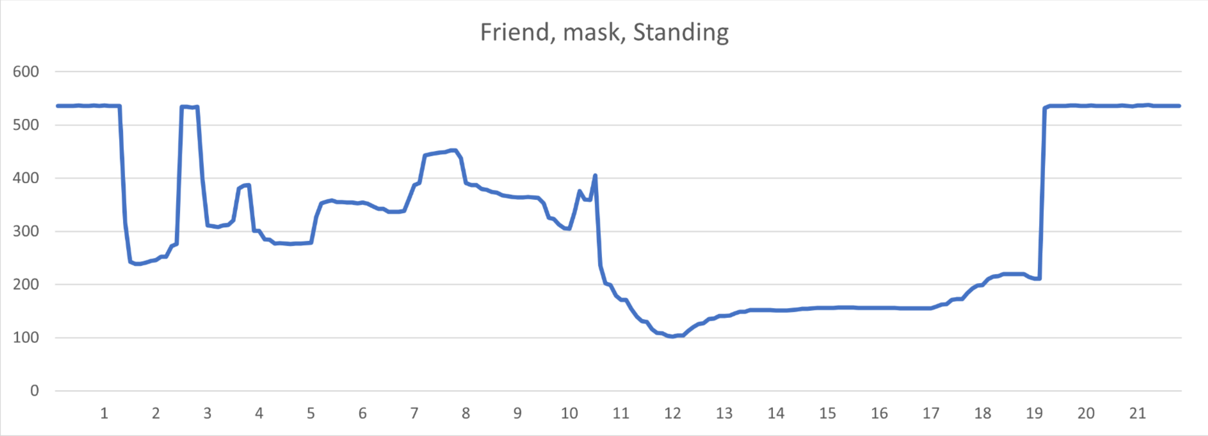
Friend, food, Standing

Friend, food, Walking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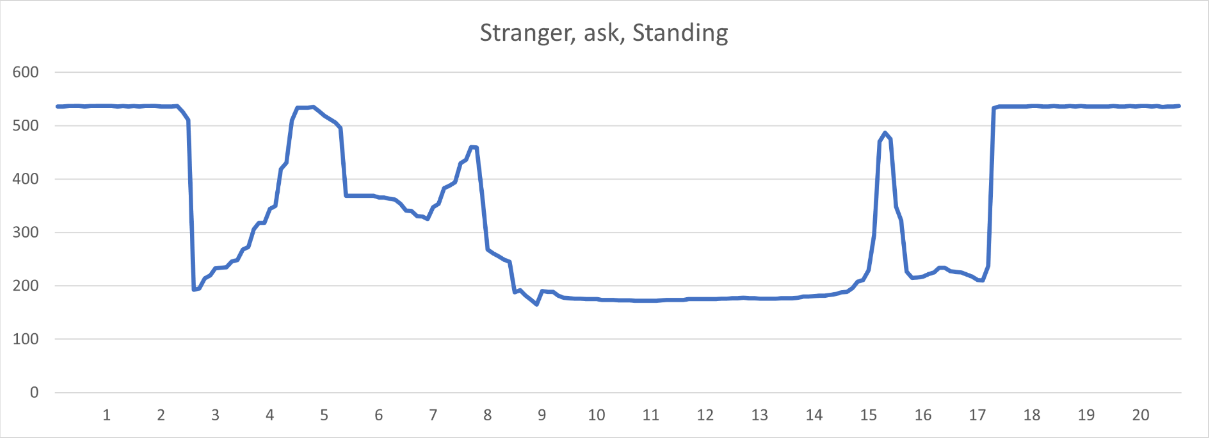
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