Bachelor Thesis
Creative Technology

End user interface for a sepsis diagnostic instrument

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0.1 Abstract

The SensUs competition brings competing student teams together with the industry of bio sensing together in an effort to accelerate the advancements in this sector. The University of Twente competes in this challenge and this year the student team TwentUs'22 is representing them. The subject of SensUs 2022 is Sepsis, a disease that is a major cause of death to this day. This year's student team is putting their efforts into detecting the concentration of the bio-marker Interleukin 6 in blood plasma through the use of micro ring resonators. The assignment of this thesis is to design and realize a conceptual end-user interface for a potential commercial product that is based on this measurement technique. The result of the assignment is used to strengthen the business case of the team. To design and create an end-user interface both the product and the user based need to be researched. This thesis plays a significant role in exploring the target group of the product, as well as creating the hypothetical product itself.

The end-user interface is designed using the iterative design method. First the requirements for both the product and the interface are determined using personas and scenarios. Once a specification is made on what the interface should be, a prototype is made. This prototype is iterated upon by having intermittent evaluation sessions with both experts and representatives of the target group. The iterative process assures that the assumptions made by the designer match the expectations and needs of the user group. In the end the result of this thesis is discussed in the context of the future applications of the potential product and what changes it will bring to society.

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Chapter 1

Introduction

1.1 Project context

Each year, students from all over the world compete in the SensUs innovation days. SensUs is an organization that strives to accelerate the development of sensors for better healthcare by bringing students, stakeholders and health partners together[1]. The University of Twente (UT) has recently joined this effort and has been sending a team to the competition each year. The objective of this years competition is to design a device that can rapidly detect for sepsis. SensUs is a multidisciplinary competition, where not only the sensor performance is of significance. Next to developing a bio-sensor prototype and demonstrating its performance at the competition, the teams are tasked with developing a business case for a potential commercial product based on the prototype. In the words of the SensUs competition: "The translation potential award expresses appreciation for translating the (real or conceptual) biosensor towards future applications in healthcare and towards industrialization." (IP June p.22 [2]) This thesis is conducted in collaboration with and to the benefit of the student team. The assignment is to design an end-user interface for the potential commercial product. The goal of this assignment is to strengthen the business case of the team by working out said product and doing research on its target group.

Figure 1.1: Team photo of TwentUs'22

1.1.1 The student team

The student team consists of 9 bachelor students with different backgrounds. We have formed 3 departments within our team, where each department has a different role in the project.

- Nursing: Provide background information on the use context and perform interviews with contacts in the medical field

- Business: Developing a business case and conceptualizing a potential commercial product
- Tech: Developing a working prototype to test samples with at the competition and providing a proof of concept for the business case.

Anton (Tech) and I have both volunteered to be team captains at the start of the project. Although being team captain has given me duties to fulfill within the team outside of the thesis, the closer involvement with the team has provided an extended understanding of the results of each department. This extra information has proven to be useful throughout the project.

1.2 Thesis assignment

The task at hand is to create a user interface for a potential commercial product to support the business case of the student team. To complete this assignment, the following is important:

- What is the target group and the context of use of the product?
- What are the features of the potential commercial product?
- How can a safe and efficient workflow be created through the interface of this product?

1.2.1 User group

The user group of the product is defined by the target group in the business plan of the team. As a result of interviews with hospital staff and an analysis on the current diagnosis method of sepsis, elderly homes have been chosen as the primary target group of the product. Meaning that the doctors at elderly homes need to be able to use the machine. A challenge in this thesis is to analyze and sympathize with this user group to establish their differences to a typical researcher, which I myself am more familiar with.

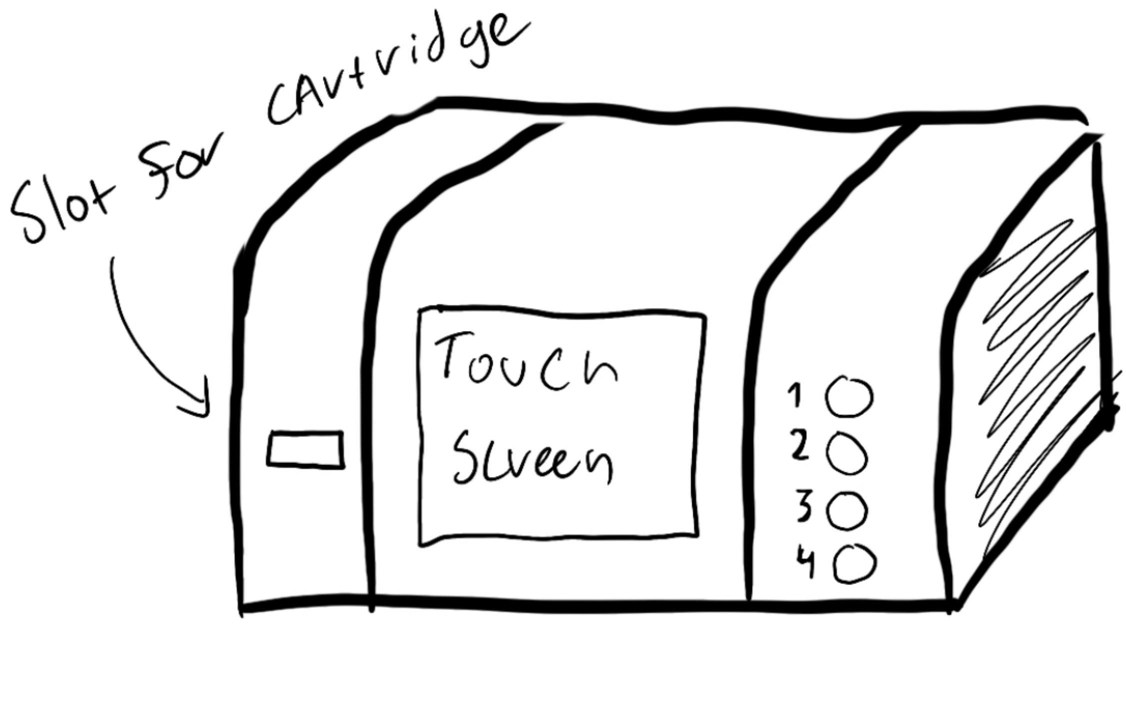

Figure 1.2: Rough sketch of potential commercial product

1.2.2 The product (machine)

Throughout the project (SensUs competition) the student team has made advancements with their technical (real) prototype and as such established the measurement technique upon which the product is based. This in combination with the user analysis functions as a basis upon which the product is designed. The conceptualized product is a desktop machine with an interface, a slot for the measuring chip and 4 slots where blood samples can be added. During the design of the machine, consultations with experts, conducted through the team and independently, have helped making design feasible in a real application.

1.2.3 Interface design

The challenge in the interface design is to translate a complex process (testing blood samples) into a simple workflow. It is crucial for the interface to minimize the room for error as an error could mean the death of a human. Especially, considering the user group is not a professional in the field of bio sensing, it is important that the process of doing a test is as straightforward as possible. The interface is realized through iterative design, in total 3 prototype versions of the interface are made in this thesis. The prototypes are non-functional interactive mock-ups made using Adobe XD [3], a prototyping software. The prototype versions have been evaluated with experts and people representative of the user group, who have been interviewed to acquire intermittent feedback. In the final version most tasks are done autonomously by the machine. The user is in charge of planning the tests and performing the physical tasks required by the machine. The interface is suited for 4 testing channels (respective to the 4 sample slots in the machine) that can be used independently and simultaneously. In future applications, these four channels could be used to measure a panel of target chemicals, which would allow the machine to determine the type of Sepsis. Furthermore, with different chips, the machine could be applied to other illnesses. This thesis is a conceptual application of a promising generalist measurement technique, that I predict will play a significant role in the future of healthcare.

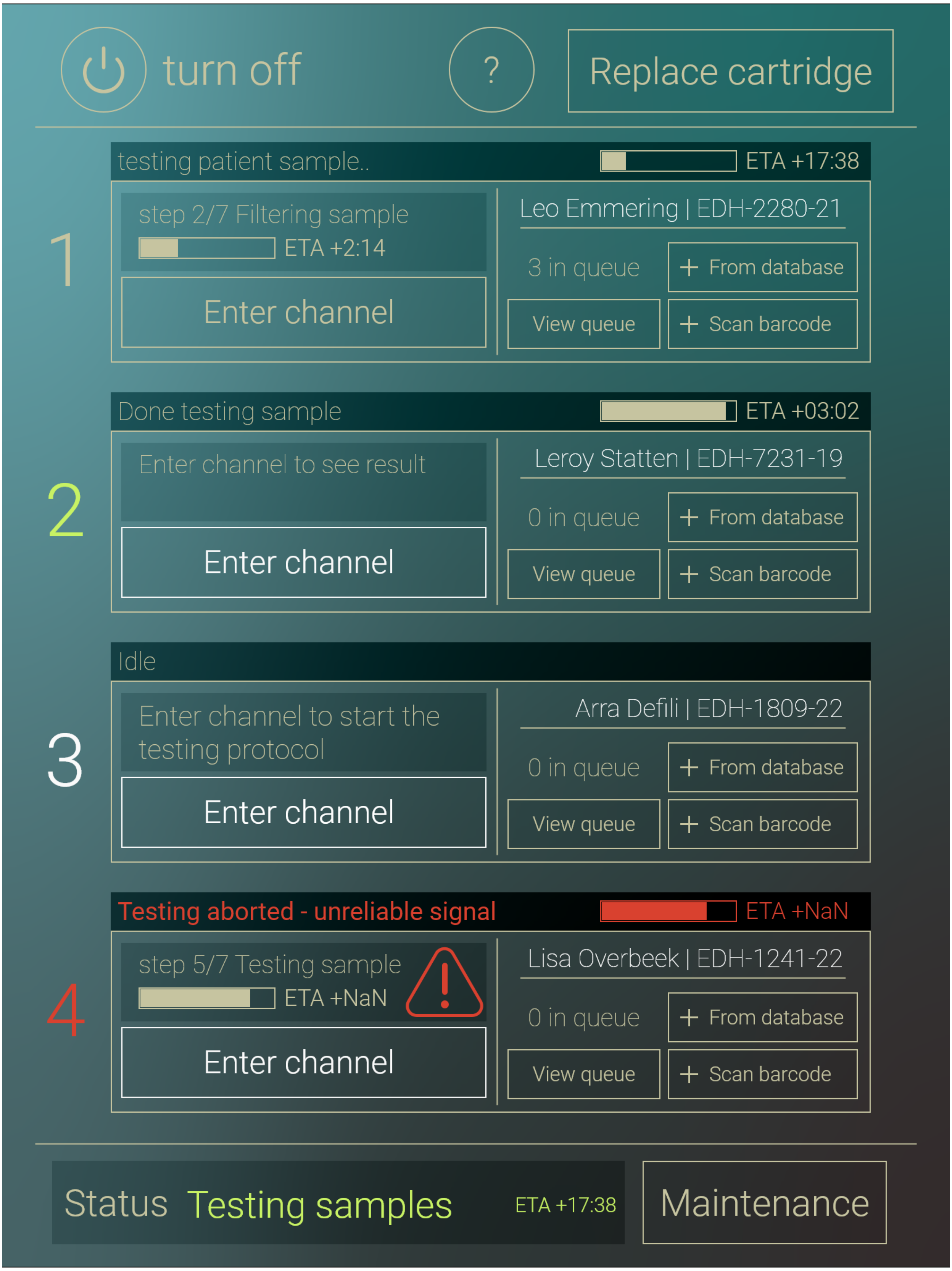

Figure 1.3: Home screen of final interface prototype

Chapter 2

Background research

This chapter discusses the technical information that is needed to build an user interface for a bio sensing product. This ranges from an explanation on the sensor itself to literature on design principles.

2.0.1 Definitions

- **Instrument** Analogous to machine and sensor: it stands for the complete device that measures the samples and outputs data that is to be processed to the interface.
- **The interface**: The **user** interface of which the design and realization are the objectives of this thesis
- **TwentUs'22**: The student team that the interface is being designed for.
- **UT+ team**: The name of the team that is the predecessor of TwentUs'22.
- **SensUs**: An international bio-sensing competition hosted in Eindhoven. TwentUs'22 is partaking in this competition, the goal of the interface is to improve the results of this team.
- **UT**: The University of Twente (Enschede), the university at which this thesis is conducted.
- **Saxion**: A university of applied science located in the same city as the university.
- **Delta (Diagnostics)[4]**: A private company that is currently realizing a bio sensor based on micro ring resonators. They have provided the physical prototype the team is using to test on.

2.1 The micro ring resonator instrument

To design an interface that is connected to data created by an instrument, it is important to know how it operates. Though the scientific background of the inner workings of the instrument that are not directly relevant for the interface, a rudimentary understanding of the machine provides a useful context in which the outputs and inputs of the instrument can be processed.

This year, the SensUs competition aims to find a new solution for the rapid detection of sepsis. All teams are trying to determine the concentration of the target chemical (IL-6) in the solution (blood plasma). There is a wide range of techniques that can be applied to fulfill this task. The TwentUs'22 team uses a somewhat novel technique, optical sensing. Their instrument is a prototype provided by Delta Diagnostics [4] that uses micro ring resonators (MRR) to determine the concentration of one chosen chemical in a solution.

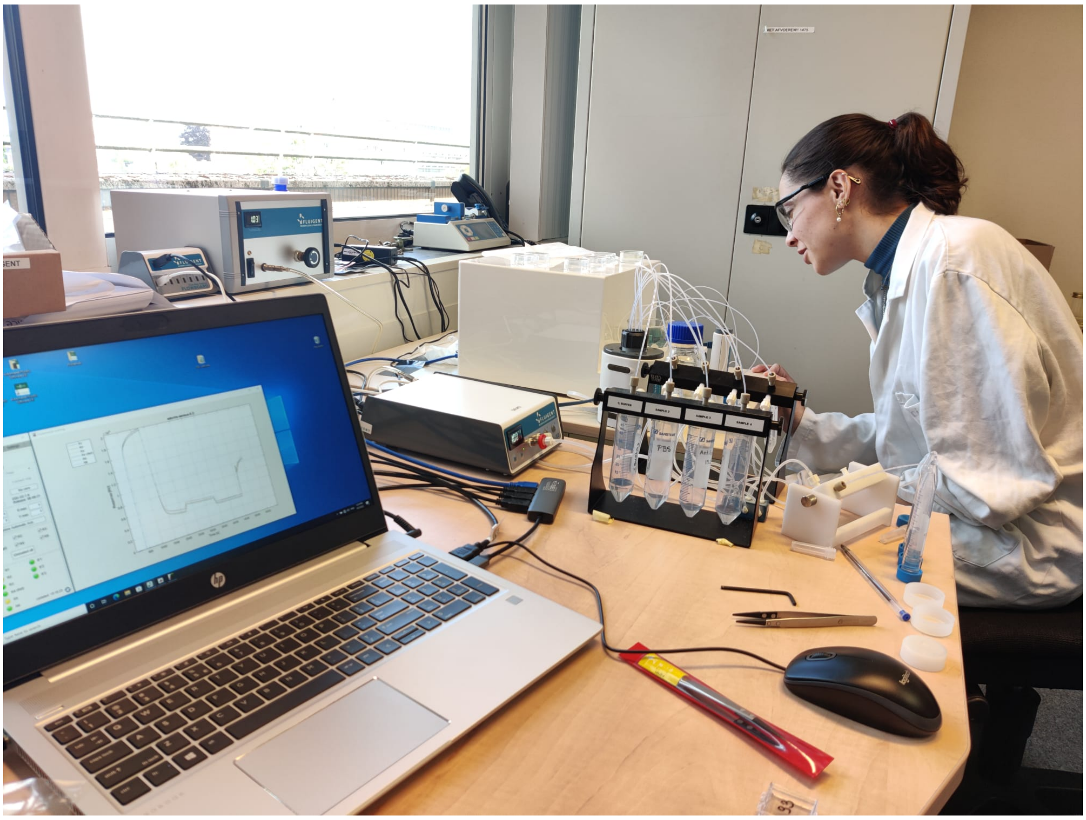

Figure 2.1: Lab session with the MRR prototype

To get all team members up to speed, one of our supporting professors has given us a lecture on how micro ring resonators work. The UT+ team, our predecessor, has worked with a similar prototype. The explanation of the technique provided in their team results document (TRD) [5] in combination with the lecture has made it possible to understand the concept of MRRs without a significant background in physics. Through working with the MRR prototype in the laboratory sessions with the TwentUs'22 team, the workings of the technique have become clear in its entirety.

The inner components of the prototype are proprietary, as such they cannot be discussed in this paper. However, the general principle of the technique can be discussed. The prototype consists of 2 devices, the measurement device and the photonic chip. The chip consists of wave guides (busses) embedded in a neutral material. A wide frequency spectrum is transmitted from the measurement device into the bus via a specialized laser emitter. There is a ring made of the same material as the bus placed so close to the bus that the optical signal travelling through the bus will partially travel through the ring and back into the bus (see fig.2.2). The diameter, temperature and the refractive index of the material surrounding the ring determines the (frequency of the) resonance frequency of the ring. At the resonance frequency, the ring loses part of the signal to its surroundings. As the ring feeds its signal back to the bus, the dip in the spectrum (emitted part of signal) will be visible in the output of the bus, measured by the measuring device. As a result, the resonance frequency of the ring can be determined from the bus signal.

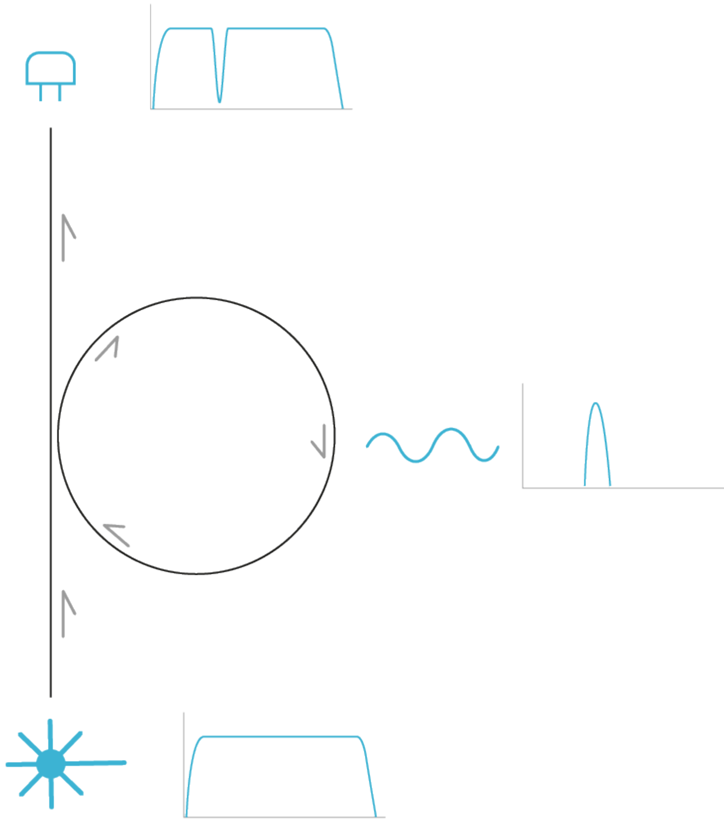

Figure 2.2: Micro ring resonator schematic

As earlier discussed, the resonance frequency is determined by 3 factors. By keeping the diameter of the ring and the temperature constant, the refractive index of the surroundings will be the only parameter to influence (the frequency of) the resonance frequency. Said refractive index is heavily influenced by the mass attached to the ring. Therefore, attaching chemicals to the ring will create a response in the form of a frequency shift of the resonance frequency. The coating applied to the ring is done is such a manner that only the target chemical can bind to the surface. As such, (theoretically) any change in the frequency can only be attributed to the target chemical being present in the fluid that is flowing over the coating. Using a strong acid the binding between the target chip and the chemical can be dissolved. Therefore, the chip can be 'reset' and can be used to test for the target chemical again. The frequency shift that is observed from the binding of the target chemical to the chip is to be processed by the machine and communicated to the user.