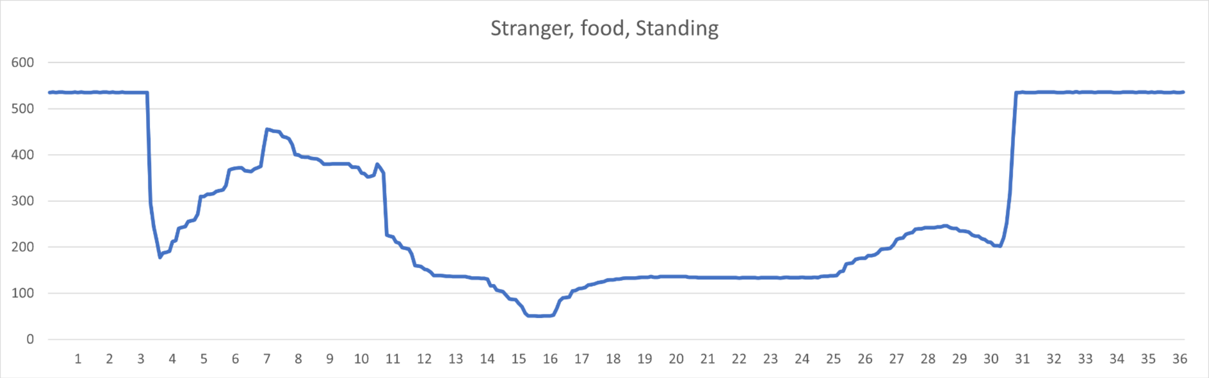
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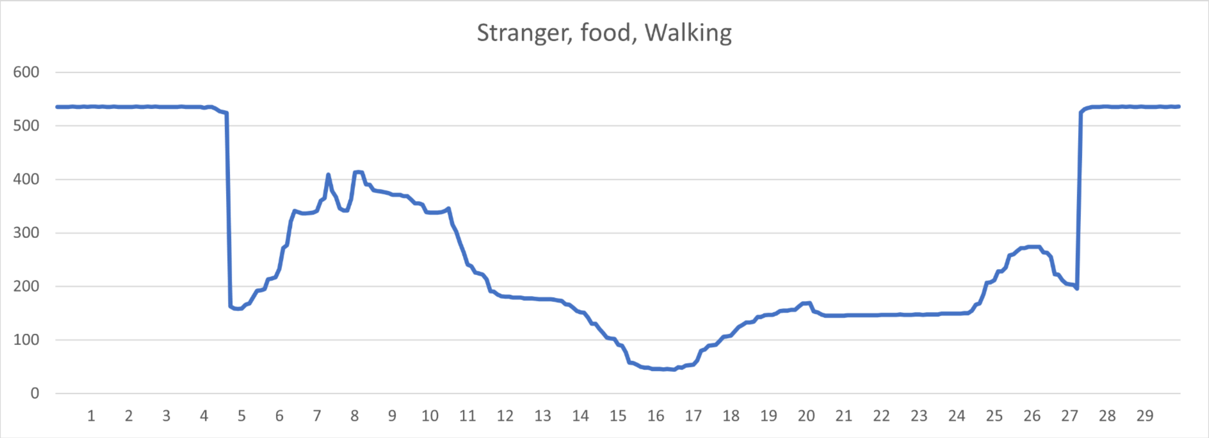
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