2.2 Interactive interfaces

Next to the instrument communicating data to the user, the user needs to give their instructions to the instrument. This is done through a Graphical User Interface (GUI). The GUI is used for the user to navigate through the software and the data that the machine has produced, as well as starting measurements. The GUI consists of graphical elements that have certain functionalities, such as buttons and sliders. As well as visualizations of data and information on the status of the system. These building blocks can applied and connected to one another in an infinite number of ways. In the same way a car is designed to provide an efficient and pleasant experience to the driver. A GUI must be intuitive, efficient and pleasant to look at to whoever is using it.

2.2.1 Usability design

An important piece of literature in the field of human computer interaction (HCI) is a paper written by J. Nielsen called the 'Ten Usability Heuristics' [6]. It consists of ten heuristic rules that should always be followed when designing an interface. These rules are focused on the experience of the user and aim to prevent certain pitfalls as well as enhancing the feeling of the interface. Another paper [7] elaborates on these rules in the context of medical devices and with a focus on patient safety. If an interface allows for errors to be made while operating the instrument, these errors could result in the death of a patient. Especially in the case of Sepsis, where a wrong diagnosis could be fatal within the span of a day. This paper has constructed its own 14 heuristic rules based on the heuristic rules from Nielsen and the 8 golden rules of Shneiderman [8]. As the following list is an extension on both the heuristics from Nielsen and Shneiderman, as well as being put in the right context, these heuristics will be used to evaluate the prototype.

1. Consistency: Aspects of the interface should be consistent, they must reflect their similarities with other aspects through their function.
2. Visibility: Users should know what the machine is doing, and how long it will take to perform the task. Especially if the task takes longer than a few seconds.
3. Match: The aspects of the interface should reflect the real world. The interface should be conform to the users expectations from their experience in the world.
4. Minimalist: Any extraneous information should be avoided, the interface should be designed for the core tasks and should not distract from it (Low data-ink ratio).
5. Memory: Try to reduce the memory load, any **relevant** information the machine has on the task that the user is performing should be visible.
6. Feedback: Users should be given feedback on their interactions with the interface. Keep the user informed on the consequences of the action they perform with the machine.
7. Flexibility: Each user is different, give the user the option to customize the interface to best fit their desired workflow.
8. Message: Make sure that the communication to the user is complete and understandable without extensive knowledge on the machine.
9. Error: Prevention of errors is better than retrospective action. Try to put systems into place that minimize the room for error from the user's side.
10. Closure: Clearly communicate to the user when a task is complete. Give the user information on the scope of the task and the steps needed to complete it.
11. Undo: Make sure that the actions of the user are reversible where possible. This will allow the user to recover from errors and prevents user from getting frustrated.
12. Language: Use a language that is understood by the users. Be this the language itself (Spanish, French, *etc.*) or the level that the language is written in.
13. Control: Make sure that the user feels like they are in control of the machine and not vice versa. The user must initiate the actions, the machine should respond to their input.
14. Document: Provide help and documentation where needed.

This is quite an extensive list and though these heuristics should be kept in mind whilst designing an interface, they will not all be correctly implemented in the first version of a design. They work better as a retrospective tool with which a prototype can be evaluated to improve it in its next version. Ideally the evaluation should be done through consultancy from experts in the field of design [7].

2.2.2 Interactivity

Interactions themselves have certain aesthetics, a feel that the user experiences while interacting with the machine. A paper published 2011 [9] proposes that interactions have attributes which can be applied to all types of interactions. To illustrate, certain android phones have adopted a system of swipes from and to different points in the screen to navigate through the phone instead of the standard 3 digital buttons on the bottom of the screen.

Though both approaches have the same functionalities (the instructions to the machine are identical) the interaction is quite different. An interaction is not a tangible thing, its more of a concept or a process. To be able to assess the qualities of an interaction, the aforementioned paper [9] has divided an interaction into 7 attributes:

- Concurrency: Things happen at the same time/ Things happen after one another.
- Continuity: Input is on a spectrum/ Input is discrete.
- Predictability: Events follow logical patterns/ Things happen at random.
- Movement range: Things move narrow distances/ Things move wide distances.
- Movement speed: Things happen slow/ Things happen fast
- Approximativity: Data is precise/ Data is represented approximately
- Response speed: After input things happen after a delay/ After input things happen immediately.

These attributes can serve as a tool to design interactions. The desired point in the range of each attribute is dependent on the interaction and the context. Designing an interaction in a video game is entirely different from designing an interaction with hospital equipment. In a user interface for an instrument to test sepsis it is important that the interactions are predictable. However, the interactions shouldn't necessarily be precise, sometimes an approximate of the data is more useful. The desired interactions and their attributes are specific to each user and the context in which they are performed. Therefore, the intended user group must be analyzed and consulted to fully determine how the interactions in the interface should be.

2.2.3 UX design

The products that we put together as designers are made for users and to be used by users. The field of user experience design takes this to heart and looks at the challenge (helping patients with sepsis) from the users perspective instead of trying to solve the challenge as an engineer [10]. In the case of this thesis, the focus is not put on providing a general tool for diagnosing patients with sepsis. Instead, the focus is put on figuring out what the users needs to provide care for people with sepsis. The difference might seem subtle, but it changes the approach to the challenge entirely. Instead of designing a tool that can diagnose patients, we design the experience of the person who has to care for them.

To design a user experience one must understand the context that the product is going to be used in. Furthermore, the designer needs to know what is important to the user and what the capabilities of the user are. User-centric research starts with empathizing with the user group. Through this process one can determine what things are of importance to the user group, their motivations and what grievances they have with the current method of solving the challenge. Being able to immerse oneself in the user is an important skill in human-centered design. [11]

A common method of immersing ones self in the user is to create personas and user scenarios. Instead of stating what attributes the product must have to solve the problem, the method of solving the problem is written out from the perspective of the user. To better understand the user we create a fictional person that we think closely resembles someone that would use the product. Then this fictional person (persona) will be trying to use the product and all their actions will be narrated in detail. If there are parts in the system that are missing or require certain background knowledge that the persona lacks, they will become apparent when walking through each action that is to be performed. As such, the designer can find shortcomings of their approach without requiring user tests. The method of scenario based design is especially useful as an exploratory tool to evaluate an early prototype.[12][13]

2.3 User testing

The method of user testing in this thesis is a demonstration of the prototype followed by an interview. Here users are asked to share their views on the approach of the designer. User tests compliment the more heuristic approach of fictional scenarios by being more concrete and grounded. Where the heuristic is a more general approach which can uncover a high number of usability problems, user testing is a focused approach that uncovers problems most important to the user [14]. User testing is an important step in which the assumptions made in first stages of prototyping can be validated. The prototype that is created using personas and scenarios can function as a basis on which the testing is performed. There are various methods to perform user testing ranging from observations in a lab setting to online forms [15]. With respect to the resources available, this thesis will exclusively use prototype demonstrations and debriefings in the form of interviews to validate the prototypes.

2.3.1 The participants

To perform a user test one needs participants and these participants need to be recruited. The method in which participant are recruited is less important in usability testing than it is in experimental research. Though it is important that the participants reflect the target user group, they don't have to accurately represent the entire user group. Although Tan et al. [14] does recommend having diversity in the participant group. User testing can be done on different scales and the right amount of participants in a usability test is a debated topic. In the book of Lazar et al. [15], different sources are compared and most indicate that a participant group of 5-15 people is sufficient in uncovering approximately 80% of usability problems. In a paper from Nielsen (the same person that created the 10 usability heuristics) and Landauer [16], they concluded that up to 16 participants still be cost effective and that the best benefit/cost ratio lies at 4 participants. As this thesis is an individual project and the target group is specific, there will only be 3 participants included in the usability testing.

2.3.2 Interviews

Most of the user feedback in this thesis has come from interviews that follow a prototype demonstration. According to Lazar et al. [15] there are 3 types of interviews that can be conducted: Structured, semi-structured and unstructured. This categorization is made on the amount of structure that is used in the interview. Where a structured interview has a predefined set of questions that will not be deviated from and an unstructured interview only uses a few guideline questions to facilitate the conversation. A semi-structured interview uses the predefined questions from a structured interview, but leaves room for clarification and follow up topics. Each approach has its respective advantages and drawbacks. A structured interview allows for easy comparison between participants, but leaves little room for exploration. Whereas semi structured and unstructured interviews are best at searching for digging deeper and getting an understanding of the user. In this thesis the approach of a semi-structured interview will be taken as there are few participants and the knowledge on the target group is limited. Therefore, being able to ask for elaboration on certain answers is important to get an understanding of the user group.

The questions that are asked in the interview must be put together in a thoughtful way. In general one should avoid putting any kind of bias in their questioning. Especially when the interviewee is an acquaintance, they might be inclined to give the feedback they think you want to hear, instead of their real thoughts. Phrasing questions in a neutral way can help minimizing this bias. Additionally, it should be clear to the interviewee that the product is being tested, not them. For example, they might feel judged or embarrassed by stating that they did not understand certain parts of the prototype. Though it might be hard to account for the more subtle biases in the interview questions, the most apparent biasing problems should be addressed. [15]

2.4 State of Art

There is a wide range of medical products, each with their own software. However, this software is often not easily accessible. Therefore, this state of the art is focused on software systems that are related to the assignment.

2.4.1 Autoscribe LIMS

Matrix Gemeni is a Lab Information Management System from Autoscribe. A system like this keeps track of all the tests that are being performed within the institution. The instruments interface with the system through mainly CSV and text files. This particular product can automatically store the results of the sample and connect it to the measurement once the operator tells the system it is performing a certain measurement. The operator then has the option to review the measurement and approve it, such that the system knows this measurement is performed correctly and can be communicated across the institution. To approve a measurement the operator must fill in a digital signature (username + password). Once approved the information of the measurement will be put into a form where all the data is easily readable by others. [17]

There are multiple of these packages used throughout the medical sector. Each function with a certain API on which the Information management system is linked to the machine. This means that there should be infrastructure in place through which data can be accessed by the machine. Therefore, we can assume that the information is available, and that information can be transmitted back to a central system. Even though the technical details on the connection between machine and information system is not yet clear.

2.4.2 Adobe XD

Adobe XD [3] is an application from the Adobe creative suite. Its primary purpose is to create mock-ups of software applications. The software functions similar to Adobe illustrator, it has multiple layers on which shapes and text can be put and multiple art boards that can be worked in within one file. The main difference is that in Adobe XD, the art boards can be linked to one another with animations. The final result of a mock-up in Adobe XD consists of multiple pages that have interactive elements which can refer to other pages. Similar to how a website has links to other web pages, some of the elements in the mock-up link to other pages.

As the interface does not have to be functional (as the product does not yet exist), a mock-up software like Adobe XD is great at providing the tools to make a prototype interface. Using the animations between pages and connecting the art boards one can demonstrate the prototype well to potential users, who can provide their feedback on the prototype.

2.5 Summary

The measurement technique puts out a single piece of data, the resonance frequency shift. The user must be able to navigate to this data and initiate the tests that produce said data. Therefore, a graphical user interface is build to facilitate the interactions between the operator and the machine. There are fourteen heuristic rules put together by J. Zhang *et al.* that help the designer create a user friendly experience. These are used in combination with an analysis on the context of use, where the needs of the user are identified. In addition, user tests will be performed to test the assumptions of the designer to the real world. These three methods are used in the creation of the end-user interface to increase the quality of the final product of this thesis. The user interface itself will be a mock-up that is designed using Adobe XD, a software that can create non-functional interactive interfaces.

Chapter 3

Requirements capture & Ideation

3.1 Impact of sepsis

Sepsis is a disease that is caused by our immune system and is induced by an infection somewhere in the body. This extreme (dysregulated) immune response can cause organ failure, resulting in death [18]. The business department of the student team has done an assessment on the scale and consequences of sepsis in the Netherlands [19]. The disease is quite common, it is the cause of death in 19.7% of cases worldwide [20]. Individuals from ages 1-40 rarely die from Sepsis in the Netherlands, this number dramatically increases in the age group of 65-85 years (see figure 3.1). It is mainly elderly that succumb to the illness, although newborn babies also have a significantly increased risk. There are currently 3.457.535 people older than 65 in the Netherlands, which accounts for 19.8% of the population, this share is suspected to increase over the next few decades [21]. Therefore, the amount of sepsis cases is expected to rise significantly.

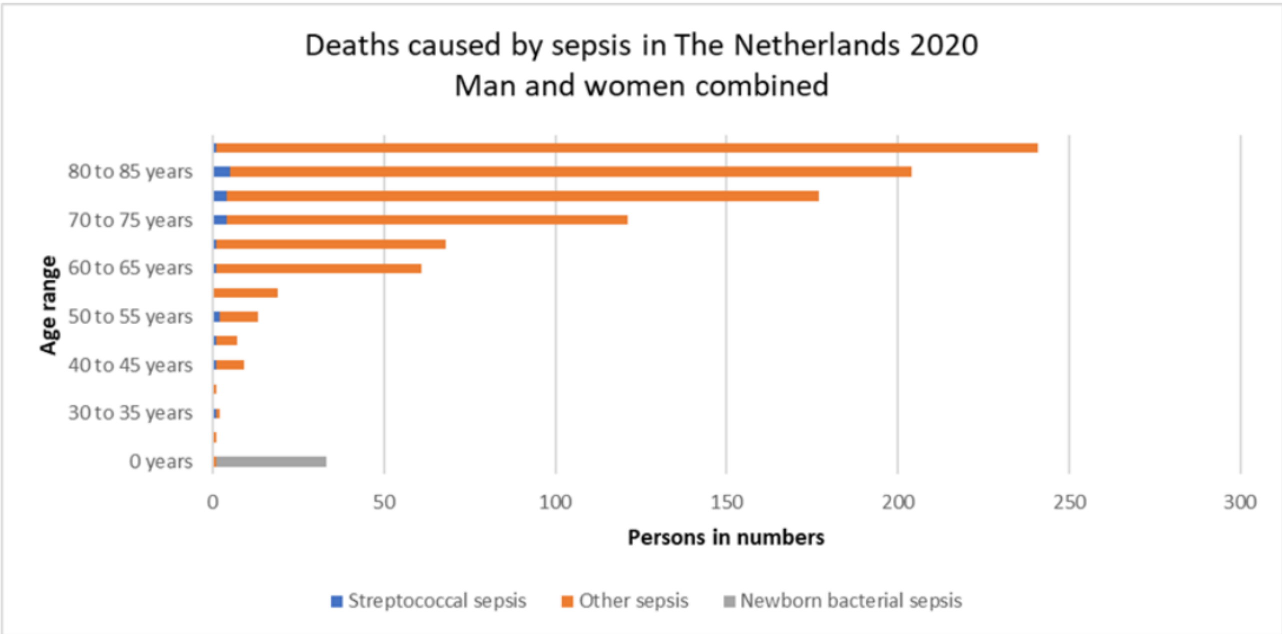

Figure 3.1: Sepsis deaths per age group (from the TwentUs'22 TRD) [19][21]

3.2 The qSOFA sepsis diagnosis technique

The current method of detecting Sepsis is by doing a qSOFA (quick sequential organ failure assessment), supported by conducting a bacterial culture. Whenever a patient is suspected to have sepsis their vitals are assessed. qSOFA tests for 3 metrics:

- Respiratory rate $\geq$ 22 breaths per minute
- Systolic blood pressure $\leq$ 100 mmHg
- Altered mental state

If two of these three symptoms are observed in a patient, it is assumed that the patient is suffering from sepsis [22][23]. After this diagnosis further research is done on the patient to determine the origin of the sepsis. This is done via blood cultures. **These tests can take up to roughly two days to complete whilst the patient has an average decrease in chance of survival of 7.6% per hour**. To slow down the infection, the patient gets administered a broad spectrum of antibiotics the moment they are diagnosed with sepsis. This broad spectrum of antibiotics is a cocktail of different antibiotics that effective against most kinds of infections, but are more less effective in combating the infection and destructive to the beneficial micro-organisms of the patient. After the pathogen responsible for the infection is identified, the patient will switch to a narrow spectrum of antibiotics specific to the pathogen. [23]

Detecting early cases of sepsis seems to be challenging for general practitioners according to a paper from Loots et. al. [24]. Generally, the doctors who assess their patients in these situations send them to the hospital when they are in doubt. A proposed protocol from aforementioned paper [24] is to refer a patient to the hospital if one red flag such as the components of the qSOFA tests is observed. This consumes unnecessary resources at the hospital and a hospital referral is not without its dangers for an elderly patient either [24].

3.3 Target group

In the exploratory stage of the market research performed by the student team, two interviews have been conducted by the medical department with a medical professional [25][26]. Though both state that a device that can do a rapid diagnosis in the hospital would be beneficial, B. van Hees suggests that such a device would be of more value at a nursing home. Their reasoning is that patients that are referred to the hospital with the suspicion of sepsis are often easy to diagnose with qSOFA. The biggest selling point of our prototype is that it can detect asymptomatic sepsis, meaning it can detect sepsis in its very early stages. At this time the pathogen might not as much of a problem yet, and the patient could be cured without going through severe illness. As such, having a rapid testing solution at a nursing home would significantly reduce the harm caused by sepsis. The product will be relatively expensive for a nursing home, as such it might be the case that multiple institutions in the same region use one instance of the product. The fact that the product will not be employed at a hospital does mean that the product will not be used by a trained analyst, but rather the medical director of a nursing home or a visiting doctor.

3.4 Context of use analysis

A nursing home not have a laboratory or laboratory equipment available on location [27]. Therefore, it is of importance that the product does not require such tools to be operated. Considering the high stakes of the results and the limited expertise of the medical staff on the instrument it is of importance that the product is a closed system. Meaning that flexibility of the product is reduced and the user will not be able to adjust the settings of the instrument. A closed system will limit the possibility of improper use of the instrument, hence it will be safer to use. However, the need for certain chemicals that are used to operate the machine cannot be avoided. The interaction the user has to these chemicals and how they need to be connected to the machine should be as safe and intuitive as possible. Therefore, very specific protocols need to be written to change these chemical and the actions that need to be performed should be specifically designed for users that do not have a background in chemistry. Furthermore, the product must be able to tell if there are any errors made be the user in its maintenance and should inform the user if anything is connected incorrectly. Routine maintenance by a professional might be needed to ensure that the device remains accurate.

From our interviews we concluded that the obtained data is of lesser importance to acting medical staff, the most important is the actual result. The product is envisioned to autonomously detect sepsis reliably, but it will not be accurate in all cases. Therefore it is important that the measurement data is still assessed. The typical user might not have the expertise to make any conclusions from the raw data, which might be the reason that they suggest that being able to see the data is of little added value. However, there could be algorithms build into the instrument that can assess the data on anomalies or otherwise suspicious patterns that could indicate an inaccurate result. So not only should the product automatically derive a conclusion from the data, it should add a level of confidence to the result such that the operator is aware of potential false readings.

3.4.1 Personas & scenarios

In the exploratory phase of the design, 4 scenarios were created to get a better understanding of the target group. Each scenario is linked to a persona, a fictional person that is an actor in the scenario. The pictures of these personas are not real people, instead they are generated by an AI at "this person does not exist" [28]. This allows for the use of faces without the need for permission from a person or buying the rights to such an image. As stated in 2.2.3, scenarios help the designer emphasize with their user group. Albeit fictional, having tangible users with a backstory interact with the product in various contexts will help to make assumptions on the motivations and needs of the target group. The addition of scenarios that lie slightly outside the user group (a hospital nurse or analyst) is to highlight the differences between these groups which makes the specific needs of the actual user group more apparent. The follow scenario's are focused on understanding the motivations and capabilities of the different personas, not so much on the details of interaction with the product.

Scenario 1: General practitioner

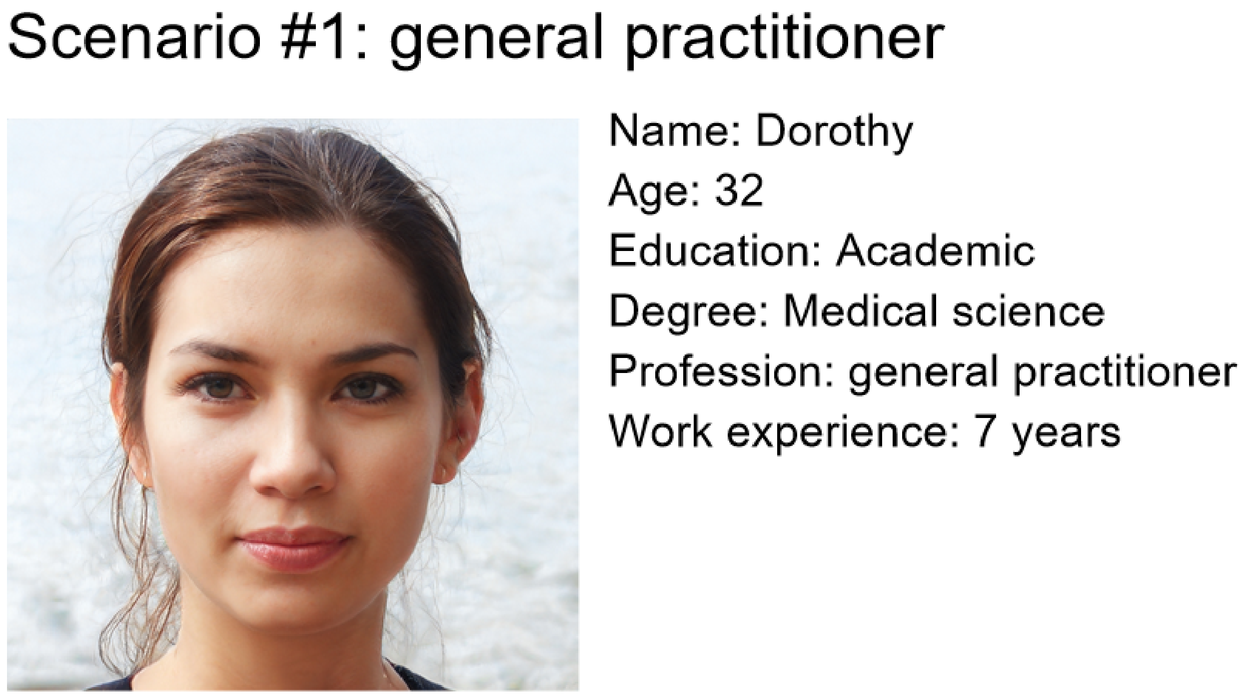

Figure 3.2: Persona 1: Dorothy

Dorothy is expecting an elderly patient, a man 62 years of age. He was feeling unwell at home. When the patient arrives, Dorothy has a little talk with the patient to establish his symptoms. He is feeling dizzy and slightly disoriented. Dorothy decides to do some tests using the equipment she has at the office.

- She measures his blood pressure, this is lower than average.
- She measures his respiratory system, the patient seems to breath more shallow and more frequent than average

Dorothy has multiple explanations for the anomalies. A shortage of minerals is most probable, but it could also be something life threatening like sepsis.

Without sepsis rapid test Dorothy does not have the medical equipment and machinery to confidently exclude Sepsis as a possibility. As the man's life might be on stake, Dorothy decides to refer him to the hospital for further examination.

With sepsis rapid test Dorothy has a machine in the clinic which can rapidly determine sepsis in a patient through a blood sample. She asks the man to sit tight as she prepares drawing a small sample of blood. She takes the blood sample to the machine and places the sample in a tube that will be fitted onto the machine's fluidics system. She presses the start button in the machine, which starts a sequence. In about 5 minutes the machine is done with the examination of the sample. She takes a glance at the interface to see if the measurement has the expected shape and reads the result that the machine provides. The machine categorizes the sample as category I (healthy), with 98.5% certainty. Taking in her own intuition and the machine's outcome, Dorothy decides to advise the man to take some mineral supplements and come back to her if the situation does not improve the next day, if needed the test can be run again.

Scenario 2: Hospital nurse

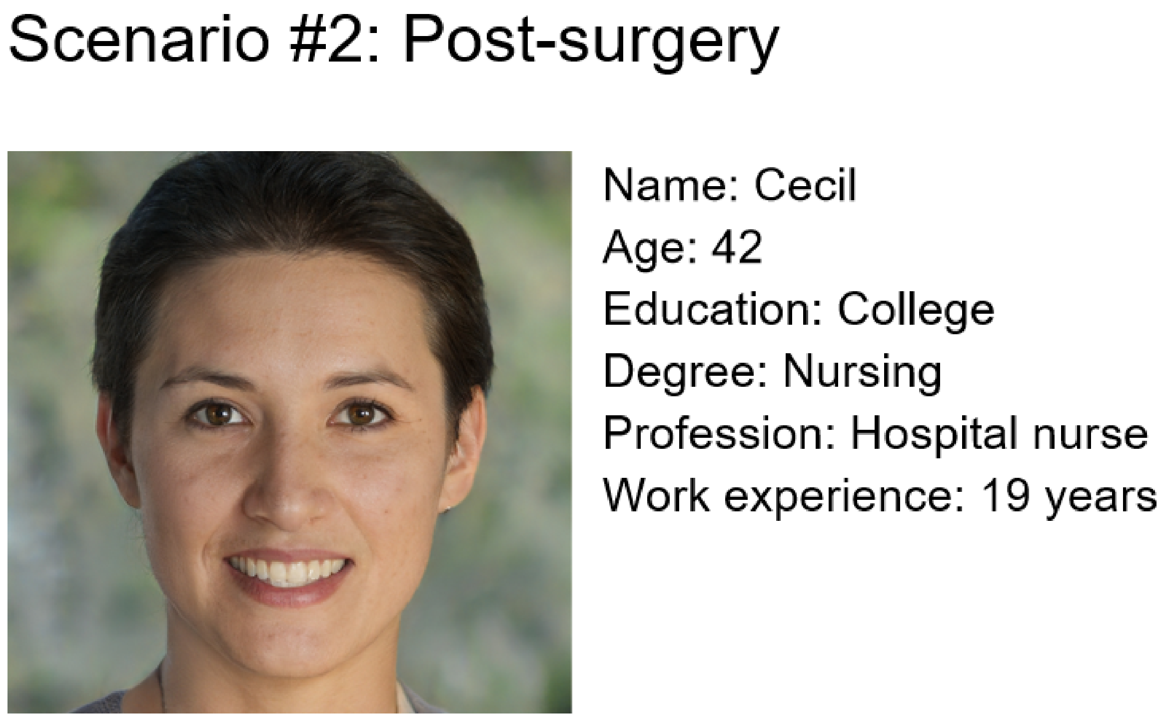

Figure 3.3: Persona 2: Cecil

Cecil has many patients which she cares for during the day. She is quite an experienced nurse and works in the department of surgery. Cecil has had quite some experiences with sepsis and multiple of her patients have died as a result of it over the years. Though most of the patients contracting sepsis are elderly and newborn babies, one of the patients that she lost through the disease was a 21 year old woman that died after a common surgery. As a result the hospital has recently bought a sepsis rapid test machine. This machine can determine the presence of sepsis in a patient through a blood sample.

One of her patients, Michael, has had a surgery on his knee. Michael is 26 years old and has had a chronic condition in his knee that could only be helped by surgery. The surgeon said the operation did not go as smoothly as they had planned, and he might need additional days in the hospital to rest. Since the surgery was messy, Cecil draws a blood sample from the patient to run some tests. One of these tests is the sepsis rapid test, the hospital has mandated this as a precaution measure for surgeries that did not go well. Sepsis is a disease that is rooted in an immune response to an infection, this infection can be caused by the surgery. Normally, the presence of sepsis is determined by qSOFA, an analysis of symptoms. However, in young people the symptoms are not always apparent and as such sepsis can occur without the hospital staff noticing it.

The rapid test machine is located in the emergency department as the rate of patients with sepsis is highest there. Cecil hands the blood sample over to an analyst working at the hospital who performs the measurement using the machine. Cecil returns back to her department as the analyst has a busy schedule and her measurement will take place at a later time. After 30 minutes she gets a call from the emergency department stating that the machine has measured a category 2: Systemic inflammation stage I. This means that the patient has gotten an infection from the surgery, but is not yet suffering from sepsis. Nevertheless, this is a very important signal and the patient must be closely monitored in the coming hours, testing his samples as time progresses. If the situation worsens, antibiotics will be applied to the patient.

Scenario 3: hospital analyst

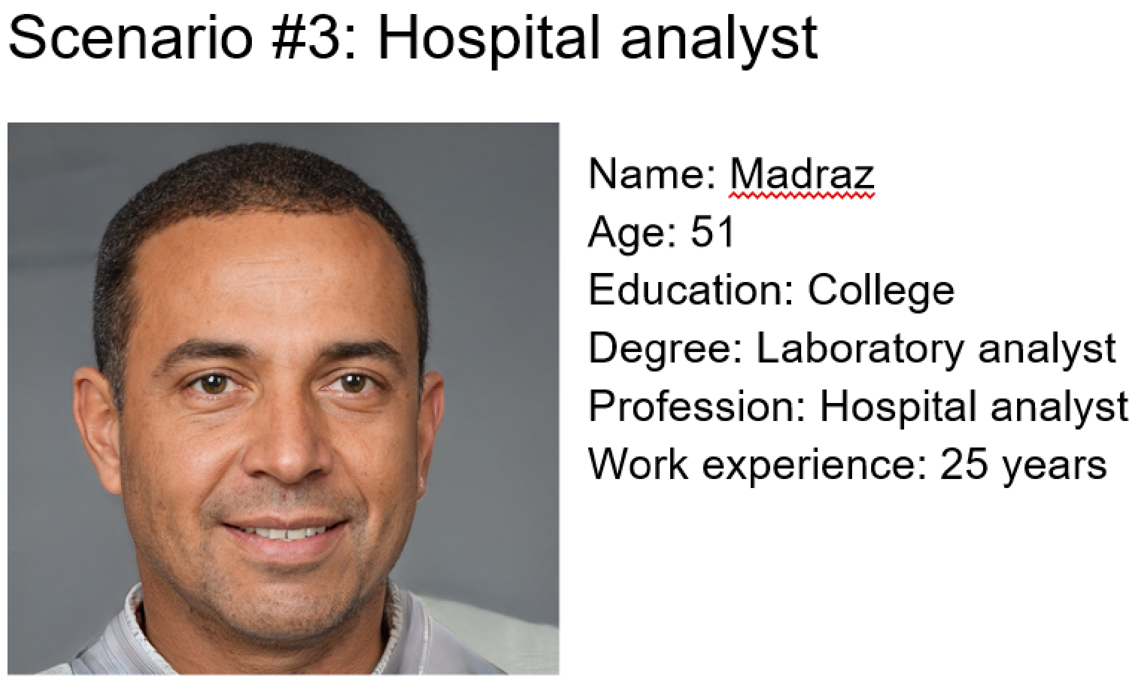

Figure 3.4: Persona 3: Madraz

Madraz works at a large hospital. He processes the samples of patients given by the nurses. One of his duties is to test for sepsis in patients using a rapid testing machine. This machine uses regenerative chips that can last for about 200 tests. The machine displays the health of the chip and signals when the chip needs to be replaced. Today the machine signals that the chip can no longer be reliably used and should be replaced. The machine comes with a protocol for replacing its chips. First Madraz is to remove the old chip from the machine. Madraz takes a new chip from storage and puts it in its designated slot. The machine further aligns the chip automatically. Occasionally, the chip needs to be readjusted, the machine signals when this is the case.

The machine recognizes that a new chip has been inserted and asks to start the calibration protocol. The machine tells Madraz to connect the fluidic system for the calibration. The machine first needs to prime all the fluidics, this takes about 5 minutes. After everything is set up the machine automatically goes through all the samples it uses to calibrate itself and washes the chip afterwards.

While the machine is going through its protocol, Madraz keeps a close eye on the measurements, although the process is automatic, it is always good to look at the data the machine is putting out. Everything seems to be alright though. Madraz switches the fluidics system back to the sample testing mode and starts a new measurement.

Scenario 4: Elderly home nurse

Figure 3.5: Persona 4: Mark

Mark works at an elderly home, he has been doing so for 11 years. During his time he has seen people come and go, at an elderly home death is a common occurrence. A significant amount of the elderly die of sepsis. It is for that reason that mark was happy to hear that the nursing homes in his area have collectively bought a sepsis rapid test machine. Though the machine is not at his nursing home, it takes about 15 minutes to go back and forth to the location where they do have one. Normally when Mark suspects something is wrong with one of the inhabitants he refers them to the hospital, Mark does not have the right equipment to accurately determine the cause of the symptoms the elderly have. However, Mark cannot send someone to the hospital for every minor thing, the elderly have issues with their health regularly.

Nowadays Mark takes a blood sample from one of the elderly the moment he sees they are having a bad day. He collects all samples he takes in the morning and goes by the testing location before lunch. Sepsis can be lethal within 6 hours. The machine is already prepared for testing as during this time all the elderly homes in the area test their samples. The testing of the samples takes about 5 minutes per 5 samples, they can be tested in parallel. Mark usually spends about 20 minutes at the other nursing home before returning to help with lunch.

Whenever one of the test results suggests any other outcome than healthy, Mark refers that person to the hospital immediately. Elderly have weaker immune systems and will develop sepsis commonly when they have an infection. More than most, Mark values the peace of mind that he no longer has to make the difficult decision of deciding whether someone should go to the hospital or not.

3.5 Product requirements

The target group might expect a significant amount of features and attributes from the product. Though these wishes are a good basis upon which to base the requirements of the product, they still need some refinement. Some features that the user might want in the product are simply not feasible and therefore can not be implemented. Other features might not actually be desirable and should not be implemented. The user does not have the same expertise as the designer and as such may not understand the negative consequences of a certain feature or attribute. Additionally, some requirements may be derived by the designer themselves. Either through methods in the field of UX-design or technological knowledge on the subject.

A common method in categorizing and prioritizing requirements is the MoSCoW method. In this method the designer identifies Must haves (Mo), Should haves (S), Could haves (Co) and Wont haves (W). Must haves are things that form the core of the product, if any of these requirements are missing in the final product, the product will most likely not be successful. Should haves are features that should be implemented in the product if possible, they are expected to be beneficial to the product. Could haves are features that either have a low priority or are only potentially beneficial to the product. Whereas wont haves are features that are either not possible, not efficient or not beneficial to the product. The MoSCoW list functions as a foundation of the ideation process. [29]

The product must:

- Autonomously diagnose sepsis reliably (>90%)
- Detect sepsis in less than an hour
- Be affordable for a nursing home
- Have an integrated fluidics system
- Have a collection tray upon which samples can be placed
- Minimize room for error by the user

The product should:

- Autonomously diagnose sepsis reliably (>99%)
- Give a confidence rating in its diagnosis
- Detect sepsis in less than 20 minutes
- Indicate the severity of sepsis (classified in 5 levels of severity)
- Have an API that can be connected to an institution's information management system
- Be able to test multiple samples in parallel (2-4)
- Be indifferent on its environment (temperature and moisture)
- Need minimal regular maintenance on fluidics an chemical materials.
- To process raw blood samples (by automatic filtration)
- Automatically align the photonic chip
- Be able to perform maintenance on the photonic chip automatically
- Be intuitive to use
- Not require significant background knowledge on biochemistry to be operated
- Have a low cost per test

The product could:

- Have a build-in re-calibration protocol
- Have a debugging system for errors to be used by users
- Have a fluidics system integrated in the photonic chip
- Have a regenerative chip
- Have a chemical materials package that can be ordered by the user
- Display the care the must be applied to the patient for the specific severity of sepsis

The product wont:

- Detect the origin of the Sepsis
- Be a total replacement of assessment from medical staff

3.6 Product ideation

The product ideation was a team effort. The nursing department gave us insight into what the users might need from the prototype, whereas the technical department defined the limitations of our approach. The business department and I were most involved with the ideation of the product. The initial idea of how the product would physically look like was based on the appearance the Delta prototype that the technical department was working with. We intended to make a desktop version that would be similar to the prototype and making it significantly more automated and user friendly. Essentially we envisioned a black box wherein the photonic chip could be inserted and the to be tested samples and supporting chemicals could be attached. With little expertise in the field of bio-sensing it we had as a team it was rather difficult to make the product more specific at this stage.

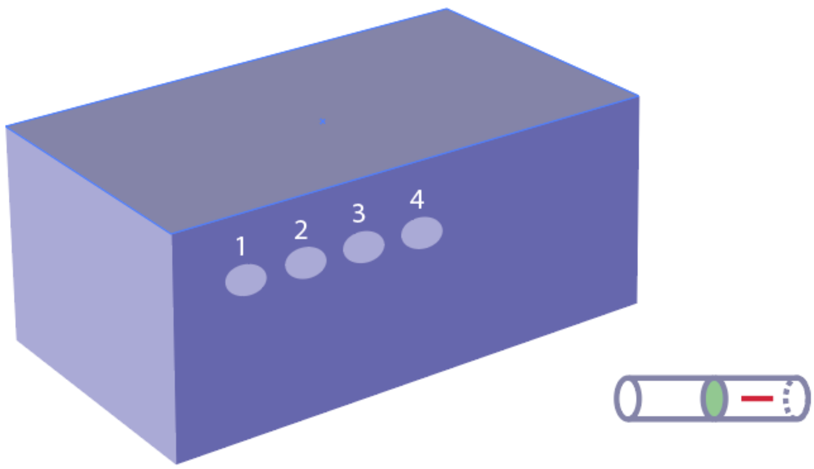

Figure 3.6: Rough initial concept of product

To gain more insight into the challenge we conducted interviews with industry partners provided to us through the SensUs competition. In particular in an interview with the CTO of Micronit we discussed a flaw with our implementation of the blood filtering. They stated that a blood filter will be hard to clean and that it might be better to use a disposable filter. During this interview I came up with a vial that has two open sides and a filter in the middle. One side of the vial would be used to contain the blood sample whilst the other side would be put into a slot in the instrument. The vial would be disposable and as such, the blood filter would not need to be cleaned. Changes like this would be commonplace if this product would ever be realized, our team simply does not have the expertise to go further than a general concept. Which is not a problem for the SensUs competition or this thesis. It is most important is that it is known what the product will do and to have a rough idea on how certain tasks are performed, the technical details are of less significance.

3.6.1 Use case

Walking through a concept from the perspective of the user in detail provides rich information on how someone interacting with the product will experience the design. Especially features that are easily overlooked from the perspective of the designer can be uncovered with this method. For example, the designer might determine that the user must perform a certain action, but the user is never told by the interface to do so. A use case is still an exploratory tool and is subject to change in further stages of the design, but is useful in evaluating the early concepts of a product.

Use case 1: sample measurement

At the start of a measurement, a blood sample is taken from a patient, its volume is small (5ml), but very precise. The blood sample does not have to be processed, though it does have to be put into a specific vial. The vial has a top that can be screwed on one of the slots of the fluidics system.