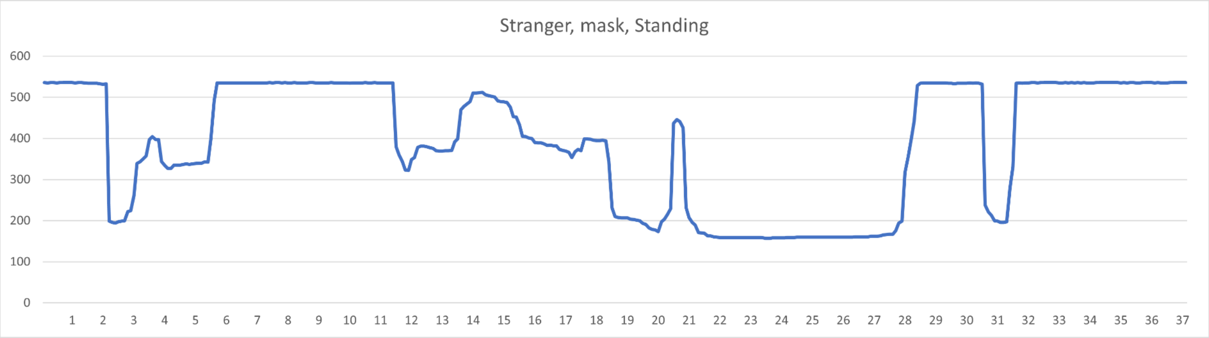
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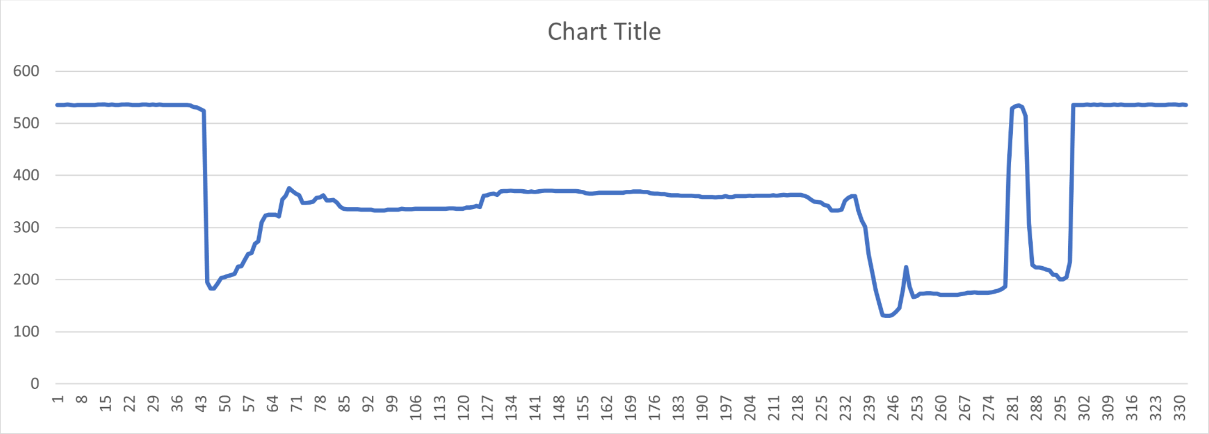
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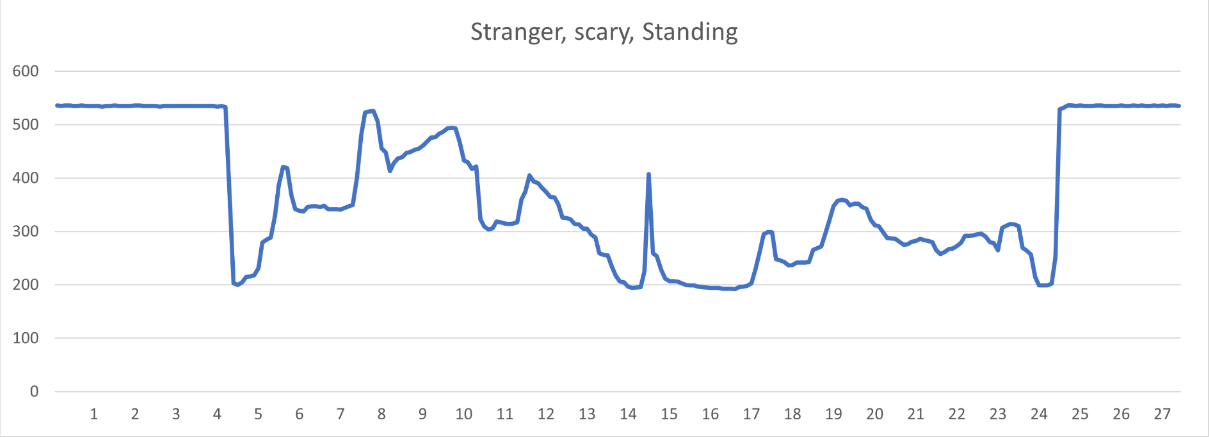
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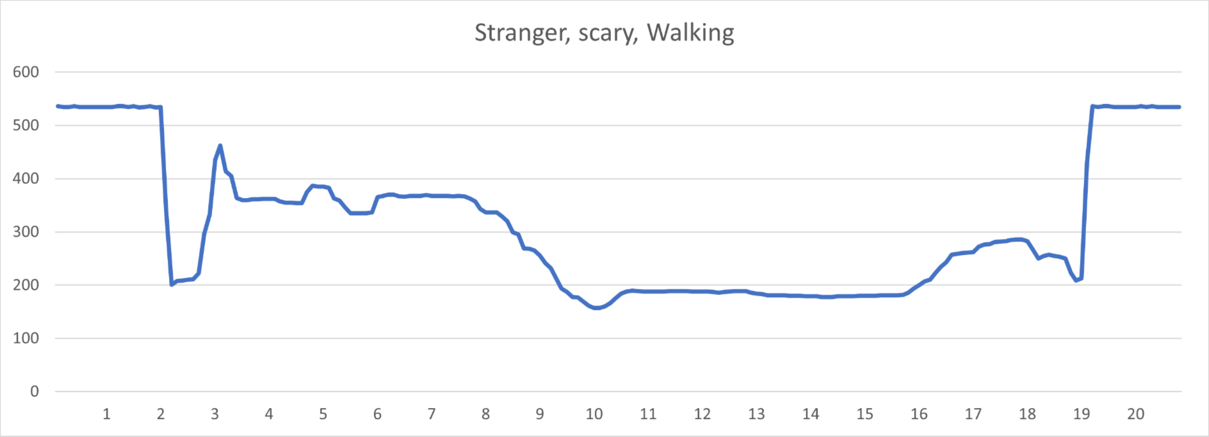
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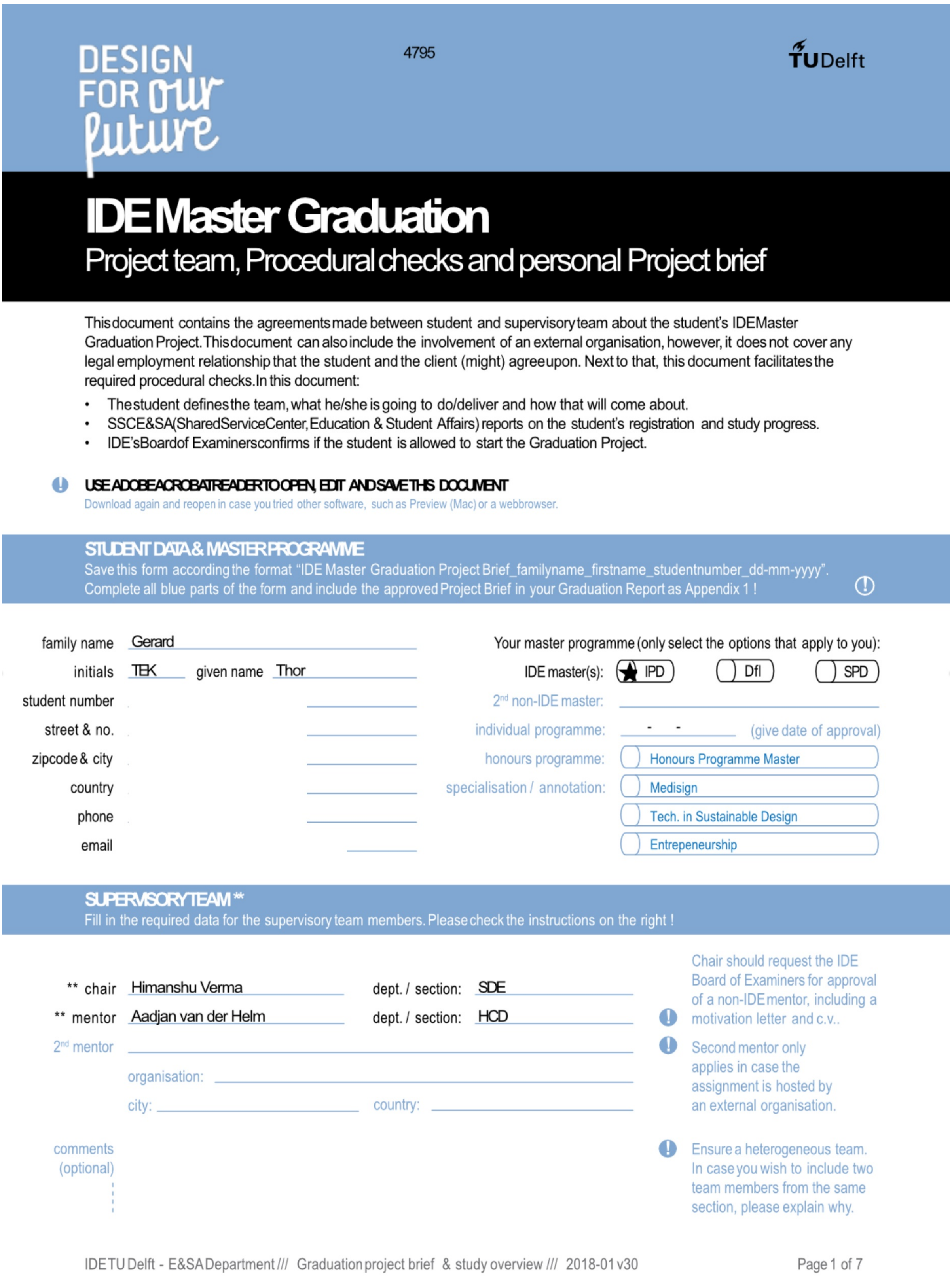
II. Project brief