When the user would like to start the measurement, they press the 'start sample measurement' button. Before starting the instrument verifies that there is indeed a sample of about 5ml in the sample vial and that the fluidics system is closed. The instrument proceeds to add some fluid to the blood sample, after which the tubing is primed with the sample. After about 2 minutes, the actual measurement starts, this happens automatically. The user can monitor the progress of the measurement through the data plots and the status panels. The terminal present in the interface displays any errors that may come up and updates the user on which process is being executed at any given moment. Additionally there is a progress bar which displays the entire protocol that is to be done and communicates to the user that the program is still running.

In about 5 minutes, the instrument is done testing the sample. It returns the classification of sepsis in the patient to the user and gives a confidence it has in its measurement. This confidence is determined by the health of the chip (it is re-used between measurements) and the fluctuations in temperature. Furthermore, the machine tests for anomalies in the measurement and communicates any that come up to the user. After having received the classification and its confidence, the user verifies that this information is correct in the machine. In the background the machine communicates the result to the digital patient system of the institution. The user knows what to do with the classification and takes the actions needed.

Use case 2: sample measurement version 2

To start a measurement the user pulls the patients they are measuring for from the management system. The user loads this patient into one of the queues and starts the measurement. Beforehand, a blood sample is taken from a patient, its volume is small (5ml). The user puts the sample in the collection tray corresponding to the number that is shown on the screen and lights up on the instrument.

The instrument verifies that there is indeed a sample of about 5ml in the sample vial and that the fluidics system is closed. The instrument proceeds to filter the blood sample and purify it for the measurement, after which the tubing is primed with the filtered sample. After about 2 minutes, the actual measurement starts, this happens automatically. The user is informed on the duration that the measurement will take and can focus on other tasks in the meantime (15-30 minutes). If anything comes up during measurement (an error of some kind) the machine will give an audible signal and if possible alarms the user through their pager.

When the measurement is done it will display the result of the measurement, both categorized and the exact value. In addition, the instrument will display the confidence it has in the measurement, if too low the measurement might need to be repeated. A lower confidence might be determined through anomalies in the measurement or a poor chip signal. The user can accept the measurement after which it is added to the patient's digital file in the management system.

The user knows what to do with the result and provides care for the patient.

3.6.2 Edge cases

The use case resembles the workflow of typical use. However, there are cases where the situation is atypical. Though these edge cases are usually not desirable, they must be accommodated for in the design as they can't be entirely avoided. It is important that the product keeps working if such an edge cases arises and that the user is provided the necessary tools to fix the problem.

Edge case 1: anomaly in measurement

After the measurement is finished, the machine gives a warning in a pop-up screen. "an anomaly has been detected, please refer to the data plot and repeat the measurement if necessary". The user looks at the data plot. There is indeed something strange going on in the data, the control measurement has a high response at a certain point in the measurement.

The user walks through the following steps respectively to fix the problem.

1. The user repeats the measurement with a new sample from the same patient.
2. The user starts the deep cleaning protocol, proceeds with 1.
3. If after 1. and 2. the anomaly persists, the user switches out the chip with the chip replacing protocol, proceeds with the calibration protocol. If the chip seems fine after calibration the user will proceed with 2. and 1.
4. If possible a lab worker will be asked to manually clean the setup and refresh the chemicals, return to 2. and 1.
5. If none of the above possibilities work, the supplier will be contacted. The results are not reliable and the actions to be taken are at the discretion of the user.

3.7 Summary

Sepsis is currently diagnosed through the symptoms of the patient. The biggest selling point of our product is that it will be able to test for asymptomatic sepsis. This means that patients can be cared for in an earlier stage of the disease which decreases the damage done to the patient. Through the interviews with medical staff performed by the team, we have concluded that our target group will be nursing homes, as elderly are far more likely to suffer from sepsis than younger people. A context of use analysis is performed using 4 personas and two use case scenarios. These have provided a more detailed set of assumptions on the user and their needs. Through this process a MoSCoW list has been established, where the features of the hypothetical product are categorized on importance. The hypothetical product itself is created in this chapter and made more concrete as to clarify what the interface needs to account for. The research performed in this chapter functions as a basis on which the user interface can be based on.

Chapter 4

Specification

4.1 Exploratory Prototyping

In this chapter the requirements set up in chapter three are used to define the user interface. The specification functions as a blueprint upon which the final design will be based. In this project an early prototype is used to convey the general idea of the product that is to be made. The initial prototype is a fast prototype that lacks detail. Its aim is to try out the main ideas of the designer in a practical setting. Not only will the designer face certain problems in the creation of the design, the initial prototype will function as a conversation starter with the client. This prototype reflects the main ideas of the designer on the project and defines the features that are at the core of the design.

4.2 User interface requirements

The hypothetical product (HP) has been established in chapter 3. The interface must accommodate for all the features and functionalities of this product. However, the interface is not only the sum of features in the HP. In addition, the interface needs to facilitate the user in navigating through these features and provide the communication between the user and the machine. Moreover, the interface must accommodate for edge cases in usage of the machine and must provide a pleasant and efficient workflow to the user.

For the interface the MoSCoW [29] method is used again, but in relation to design heuristics established in chapter 2.

The product must:

- First and foremost, prevent errors made by the user by minimizing the room for error on the users side.
- Show its current task at all times.
- Be consistent throughout the entire interface.
- Inform the user of the consequences of the actions they will take (where consequences are significant).
- Provide the information on its usage to the user, such that a user unfamiliar with the machine will be able to use it.

The product should:

- Provide the user with an estimation on how long tasks will take.
- Be of a minimalist design, each component in the interface must be of significance to the user experience.
- Provide information on the task of the user where possible, as to reduce memory load.
- Give the user information on the steps needed to perform a task and communicate to the user once a step or task is completed.

- Allow the user to undo their actions where possible. This allows the user to recover from errors they made.
- Provide the appropriate language so that the user understands the information provided by the machine. In this case special care must be taken to minimize the technical terms that would be known to an medical analyst, but not a member of the general nursing staff.

The product could:

- Have its aspects reflect the real world to conform user expectations
- Make sure the user feels like they are in control. Though at some points the machine should take a leading role in certain processes.

The product wont:

- Be flexible, the interface is designed to be a closed workflow that can not be altered

In short, the interface must be accessible to users that are unfamiliar with biochemistry and minimize any errors as they could have large consequences.

4.3 Product functionality

Having an expert interview with a fellow designer requires a much less refined prototype than an interview with the target group. A designer will understand how certain functionalities will work together and which thing are er fidelity prototypes, though later on these prototypes will become more detailed. The final user interface will not need to be fully functional, it is merely a demonstration of a hypothetical product that is still subject to change. The most important aspect it must show is the workflow of the operator. A detailed demonstration of the workflow will make the biosensor concept more concrete, which is the goal of this interface.

4.4 Styling

The general aesthetic of the overall design is inspired by the UI of Endless space 2. Though this is a video game, its minimalist style fits well with the project. The style consists of a blue tinted gradient background with a gold beige body. The style uses thin stripes as borders and darkened blurred overlays as fill.

Figure 4.1: UI menu in Endless space 2

4.5 Initial prototype

The initial prototype is build with the idea of a PC monitor being connected to the instrument as one would have on a laboratory. At this point in the design process the consensus was that the data was going to be important. With not much else to go on but the Delta prototype the primary objective of this interface is to incorporate the functionalities of the functionalities of the Delta prototype and to accurately show the data. There was actually a significant amount of time put into the theory of displaying such data. However, as the focus of the project shifted away from data visualization this piece of research has been moved to the appendix.

4.5.1 Interface

This version consists of 5 main components:

- A data visualization of the measurement (left top)
- A terminal which logs all the actions taken by the machine (left bottom)
- A set of buttons (middle bottom)
- The "measurement screen" which communicates the progress of the measurement and the result (right bottom)
- A sample selection screen in which patients can be selected and coupled to a sample (right top)

With the use of a desktop format there is enough space on the screen to implement most of the features on just one screen, as compared to having to go through different menus to perform a certain task. Ideally, the tasks that are most common should be able to be performed with as little interactions as possible.

Figure 4.2: Home screen

The image above is the "home screen", from there the operator can interact with the sample selection. In the sample selections two types of patients are available, patients that have previously been measured and patients that are currently in the queue to be measured. The operator can add new patients to the queue through interaction with the institutions information management system (IIMF) and remove patients from the queue if no longer needed.

Figure 4.3: Legacy test selected

To start a new testing sequence the operator selects one of the patients that is in the queue and the machine waits for a sample to be administered to the instrument. When the operator supplies said sample the machine will automatically start the protocol to test a sample by first filtering the blood. The progress of this step is communicated to the user by having the red fill of the ring slowly fade, in addition to showing the absolute value. The fill of the ring becoming less red reflects the blood plasma being filtered from the red blood cells (3rd heuristic).

Figure 4.4: Start of new measurement

During the measurement the operator can keep an eye on the raw data being displayed. The ring signal in the measurement tab communicates how good the signal from the photonic chip is and is calibrated in such a way that any signal above 1 is good, anything below zero is reason to be alarmed. To strengthen the signal the operator can use the buttons in the center to wash the chip or otherwise remove the chip from the setup and replace it with another chip.

Figure 4.5: End of measurement

4.5.2 Feedback

With the method of iterative design in mind, this specification prototype has been evaluated with both the supervisor and the client of this thesis. Both had interesting remarks on the choices that were made in this interface. First of all, the data being visual at all times had been questioned. As this is an end-user application the data itself is probably less important. Furthermore, having such a big part of the screen occupied with a terminal is disproportionate. The choice to use a desktop monitor format was questioned, would a point of care product not work better on a tablet or something similar?

4.5.3 Conclusion

The main take from the evaluation of this prototype is that it is still too close to being an interface that would be used by a researcher. End-users have different needs and need an application that is more focused on the results than on the data. In short, the interface must be less complex with a focus on the workflow of who would be using it.

Chapter 5

Realization

5.1 Iterative design

The specification in chapter 4 is based mainly on assumptions made on the target group. The initial prototype that followed is therefore not tested with reality. Through user tests and consultations with experts, needs of the target group and flaws of the initial prototype are discovered. Intermittent evaluations of the prototype help the target group and the designer communicate, not all problems can be foreseen initially. If at this point in the design process the target group disagrees with feature in the prototype, the problem can be addressed before significant work is put into realizing said feature. However, this does mean that the initial plan stated in the specification is deviated from.

5.2 Tablet interface

This interface is an iteration on the initial prototype. The feedback on the first prototype suggested that the interface must be more suitable to end users. As such, this prototype is significantly different from the initial prototype. This iteration uses a touch screen and is in tablet format, as such is it named the tablet interface. Whether the prototype will be used on an actual tablet or a screen integrated into the machine is uncertain, both options should be possible. A large difference in this prototype is that the functionalities that were all accessible on the same screen in the initial prototype are now divided between menus. This choice stems both from the reduction in screen space and the fact that the workflow can be better defined with this method. When functionalities are only accessible through other buttons it is easier to create a well defined workflow that can not be deviated from. With removing the data from the view of the end user and putting it in a specialized tab, the user is not unnecessary confused with the information. In this prototype it is assumed that the machine will check for faulty measurements and that the user can always relatively blindly trust the result given by the machine.

5.2.1 Use case

The workflow in this prototype consists of small steps with a specific order. A test starts with drawing a blood sample from the patient. A user working the machine has the samples they want to test neatly organized next to the machine. At the start of use the user adds all the patients from the institutions information management system (IIMS) to the machine. The user then chooses the batches they want to test. For example, if 12 samples are to be tested, they can be done in 3 batches of 4. After having added the patients and putting them in the right queue, the queues can be loaded in. When the user goes to the measurement tab they can see all the loaded in queues and can decide in which order these queues are to be tested. When a queue starts testing the user gets prompted to add the samples and once received the machine starts the testing protocol. During this protocol the user cannot leave the testing screen unless they abort the test. Once the results are available and the protocol is finished, the user can start a new test.

5.2.2 Interface

When the device is powered on the interface opens with a start screen. When the area within the button is pressed the circle will expand outwards and the screen will transition to the 'home screen'. The start screen can also be used as a standby screen for when the machine is not being actively operated, but is powered on.

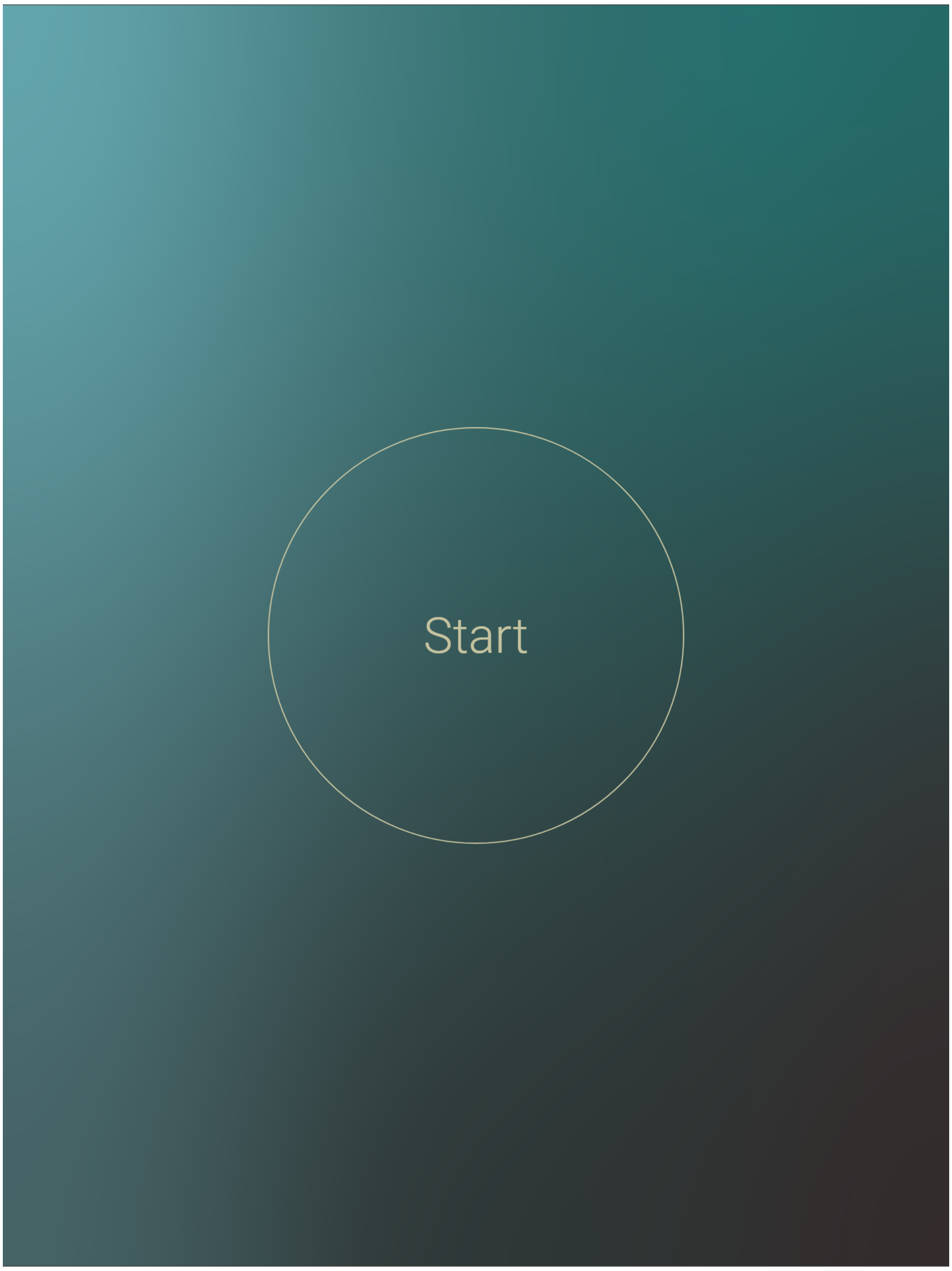

Figure 5.1: Start screen

The interface has a header and a footer that stay consistent throughout the interface. The header consists of button that controls the fluidic system and on the left side has space for a back or abort button, where appropriate. The current date is displayed in the header as well, as it might be convenient for any administrative tasks. In the footer the status of the system is displayed, if the system is functioning normally the status will display nominal in green. If the system is experiencing any bugs or failures it will display an error message with a number. The operator can call the help desk of the product who will provide instructions on how to solve the error. If the error can not be solved by the operator, a maintenance worker will be send to the machine to fix it. The maintenance button is meant for these situations. In the maintenance tab one can find the information needed to solve the problem with the machine. The daily results button brings the operator to the log of all the measurements that were performed that day.

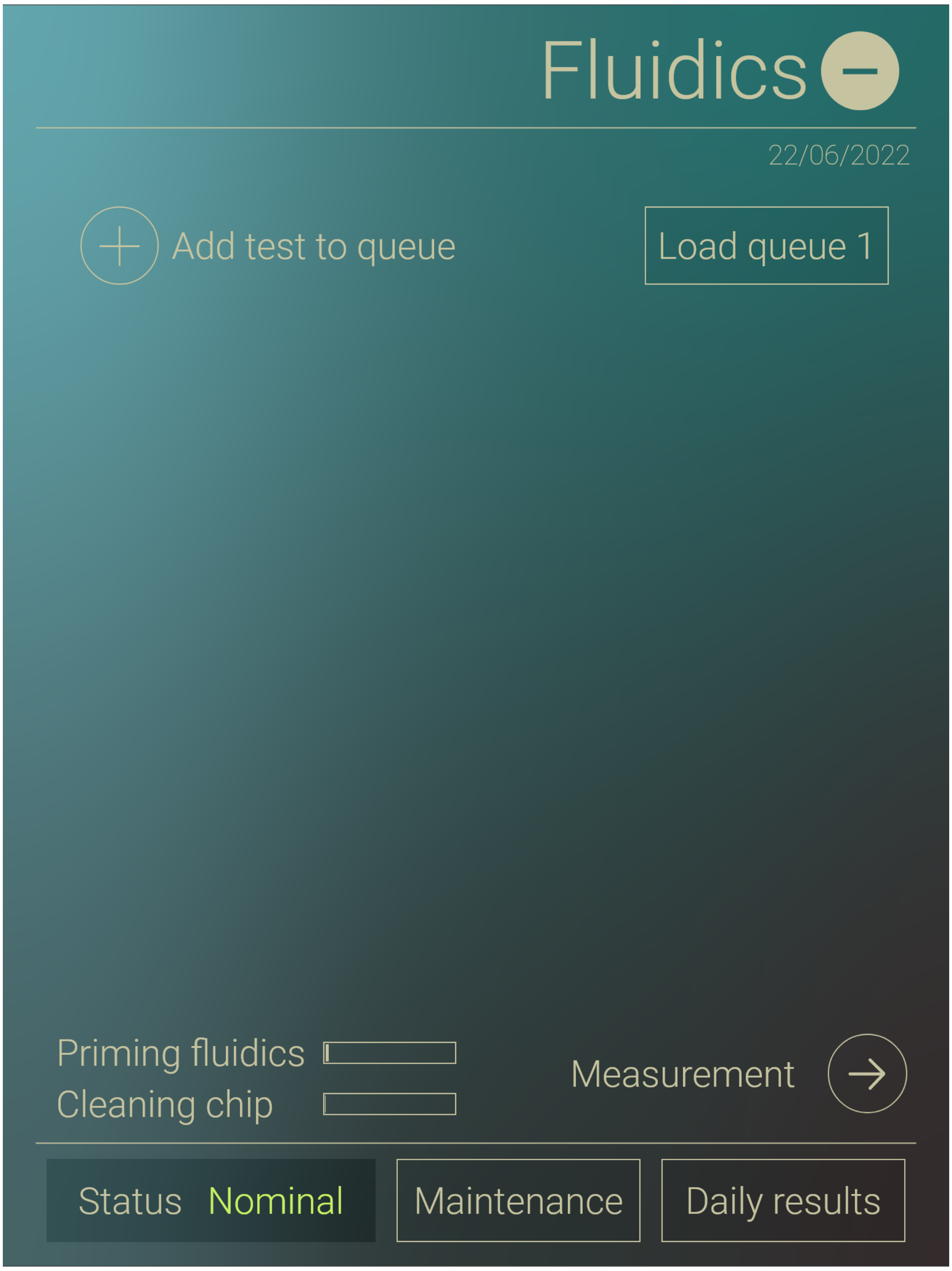

Figure 5.2: Home screen

In the left bottom of the screen the interface communicates the progress on certain actions that need to be performed before measurements can begin. These actions are only performed when the machine has just started up. Although measurements cannot start before these actions are done, it is useful for the operator to have access to the planning part of the software prior to the machine being fully operational. From the home screen the operator has 3 different actions that can be performed. They can either add a patient from the database, move selected patients to the measurement queue and go towards said measurement queue. However, if there are no patients selected they cant be moved and if there's no measurements are queued there is no data to display. These cases of illogical use by the operator are incorporated into the design.