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IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSCE&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name Gerard
initials TEK given name Thor
student number
street & no.
zipcode & city
country
phone
email

Your master programme (only select the options that apply to you):
IDE master(s): ● IPD ○ DfI ○ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ○ Honours Programme Master
specialisation / annotation: ○ Medisign
○ Tech. in Sustainable Design
○ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair Himanshu Verma dept. / section: SDE
** mentor Aadjan van der Helm dept. / section: HCD
2nd mentor
organisation:
city: country:
comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Himanshu Verma

date 08 - 03 - 2021

signature Himanshu

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 30 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

☒ YES all 1st year master courses passed

○ NO missing 1st year master courses are:

name J. J. de Bruin

date 09-03-2021

signature JdB

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ☑ APPROVED ○ NOT APPROVED

Procedure: ☑ APPROVED ○ NOT APPROVED

comments

name Monique von Morgen

date 16/3/2021

signature MvM

TUDelft

Personal Project Brief - IDE Master Graduation

Embodied Proxemic Sensing Capabilities in Cloths project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 15 - 02 - 2021

09 - 07 - 2021 end date

INTRODUCTION**

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Wearable technology is a fast-growing market. Technology is getting smaller and smaller and is more energy-efficient than ever before. This makes it more evident to fit it in wearable applications where it needs to be integrated into a small package with an unconventional shape. The most famous applications are smartwatches, smart glasses and fitness trackers.

The many benefits of wearable devices (also called smart wearable technology) become evident when you use them. When made right, it is a non-distractive way of assistive technology. It is very convenient because you can not forget using it. It blends in seamlessly with your day to day activities and it can disappear in your fashion style.

One group of those smart wearables is technology in clothing. Smart clothing is often used in sporting applications to monitor the vitals of a person. Most of these vitals need to be measured with close proximity or contact to the body and would otherwise require a separate skeleton to wear. Other than vitals (1), the movement or position (2) of a person can also be measured with embedded sensors. Other applications of smart clothing are embedded key-cards (3), gesture inputs for seamless interaction with other devices (4) and weather monitoring (5).

Almost all of these applications are about collecting data of the person itself, which makes a lot of sense because of the medium. Monitoring the context around the person is something that has not been explored. Knowing what happens around the person can be really useful. It can indicate interaction with other people or products.

Existing ways of doing this are via manual observations, video observations and surveys. You also have automated solutions, but those require a lot of infrastructure. Examples are the Estimote Bluetooth beacons that track where you are and systems like OptiTrack that use a lot of cameras and special suits to work.

This project is going to be focused on the embodiment of proxemic sensing technology in clothing. It will research which technology is needed to recognise people and objects in its surroundings in a privacy-preserving way. In addition to that, how can the information about surrounding objects and people be communicated to the user? Finally, it will explore different applications it can be used for.

In the long term, this product can also be used for researching the behaviour of people and societies at large scale to support sociological research (for example, computational social sciences). It can also be used as a tool to promote Research through Design.