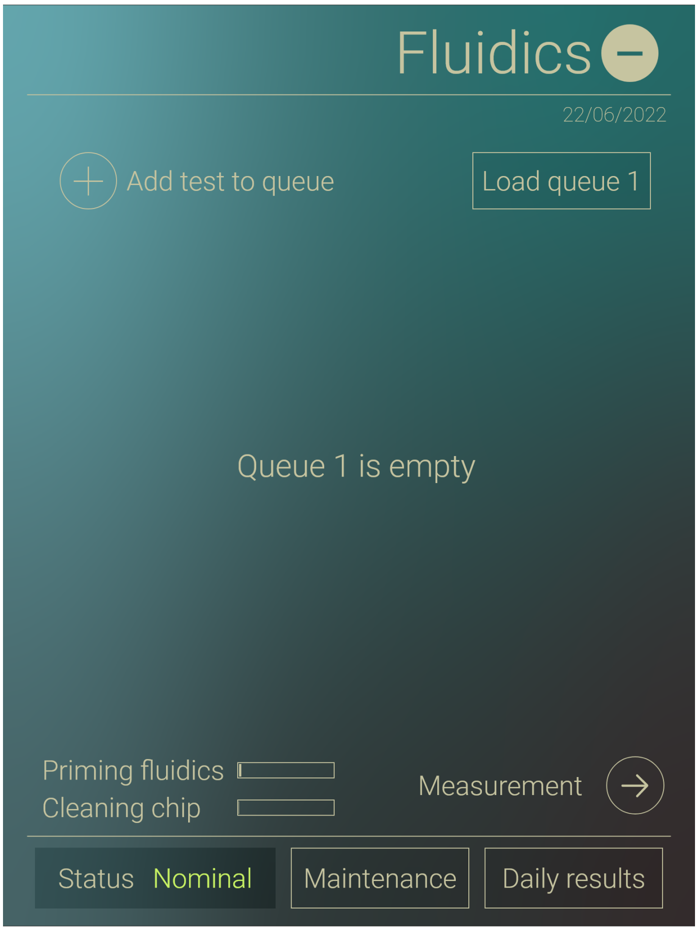

Figure 5.3: Load queue cannot be performed as no patients are selected

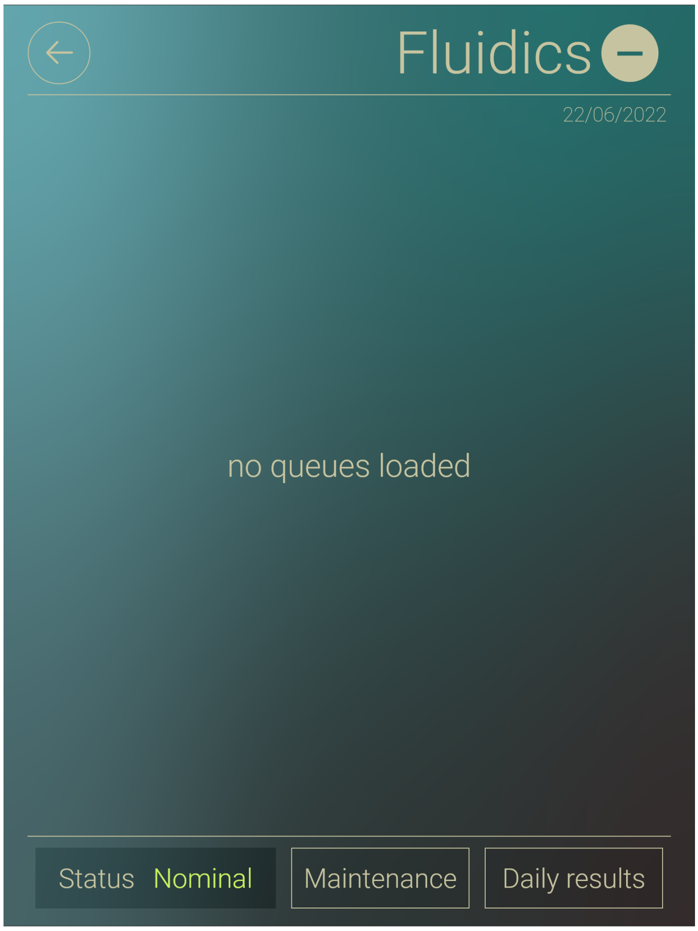

Figure 5.4: The measurement queue is empty, a queue must be loaded in first

If the workflow of the system is correctly followed, the operator will first load new patients from the IIMS. Up to four patients can be loaded into a single queue as the product can only do four measurements at once.

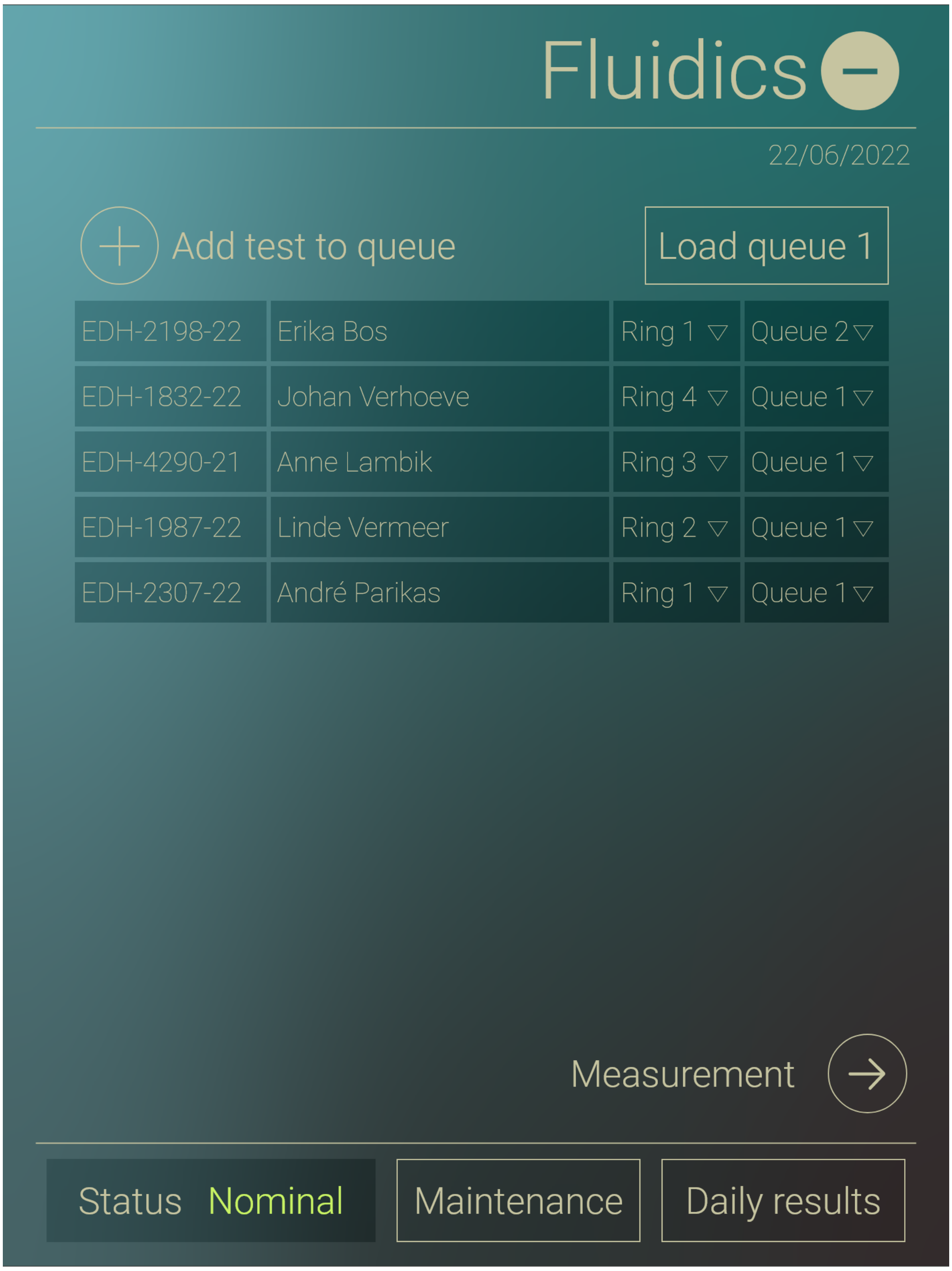

Figure 5.5: Five patients loaded in

Once the patients are loaded in and are selected to be in the first queue, the operator can make it a measurement by pressing the load queue 1 button. From there the operator will be taken to the measurement queue automatically to start said measurement. In this screen multiple measurements can loaded in and started when needed. However, once one measurement is running, another measurement cannot be started. A measurement that is in the queue can either be started or unloaded, with the latter option the patients loaded back into the home screen.

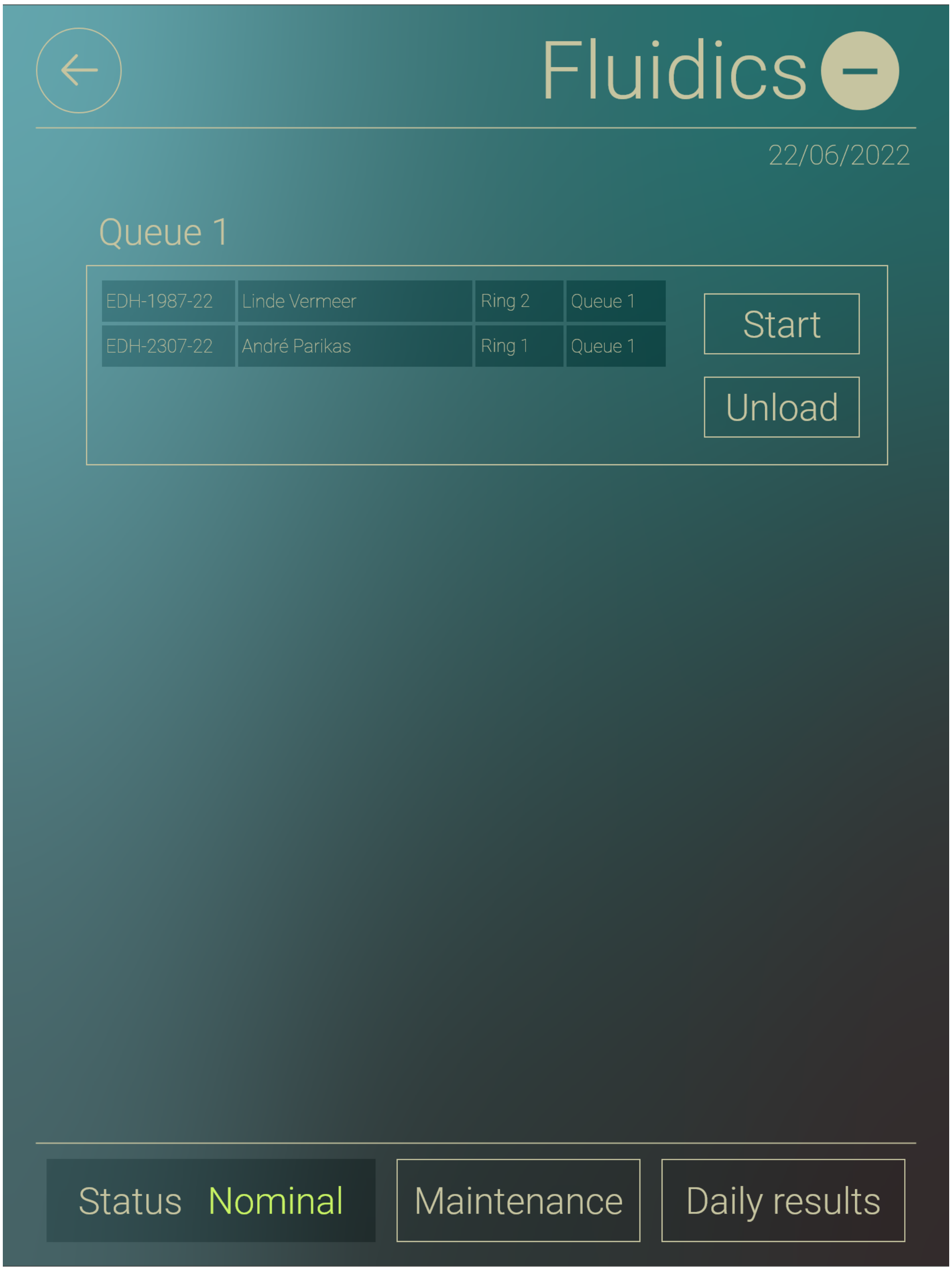

Figure 5.6: Measurement queue with one measurement

In the case that is shown through the figures only two patients are put into the measurement. If this measurement is started the operator faces a screen with an instruction. This is the point in the measurement where the samples of the patients have to be put into the machine. As the machine itself has no way of validating that the correct sample has been added, the interface puts extra effort in making it clear which patient needs to be put at which location. The machine recognizes if a sample is added and will automatically move on to the next sample, as such the big circle in the middle of the screen in the next figure is not a button.

Figure 5.7: Add sample one

Figure 5.8: Add sample two

After the samples have been added to the machine the testing of the samples can start. During testing it is not possible to go back to the home screen, as it is important the results are seen immediately. The active testing screen shows up to 4 measurements being conducted. Each measurement has a progress bar and an estimated time till completion. Furthermore, the individuals steps are displayed as well as the completion of that step in a percentage. The result will not be shown until the machine is finished measuring the sample, but will be shown before the machine is finished cleaning the channel. A result that indicates sepsis will be marked in red, an inflammation in orange and with no sepsis the result will be green. The strength of the signal is displayed for the same reason as the initial prototype.

Figure 5.9: Measurement has just started

Figure 5.10: Measurement is halfway

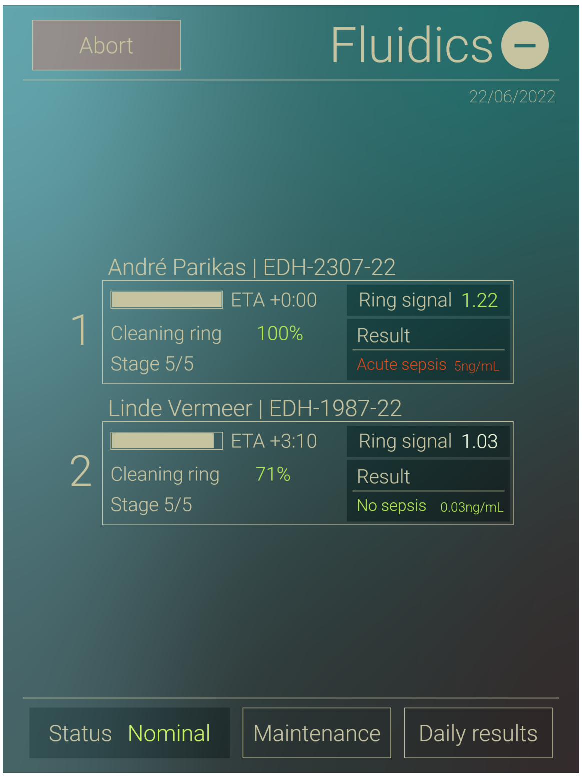

Figure 5.11: Measurement has almost finished, the result are already displayed while the chip is being cleaned for its next use

5.3 Expert/user interviews

To validate the approach and implementations of the design two representatives of the target group and a product application specialist have been consulted to discuss the design and provide feedback. The validation took place in two separate interviews, both of which were online. The first interview consisted of an apprentice hospital analyst, a nurse on the acute care department, my partner who took minutes and me the interviewer. Whilst the second interview was just between the product application specialist and myself. The interviews were semi-structured and consisted of a small briefing, a demonstration of the prototype(s) and a debriefing. The interviewees were encouraged to interrupt to ask for clarification or to give their views.

5.3.1 Analyst/Nurse

The interviewees are acquaintances of mine of which I knew they worked with sepsis. Maarten Burggraaf (M) is a friend of mine that was doing an apprenticeship in the field of microbiology. A subject within his apprenticeship is sepsis, which he has analyzed for his project. His mother, Elisabeth Burggraaf (E) is a nurse at the acute care department of the academic medical centre in Amsterdam, a large hospital. The interview left room for other observations next to feedback to the product, as understanding the context of the target group is important as well. The interview has been processed after it has been conducted to make it a coherent story.

In this interview both the initial prototype and the tablet prototype are demonstrated. As these interviewees are acquaintances of mine, comparing between interfaces might provide more objective results than feedback on only one prototype. The interview consists of a briefing with a few questions before the prototype is shown, as not to bias their answers. After a demonstration of the prototypes an interview is conducted on the specifics of the prototypes. During the interview itself the prototypes have been revisited on multiple occasions.

Though not specified which prototype is newer to the interviewees, in most questions, the tablet interface was generally preferred. Especially the minimalist look and the simpleness of the interaction in the tablet interface were appreciated. Though it should be noted that the interface had been explained throughout the demonstration. An important flaw in the prototype had been discovered by one of the interviewees, as there was currently no warning that the fluids in the system are running low. Both interviewees put emphasis on the importance of knowing what the machine is doing and that it is pleasant to see how long tasks will take. The need of knowing what kind of infection is causing the sepsis has been expressed in the interview as well. However, this project is limited to only the detection of sepsis.

At the end of the interview a few questions where asked on a Likert scale to evaluate the prototype.

Question	M: Initial interface	M: Tablet interface
Information availability?	4	3
I would use this product if available?	3	3
I think the product is safe?	4	5
Is the product aesthetically pleasing?	4	5
	E: Initial interface	E: Tablet interface
	4	3
	5	5
	4	5
	4	5

Figure 5.12: Result of Likert scale questions

For the interview, see appendix A.

5.3.2 Product Application analyst

As previously stated, the team is using a prototype from Delta Diagnostics to do their testing for the analytical performance reward. Through a professor at Saxion I had gotten the contact information of Ruben van Harmelen, the product application specialist at Delta Diagnostics. I have asked Ruben various questions regarding the prototype and the method of using MRRs to detect bio markers such as IL-6. As Ruben is close to the product that Delta Diagnostics is developing themselves he seemed as a good candidate for an expert interview on the prototype. In the interview with Ruben, only the tablet interface has been evaluated.

For this interview two extra screens had been prepared regarding troubleshooting as I wanted to evaluate my approach to solving the edge cases of the product.