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(4). https://atap.google.com/jacquard/
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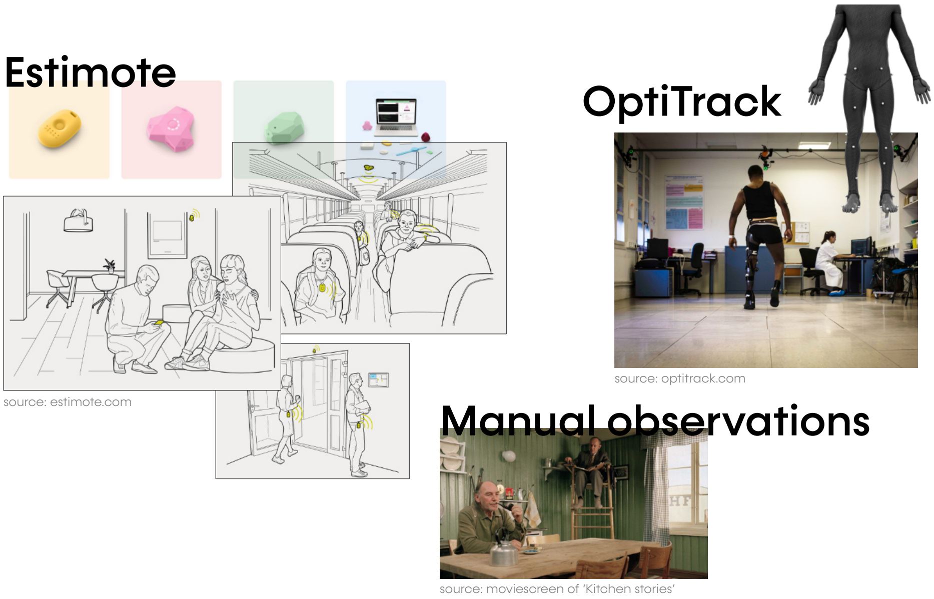


source: estimote.com

source: optitrack.com

source: moviescreen of 'Kitchen stories'

image / figure 1: Current ways of sensing the surroundings of a person

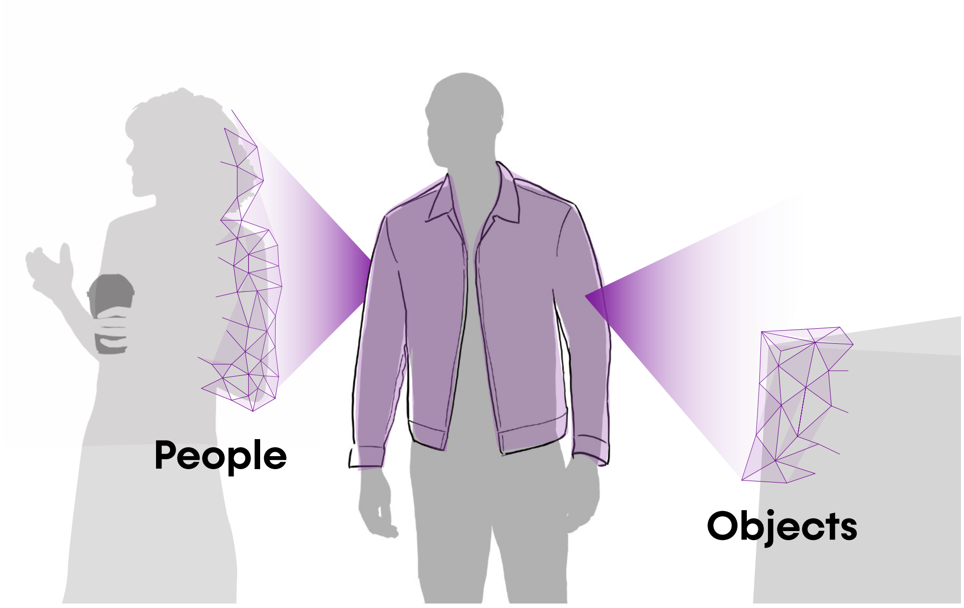


image / figure 2: Possible way that the project could turn out

Personal Project Brief - IDE Master Graduation

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The clothing needs to be a product that does not disrupt people in there every-day live. To be non-invasive to the user, the sensing capabilities should be as embedded as possible in Clothing. The sensors should be resisted against the normal wear and tear that clothing has to withstand. It should be able to sense the surroundings of the person by measuring close proxemic data. This sensing should be done with a technology that is detailed enough to recognize people and or objects. Exact distances and margin of errors is something that needs be explored. Collecting this data brings privacy issues with them and those need to be taken into account. It needs to be researched what people think about proximity in their clothing and where the limits of this technology are in terms of privacy. On the other hand, the clothing needs to give the appropriate feedback to the user. When the clothing is aware of it's surrounding, it needs to share that awareness with the user in a convenient way.