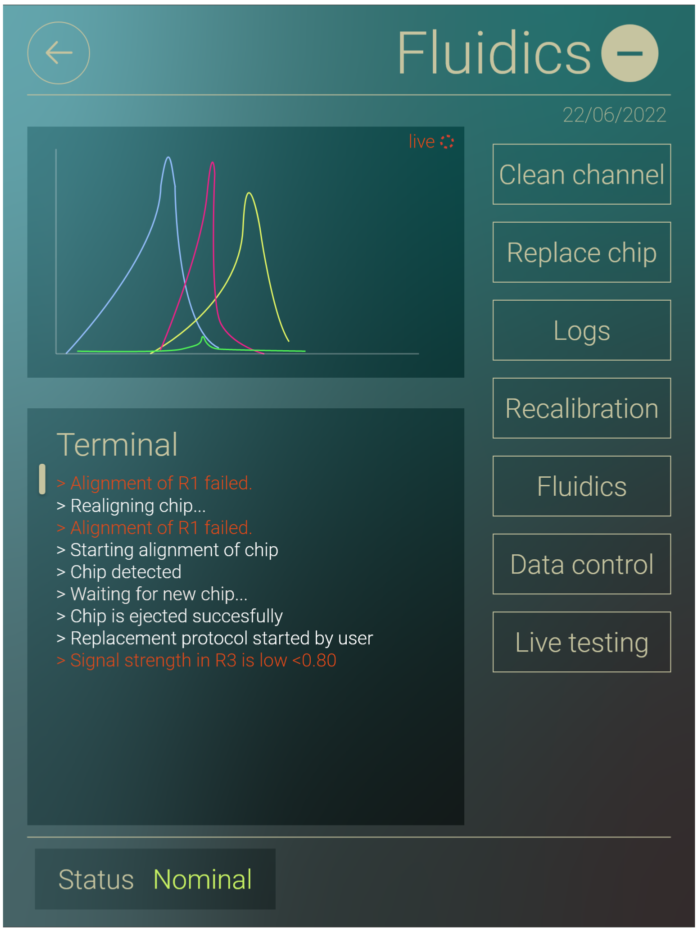

Figure 5.13: Maintenance interface

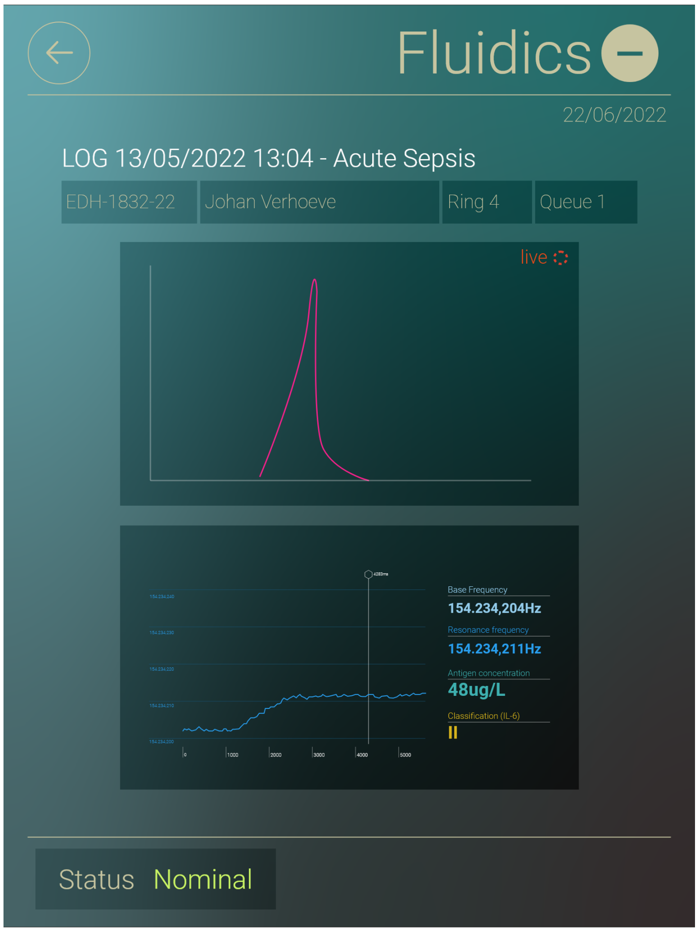

Figure 5.14: Log of specific measurement

This interview has only been conducted after the demonstration of only the tablet prototype. The first impressions where that the interface is aesthetically pleasing, simple and organized, though the interface was not intuitive. Especially the order that the buttons and features of the interface had to be used in was unclear. The interviewee did like the progress bars, but warned that the status bar was too limited. It should be clear what the machine is doing at each moment.

Another point of conversation was on the user friendliness of the product, or rather the room for error. The interviewee suggested that the user should not be in control of the fluidics button, the fluidics can be controlled by the system. Additionally, the question arose on what happens if the chip is physically removed by force, without pressing the release button in the interface. With regard to the maintenance of the product the interviewee agreed that a dedicated technician for this product is a good idea. However, there should be a troubleshooting screen for the user as well. With regard to the maintenance itself, the interviewee stated that there should be a feature that can check for the alignment of the chip. In the end the question was asked if this prototype would potentially be used as inspiration for when they would make a point of care product. The interviewee responded that they would definitely look back at this prototype, as it was well thought out.

For the interview, see appendix B.

5.4 Final prototype

With the feedback from both the target user group and an expert the tablet interface has been iterated upon once again. This new version is similar to the tablet interface. However, in this version the channels are more modular and can be used independently of each other. In the final version the shortcomings of the tablet version that came to light through the interviews are tended to. Special focus is put on making this version more intuitive. This is achieved by both refining the workflow and by using visual communication push the user in the right directions. In this version the heuristics from chapter two will be related to the design to give a more detailed insight into the considerations that were made (x. heuristic). The prototype uses a color palette of teal, beige, white, green and red. Here teal is the background color with beige as the primary color, these two form the basis of the interface. White is a secondary color that is used to bring attention of the user to that part of the screen. Green and red are accent colors; green symbolizes that something is okay and red symbolizes that something is going wrong or needs immediate attention (3. match). The green that is used is a softer color than the red that is used to match their importance.

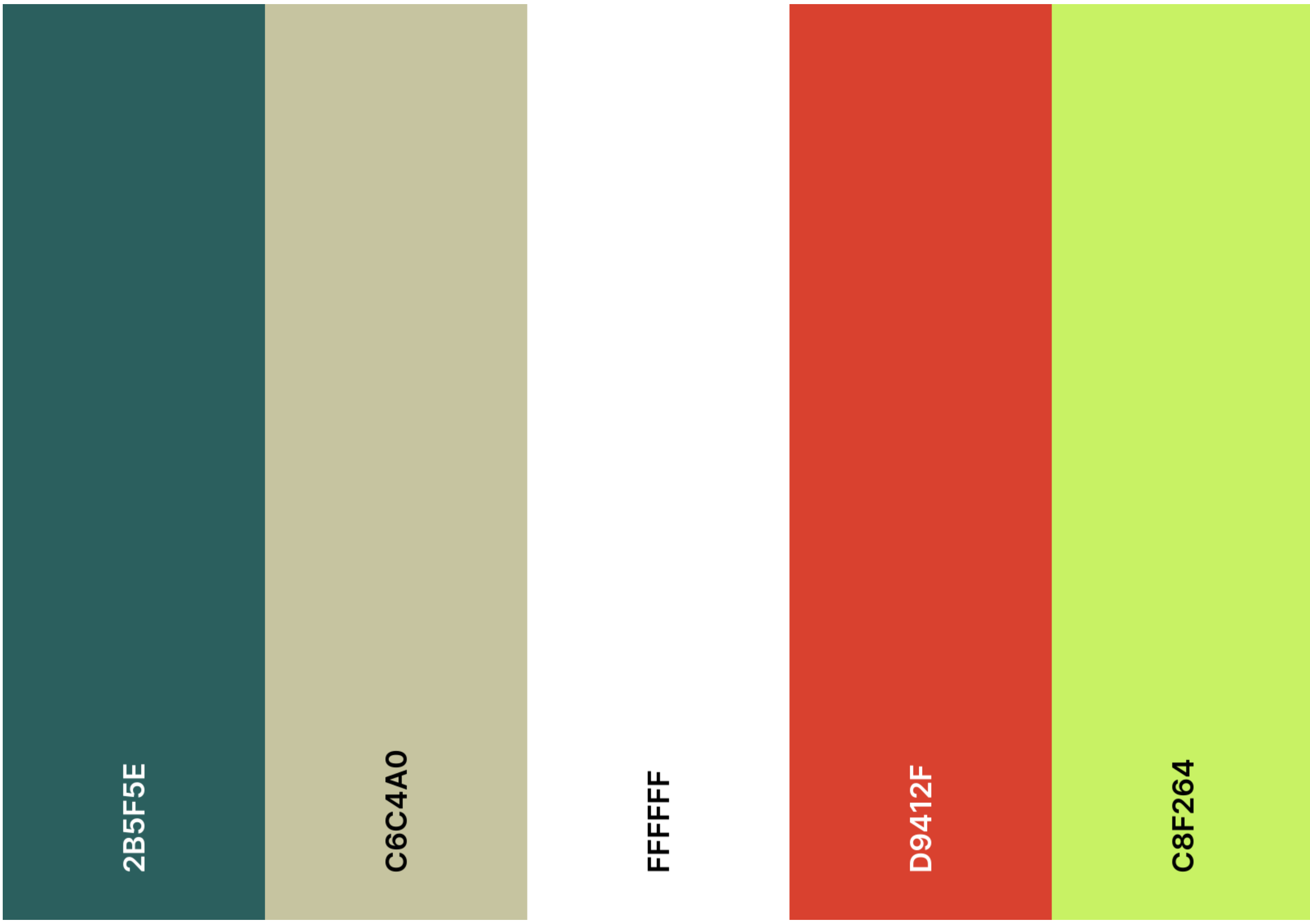

Figure 5.15: Color palette of prototype

Since the colors used in this interface contain information (albeit not crucial), the colors should distinctive to accommodate for individuals with color blindness. There exist online tools [30] that simulates various types of color blindness and applies it to a picture that is uploaded to the site.

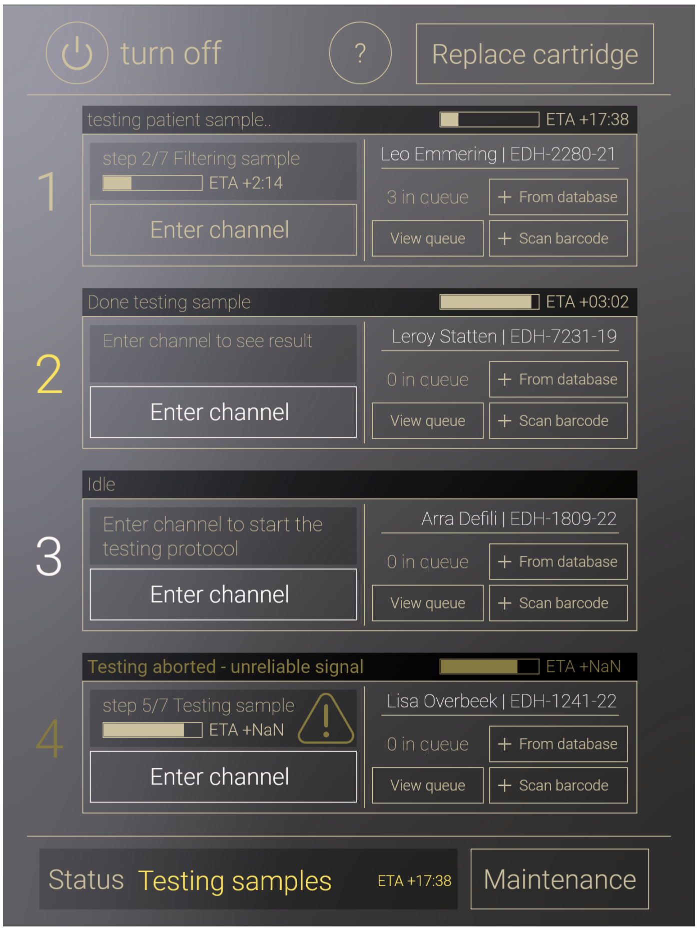

Figure 5.16: Total red blindness

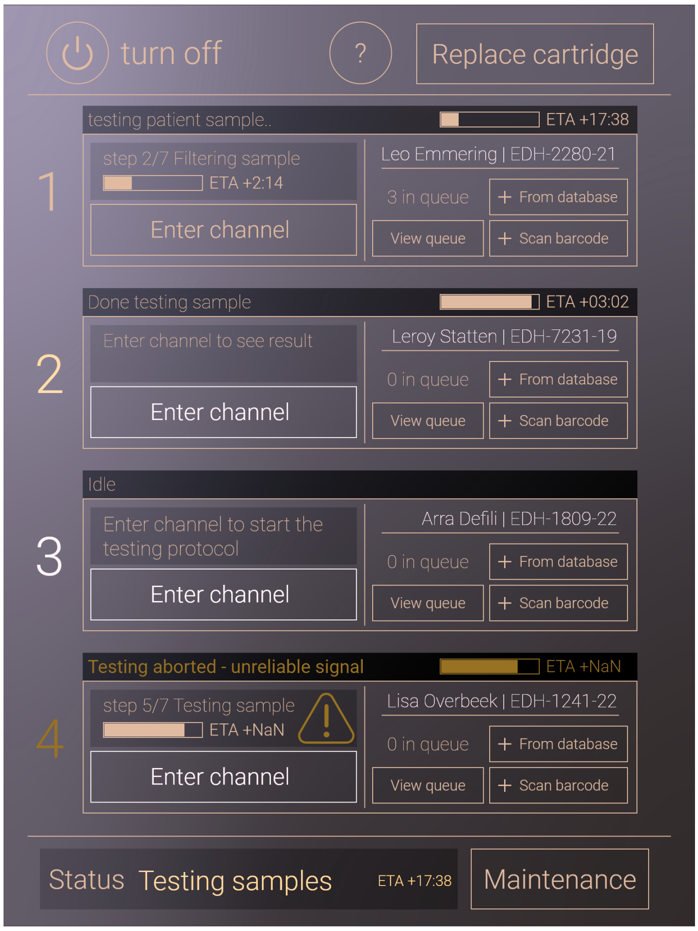

Figure 5.17: Total green blindness

With green and red blindness the 5 colors are still distinct from one another. However, with blue blindness and monochromatic view the difference between the green color and white is relatively small. However, the most important accent, which is red, is still clearly distinctive from the other colors.

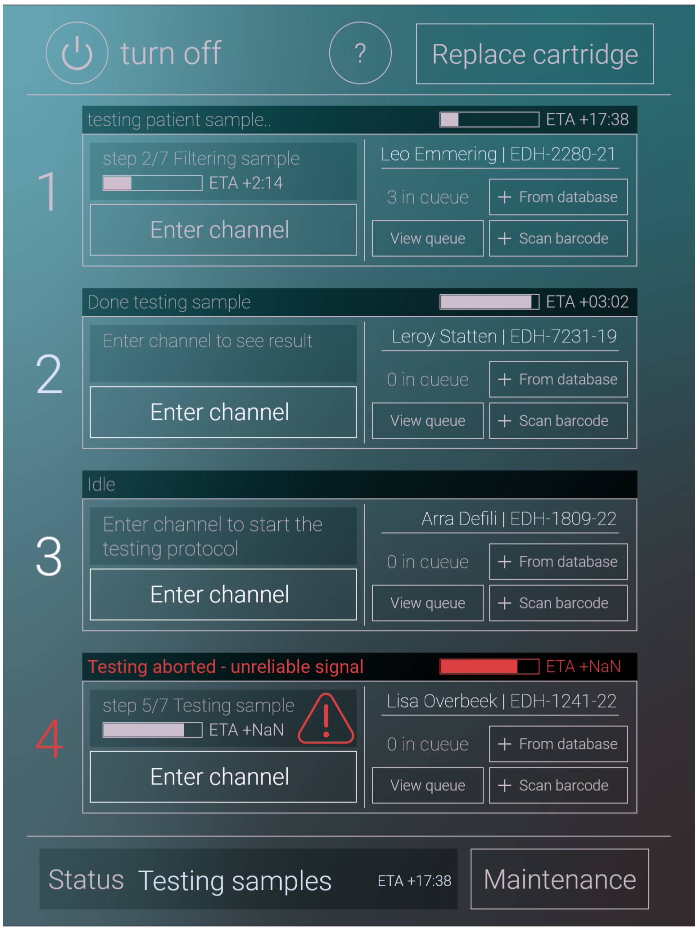

Figure 5.18: Total blue blindness

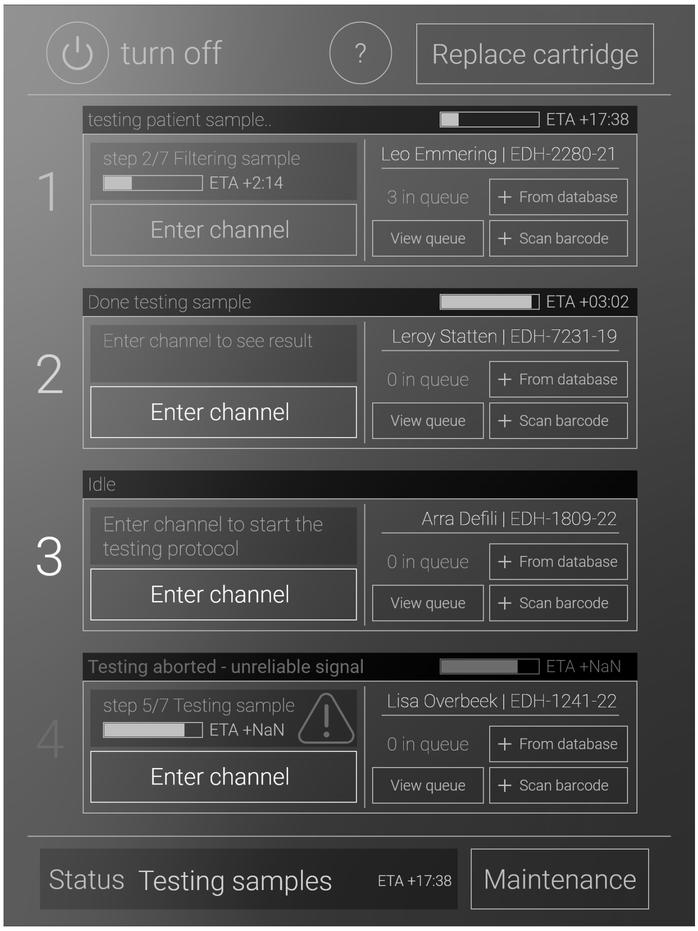

Figure 5.19: Monochromatic view

5.4.1 Use case

How the prototype would be used in this version

5.4.2 Interface

The header and footer of this version are relatively similar to the tablet prototype. The footer is kept almost the same, the daily results tab is removed and the status tab has gotten extra space to give detailed information on what the system is doing and how long that task will take (2. visibility). The status bar is shown in green to communicate the task being performed is normal. The header has completely different features. There is a turn off button that powers down the machine, a help button that explains the interface (14. document) and the fluidics button is replaced with a replace cartridge button. Replacing the cartridge or turning the machine off during a measurement would ruin the results. Therefore the user will not be able to perform these actions until all measurements are aborted or completed (9. Error). The user will be informed of this protocol if one of the buttons is pressed at an inappropriate state (8. Message). Disabling these actions ensures that the user closes the measurements and re-queues any samples that had not been completed.

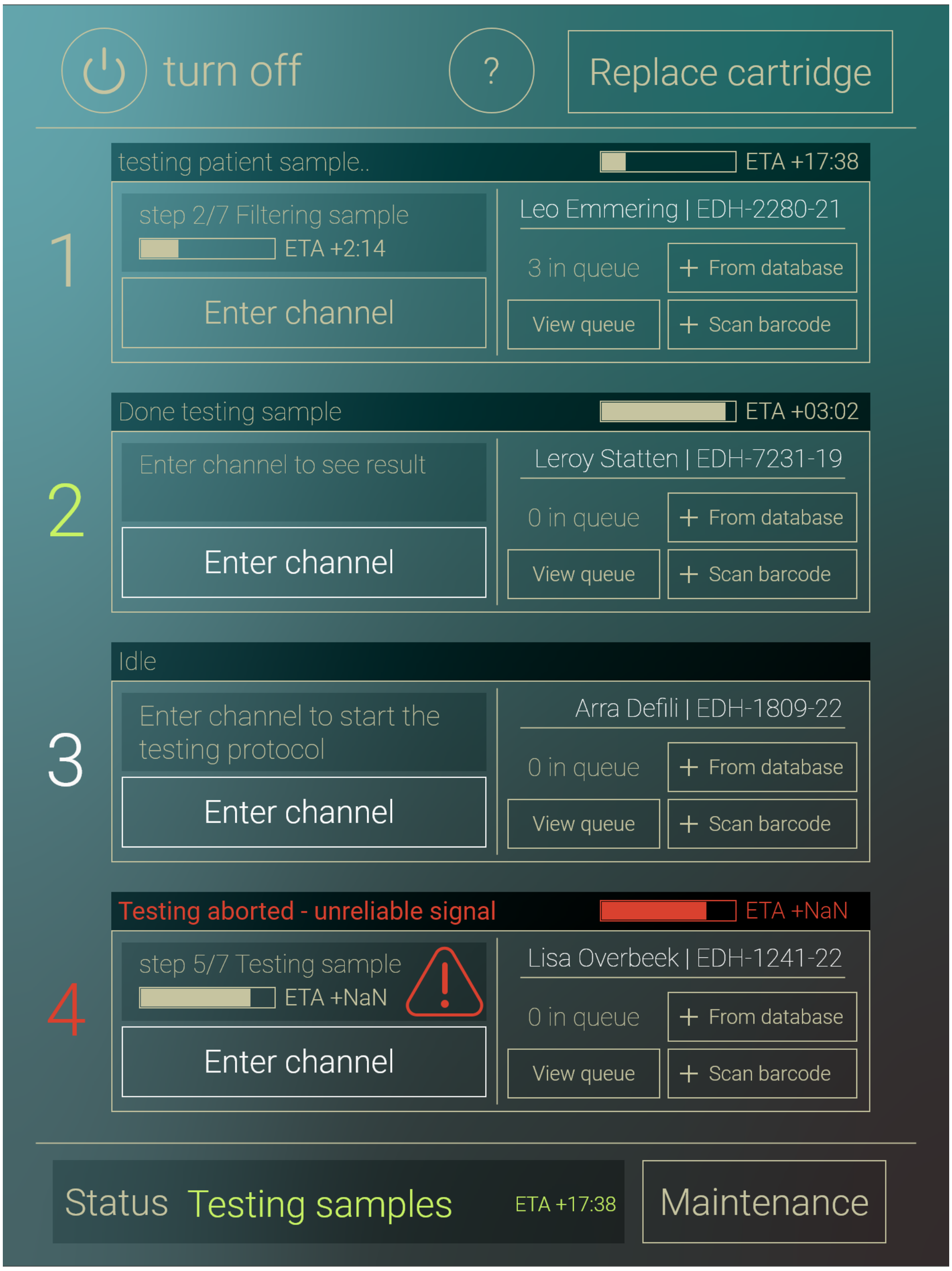

Figure 5.20: Home screen of the final prototype

In the middle of the screen there are 4 identical channels that are in different states:

- Channel 1: In the process of measuring a sample
- Channel 2: Completed a measurement, waiting for evaluation.
- Channel 3: In idle state, waiting for a sample.
- Channel 4: Experienced an error during measurement.

Apart from being in a different state the functionalities of each channel are identical. In the top bar the status of that specific channel is visible, as well as how long this process will take (note that the percentages are removed). On the left side a small panel with information on the channel is present. In channel 1 the specific step of measurement is shown while in channel 2 and 3 the information panel provides instructions to the user on how to proceed. Under the information panel is a button that takes the user to a more detailed window on that panel.

Note that channel 2 ,3 and 4 have a white 'enter channel' button as these channels have actions available that are to be done by the user (8. message). The right side of the channel provides the name of the patient as well as their code in white as it is important information (5. memory). The channel displays the amount of samples that are queued on that specific channel as well as a few buttons to interact with the queue. A sample can both be added from the IIMS database or by scanning a bar-code that is printed on the sample physically. Furthermore the queue can be viewed in detail providing the possibility to move samples between channels if needed (11. undo). Note that all buttons on the interface have a thin line surrounding the button and that none of the other elements have the same aesthetic. The distinction between button and information makes it easier for the user to identify interactable objects (1. consistency).

Figure 5.21: Channel is measuring sample

The channel window is a more detailed version of the channel with only a few extra functionalities. There is a button to abort the test and confirm the result. The latter is greyed out as there is not result to be confirmed as of yet, hence the "To Be Determined". In this detailed window a small preview of the queue is shown, the buttons related to the queue are identical to the ones in the home window. Note that the second measurement in the queue is added by the system automatically.

Figure 5.22: Channel has completed a measurement

In the second channel the warning sign immediately stands out. The reason for this warning signal being there is that the result of the sample is septic shock, which means the patient is in mortal danger and should be tended to as soon as possible. A result like this would go paired with a notification on the pager of one of the staff members and a loud noise from the machine itself. Additional to the result, the machine provides a confidence rating stating its confidence that the patient is correctly classified.

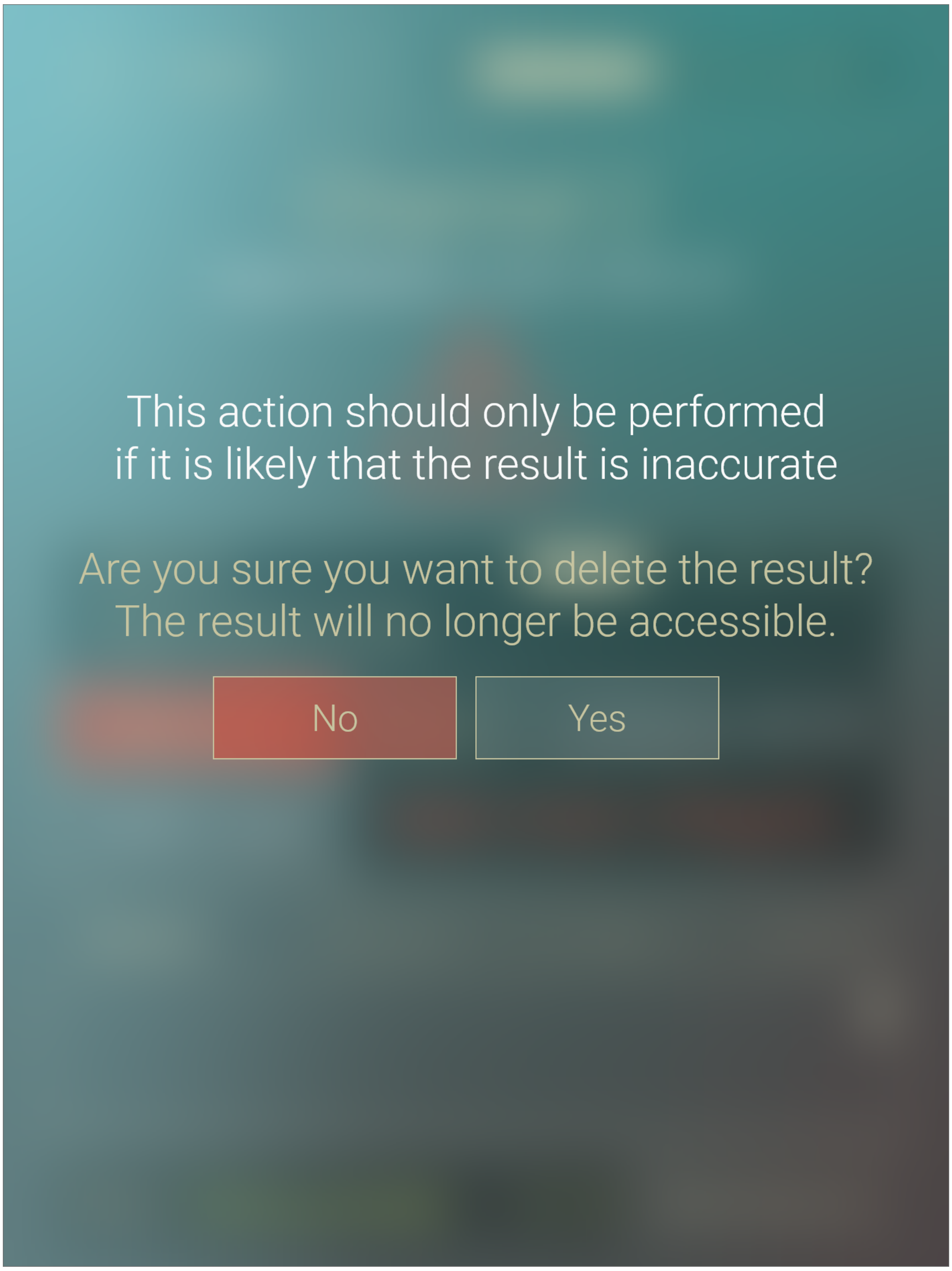

Figure 5.23: Confirmation window on deleting result

The operator has the choice to accept the diagnosis and confirm the result, this will feed the result back into the IIMS and provides the information to colleagues (10. closure). Alternatively, the operator can choose to disregard the result, this wipes the result from the system and puts the patient back into the queue to be re-tested at a later moment. Since both buttons are next to one another, the user can make the mistake of clicking the wrong button. Therefore the system asks the user if they are sure they want to go through with deleting the result and what the consequences of that action are (6. feedback, 11. undo). Similar windows will be present for the abort test button, the power button and the 'replace cartridge' button as these actions have large consequences as well.

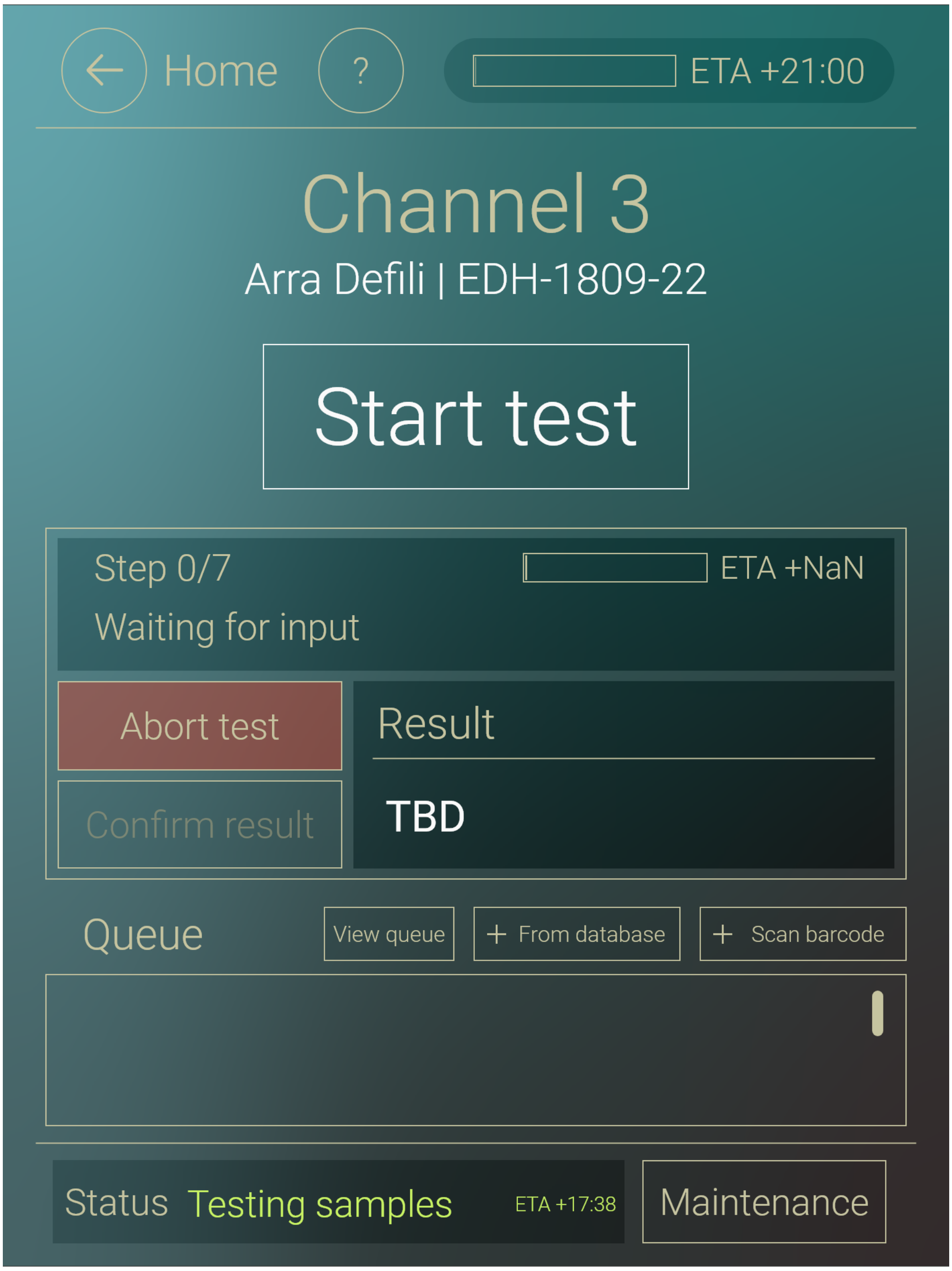

Figure 5.24: Channel is waiting for the user to start the measurement

The third channel is currently idle. Though there are no patients currently in the queue 'Arra Defili' is already loaded in to the channel. If the user does not want to test this person the test can prematurely be aborted. There is a large button visible with which the user can start the test.

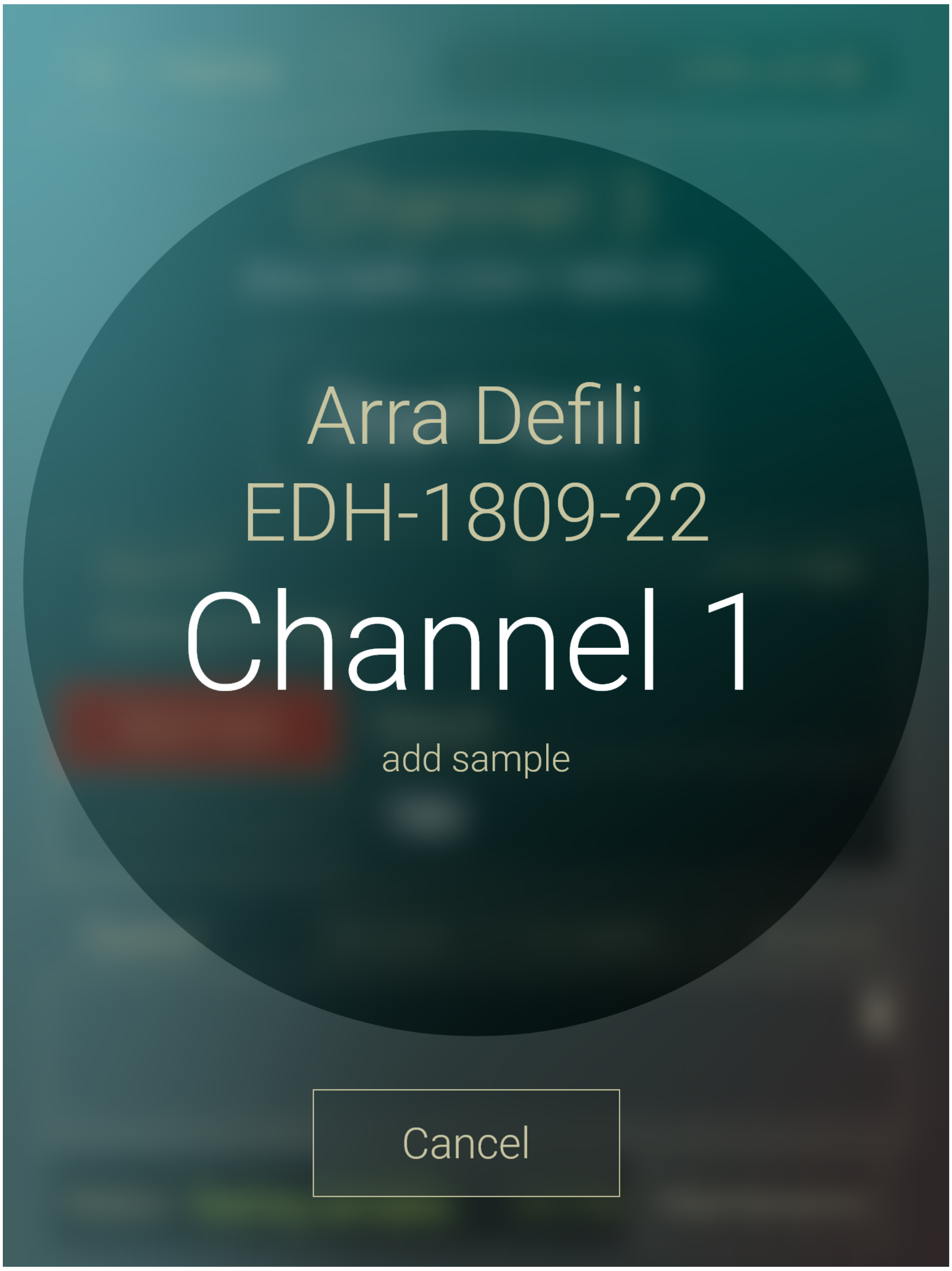

Figure 5.25: The system instructs the user to add the correct sample

Once the button to start the test is pressed a screen similar to the tablet prototype will become visible. However, in this prototype there is a cancel button present to revert back to the channel window.