ASSIGNMENT**

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in “problem definition”. Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

In this assignment, it will be researched how to sense the surroundings of a person via proximity sensing technology that can be placed on the body of that person. A solution where the sensors are embedded in the clothing will be prototyped and tested to see if it visualizes enough of the surroundings. A smart clothing solution will be designed that fit these features and communicates them to the user.

The solution is expected to be a smart clothing product.

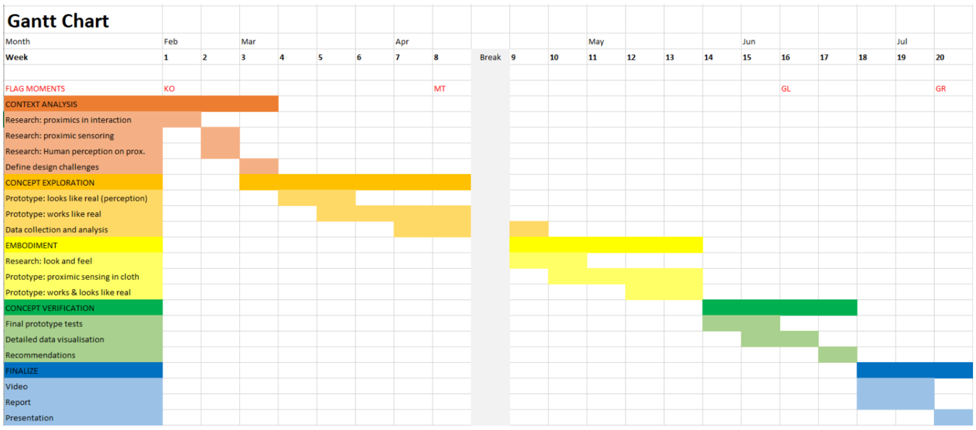
It can sense it's surroundings in the form of objects and people. It will be a non-intrusive solution for the user and the other people around it. It will be usable in everyday scenarios, so the convenience of using it needs to be very high.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 15 - 2 - 2021

9 - 7 - 2021 end date



The first 3 weeks of the project are focused on exploration of the topic. Here it will be defined what could be a possible solution.

The following next 5 weeks will be spend on making a prototype that solves a lot of the questions regarding human perception of the product, the technology needed for the product and how to use the data that has been generated by it.

After the mid-term, an exploration about technology in clothing will find place to embed all the previous work needly into a proper medium. Here lays also a focus on looks, functionality and usability.

Week 14 until 17 are used to collect all the findings and make a final prototype. With all this knowledge, some recommendations can be made for future use or exploration on the topic.

The last 3 weeks are for making a video and report, and a preparation for the graduation presentation.

Initials & Name TEK Gerard

Student number 5160014

Title of Project Embodied Proxemic Sensing Capabilities in Cloths

TU Delft

Personal Project Brief - IDE Master Graduation

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I am very excited to do this project because it combines many interests and ambitions of me. It is a human focused project with a lot of prototyping challenges.

Last semester I followed the course Connected Prototyping and learned many new concepts and theory around data-sharing products. The need for design-for-privacy sparked an interest with me and wanted to do something around that. This project makes it possible to use the skills I learned and try to understand the topic better.

Physical prototyping and electronics are an essential tool for the industrial designer I want to become. Making working prototypes are a good way to verify your design. It can also help with doing user tests during the design process.

And finally, being able to tackle a project solely on your own. In the past, I struggled to plan my project correctly and that resulted in a project I was not always happy with. Last semester I did a 4-month internship and one of the big things I learned there was to plan and document your work correctly. This graduation project is an extra opportunity to use these planning-skills and becoming better at it.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name TEK Gerard Student number 5160014

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