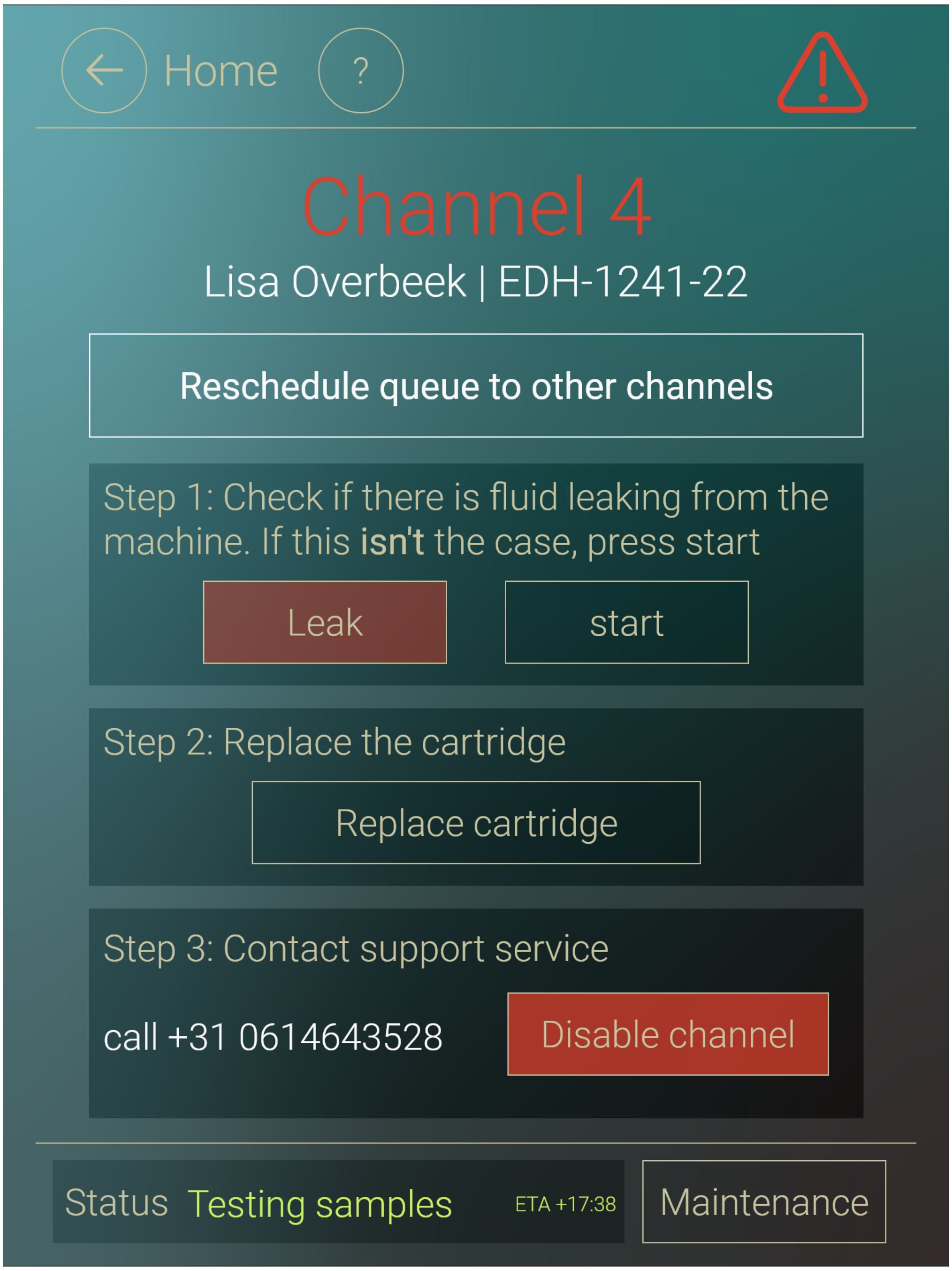

Figure 5.26: Channel that is experiencing an error

The last channel is an edge case wherein the machine has encountered an error. The machine clearly states which patients sample could not be measured and has a button to move all scheduled measurements (including the failed one) to another channel. As the channels are modular they can function independent of each other and the other three channels stay operational. Under this button is a troubleshooting page wherein the user is explained in clear steps on how to fix the problem. However, if the problem cannot be fixed, the user is to contact customer support to talk to a technician. The user can disable the channel such that the system no longer complains about the channel being broken and it will make sure that no further tests can be done with the channel until its problems are resolved.

As a final addition, a screen that signals to the user that the fluidic components of the machine are running low. To replace the fluids the machine should be turned off, this will cause all measurements to stop. The fluids being low is indicated in advance such that there are enough fluids left to complete about 10 more measurements. Therefore, all measurements can be concluded, and if needed a couple more measurements can be done before the machine pauses its measurements and the fluids are replaced.

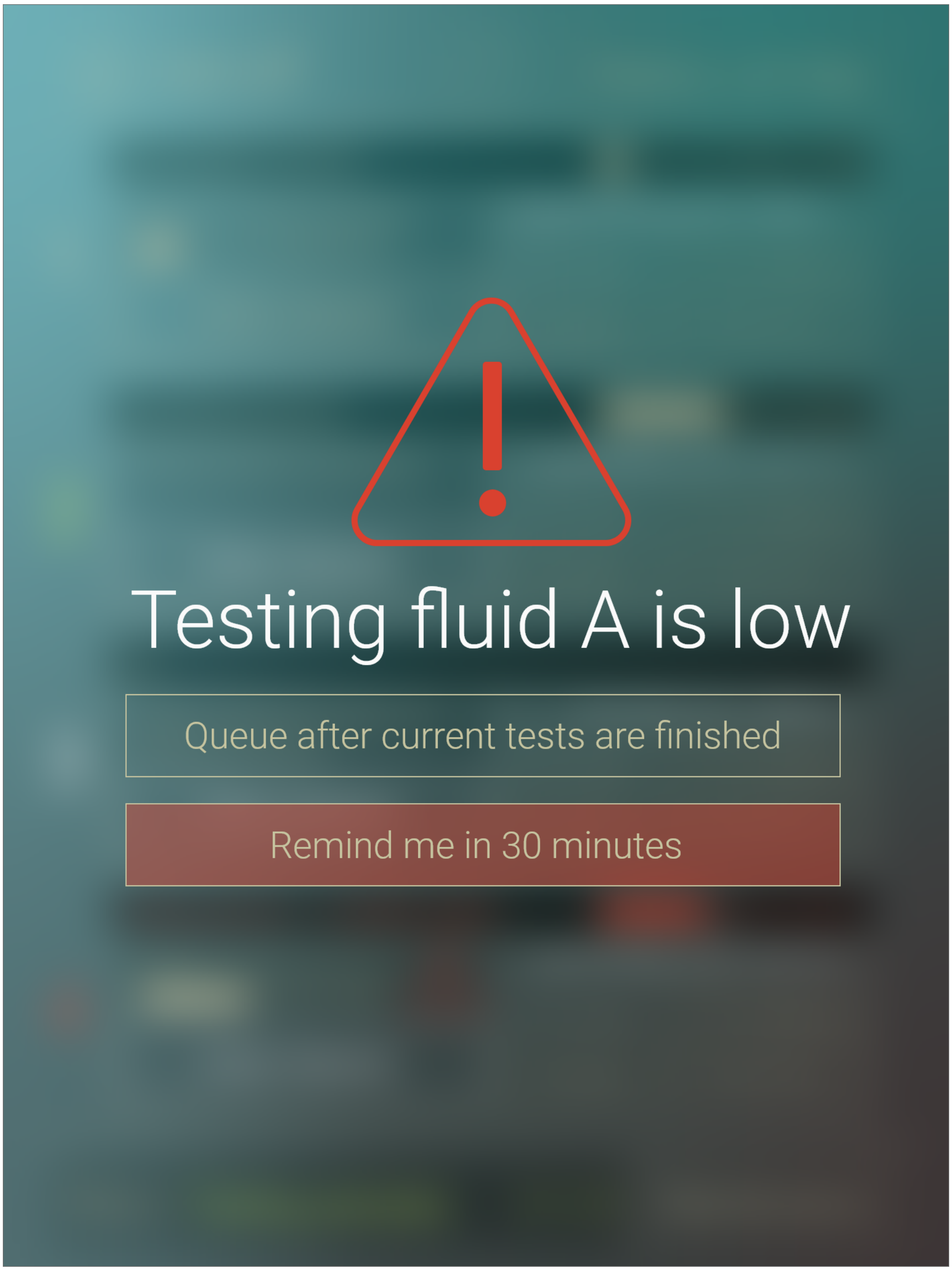

Figure 5.27: Interface communicates fluids are low and should be replaced

Chapter 6

Discussion & Conclusion

6.1 Discussion

In the first weeks of this thesis I had volunteered to be one of the two team captains of the student team. As such I have been more involved with the project than I had otherwise been. Balancing the working on the thesis and putting effort in achieving the goals of the student team has been difficult throughout the project. This balancing act has been a learning experience, but the support of my fellow teammates and supervisors has helped significantly.

Another difficulty of having a thesis interconnected with a student team is that at certain points progress could not be made before the team had progressed. However, through the close involvement with the student team a significant amount of the information needed for this project had been acquired naturally. Though it was challenging to put multiple prototypes with the method of iterative design out in a relatively short amount of time, I did manage and I am content with the final result.

6.1.1 Evaluation

The final prototype is similar to the tablet interface that was evaluated by both the target group and an expert. The main differences between the tablet and final interface are based on feedback directly from these evaluation sessions. In the interview with the target group the tablet interface scored well on the Likert scale questions. In the interview with the product application specialist a statement was made that the tablet interface was well thought out and would potentially be used as further reference for their company. Furthermore, said specialist has asked for the images of the final prototype to show it to colleagues.

6.1.2 SensUs competition

The purpose of the end user interface is to strengthen the business case of the TwentUs'22 team in the SensUs competition. I believe that the prototype built in this thesis will function as a great backbone to illustrate our product concept. In this thesis a lot of the ground work for a use case and the shape of the product itself has been done. This information is necessary to build an interface and as it had not been thought out prior to the prototyping stage by the team, I have included it as part of the thesis and worked out the concept largely by myself. That is not to say that team didn't help a significant deal in collecting the user research and background information that was used to base the product concept on.

As a team captain, involved with the product conceptualization, I volunteered to pitch the business case, which I contributed to develop. The interface will be used as a basis on which to illustrate the use case of the product. Furthermore, the emphasis on simplifying the interactions will communicate our research on and consideration of the target group without taking much time in the pitch. However, the interface prototype itself will not be enough for the presentation of our concept and further work must be done to illustrate the physical machine and other components in detail.

6.1.3 Generality

In this thesis the interface and product is made to compete in the SensUs competition. In this competition we have provided a solution to the diagnosis of sepsis with a high future potential. To illustrate, the machine and as an extension the user interface can be used to test all kinds of bio-markers, not only IL-6 to detect sepsis. Our predecessors, the UT+ team, have used the same method for the detection of influenza. Therefore with slight changes in the machine, photonic chips and software (interface included), the product could be used to assess all kinds of samples for different illnesses. Furthermore, with the multi-channel solution different channels could be used to test for different illnesses.

6.2 Challenges

The interface prototype that is the end product of this thesis is a non-functional mock-up with the function of illustrating a product concept. As such it does not have real functionalities that could be tested with a prototype machine. Furthermore, the interface is still a rough conceptual prototype and is subject to a significant amount of change. With only a limited knowledge on the chemical and technological aspects of bio sensing most of the interface has been based on assumptions. Although most assumptions have been validated through consultation with experts on the field, some of these assumptions will be false. The step between an interface concept as is created in this thesis and a fully developed product is significant.

6.3 Future work

The method of using MRR and photonic chips to test for bio-markers is still in its early stages. The real impact of this technique lies in the potential to test for a panel of bio-markers. The photonic chip will be coated with different antibodies in each channel and as such the machine will be able to test for the concentration of each chemical. With the ratios of these bio-markers in relation to each other it would be possible to detect the origin of the sepsis for example. Instead of having to do a blood test, the machine could determine the type of infection and suggest a course of antibiotics within the span of 15 minutes. This would revolutionize the treatment of sepsis, making the disease significantly less deadly. There is effort being put into making this a reality by the scientific community [31] as well as Delta Diagnostics themselves developing such panels for future use with their product. Therefore, the product as a whole must be open to the transition into testing panels of bio-markers instead of multiplexing a single bio-marker.

6.3.1 Interface

There are actually quite a few things that have to be added to the interface to bring it to the market. Apart from technical features such as robust coding and a reliable signal to result algorithm, quite some of the user interactions are to be worked out further. First of all, it was difficult to envision a queue system that connects to an information system. The part of the user interface that handles this transmission of information needs to be general enough that it can be connected to most information management systems on the market. Additionally, to find all the edge cases of the product is near impossible in such an early stage of the design. Therefore, the edge cases of the product must be explored further an accommodated for in the interface at a later stage of the product. Finally, as the machine changes the interface is to be changed with it. If at one point the machine can test panels of bio-markers the interface must be altered to fit this new application of the product.

6.3.2 Product

I only recently got myself accustomed to the field of biosensors. Although I have consulted professionals in the field on my ideas and assumptions, the product that is sketched in this thesis is still conceptual. There is a wide range of technological challenges to be overcome to make this product a reality. Nevertheless, it should be feasible to design a machine that has similar prototypes to this concept. It might be useful to take Delta Diagnostics [4] as a reference as they are currently working on a similar commercial product (DeltaOne).

6.4 Conclusion

The target group of the product turned out to be nursing staff at a nursing home. This is a user group that is not familiar with bio sensors in the way that an analyst would be. Furthermore, they don't have a full understanding on the workings of the machine or on how to interpret the measurement data. Through interviews and feedback sessions it has become apparent that the measurement data itself is of little added value to this user group. More important is the result that the machine determines from the data. The user group wants to know what their patient is suffering from and how to help them, that is their motivation.

The machine itself is a 4-channel parallel testing setup. A user can test for sepsis using this device by adding a sample to the a channel and digitally connecting a patient file to it. The machine will do the measurement itself autonomously. As there are fixed protocols that need to be followed, there is no human interaction needed. Once the machine is done with its measurement it needs to communicate the result to the patient, after which it will clean itself for another round of use. To function the machine does require certain chemicals to be available in its fluidic system and the samples themselves have to be added in a specific way. The physical actions that are to be performed by the user should be designed for in a way that it is hard to make mistakes, as the target group does not have any laboratory training.

The interface must both accommodate for all the functionalities of the machine and be as straightforward and user friendly as possible. The main goal of the interface is to simplify the complex workings of the machine and make its operation understandable for someone without a biochemical background. In the end, the machine has ended up performing most of the tasks needed to do a test by itself. The human factor is only needed for the physical actions with the machine and to plan the tests and match the sample to its respective patient. The interactions with the machine that do exist have to be clear and should follow a pattern that can not be deviated from (a fixed workflow). Closing the system to the user will make the interface more user friendly, but reduce the flexibility of the product, which is a problem when the machine encounters something unexpected. Therefore, extra care must be taken to give the user the tools to troubleshoot any problems that may arise. Ultimately, the interface turned out to be more of a planning software for a very specific machine, as this is the part of the process that needs human interaction. The remainder of tasks needed to perform a sample test is done by the machine itself as the target group would not be able to provide meaningful input into this process. The input that the user does have on the operations of the machine need to be thoughtfully designed as to minimize any errors caused by the user. It has been an interesting and engaging task to translate the operation of such a complex machine like an MRR bio-sensor into a simple and intuitive workflow that can be quickly picked up on by general nursing staff.

6.5 Acknowledgements

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Appendix A

Interview with target group

A.1 briefing

A few of the questions are asked before the demonstration of the prototype to prevent bias in the answer to these questions.

What kind of device would you like to work on with regard to sepsis
Elisabeth (E): Diabetes special plasters are used to measure the blood sugar levels in the patient. If something is wrong I will be alerted to the situation on my pager.
E: Normally when doing a diagnosis on a suspected sepsis we look at the symptoms, if someone does have symptoms we immediately take a blood sample for a blood culture and administer broad spectrum antibiotics.

During the conversation we discussed the subject of how information goes to the instrument and how the results end up with colleagues
Maarten (M): All instruments are connected to the lab system, all data is in this system. We use a LIMS system, which stands for Lab Information Management System. This system is connected to multiple instruments and is used to communicate the results of certain tests with doctors that care for the respective patient.
E: We use a similar system called EPIC. However, instruments for doing blood tests are not available in my department, they do exist on the intensive care department.

A.2 debriefing

During the debriefing the prototypes have been revisited multiple times. Furthermore, the interviewees were not informed on which version was newer, although it is likely they deducted this from the difference in quality between the prototypes.

Which interface would you rather use?
M: The tablet interface looks more user friendly, however I do think its nice that the initial prototype has a data graph and a terminal.
E: The tablet prototype is nice, very clear. I would use the tablet interface as it is more simplistic.

What are the three biggest differences between the two prototypes
M: In the tablet interface there is an estimation on how long certain tasks will take, I like this as it allows me to calculate in other work. Additionally, the tablet interface shows the steps it is going to take clearly.
E: The initial prototype has the data graph, I think that is an interesting thing to have. Additionally, in the second prototype you can clearly see what the device is doing at the moment. *Here M points out that this is visible in the other prototype, but differently.* After which E agrees it is relatively clear in the tablet interface as well, she notes that she is more inclined to look at the progress bar than the absolute percentage.

In the tablet interface, if you could add three features, what would they be?

M: I would add a button to clean the chip. Furthermore, I think there should be an alert when some of the fluids are empty.
E: I would like to know the cause of the sepsis. If this would be the case we would know what antibiotics to give directly. Secondly, the machine should tell the user when the sensor is dirty and should be cleaned. Additionally, there could be a better communication when sepsis is indeed detected. This could take the form of a notification to my pager or the machine making a noise.

We proceed to talk a bit about the application of the product
E: Although we often start treatment before we know what kind of sepsis we are dealing with, it would be nice to have a confirmation that the patient is actually suffering from sepsis.
E&M: This would for example be really nice at a general practitioners office. They often struggle with diagnosing someone with sepsis and send them back to wait out the symptoms regularly. At the point that someone is send to the hospital it is usually already pretty clear they have sepsis, but it would be nice if they could be treated at an earlier stage.

If there were three features in the tablet interface that you had to remove, what would they be?
M: It is unclear what purpose the 'ring signal' has. I would also get rid of the names, no one uses patients names where I work, just the codes. The daily results are nice, but where do they go after the day is over?
E: I do like to have the names as I often know the name of the patient and do not know their code. The daily results can go somewhere else.

How does the information system work? Is an ID and patient name enough to link a sample to a patient
E&M: Yes

Would you be comfortable using a comparable machine to diagnose sepsis, what would enhance the experience?
M: I do not actually see the patients as an analyst, so the diagnosis of the machine is the only thing I go off on anyway. At most I can see what the doctor has to say about the patient in their file.
E: I try to keep a critical eye out, but the machine is tested in clinical trials so it should be trustworthy.

Would you be able to replace the cartridge yourselves? E: With the right instructions I should be able to. However, a lot of people use the same devices so the instructions should be as clear as possible so no one prepares the machine incorrectly. If the chip does not have to be replaced often, an analyst could be given the task so that it is ensured the task is done properly.

The next section consists of a few questions on a Likert scale:

Question	M: Initial interface	M: Tablet interface
Information availability?	4	3
I would use this product if available?	3	3
I think the product is safe?	4	5
Is the product aesthetically pleasing?	4	5
	E: Initial interface	E: Tablet interface
	4	3
	5	5
	4	5
	4	5

Figure A.1: Result of Likert scale questions

The results are quite similar between M and E, but this might be due the questions being asked in the same session. Some key notes discussed during these questions is that the simplicity of the tablet interface and the fact that it has clearly defined steps is appreciated.

Appendix B

Interview with product application specialist

What is your first impression with the interface?
Pretty, simple and organized. For someone working at a general practitioners office it should be clear. Although I am not sure that it is very intuitive. For example, I wouldn't exactly know the difference between the add test to queue and measurement button. It should be clearer where one should start. Additionally, I am not directly sure what the load queue button means.

Do you think my use case would fit the instrument and if it would be feasible?
Generally speaking, it is similar to what we are planning to do with our product. The specific thing you want to do will be a design challenge, but should be possible.

If you could add three features to the interface, what would they be?
First of all, we do not have a point of care product, so it is a bit different for me. I would add a button that when clicked would show some kind of troubleshooting screen for the user. I agree that it would be a good idea to have a dedicated technician from the company available in the case of errors that the user cannot solve. Furthermore, It might be an idea to block certain parts of the software to the user. Where some features such as maintenance and technical settings are only available to a technician.

On a different note, what happens if someone were to remove the chip without pressing the release button? Did you think of some kind of locking mechanism? If the chip were to be removed inappropriately it might cause damage and serum might start leaking from the tubing into the machine. The chip itself is not very strong so it might be hard to lock it in such a way that someone cannot overpower the lock.

If you have to remove 3 features from the interface, what would they be?
Base en resonance frequency do not have much meaning to people, I would rather use units referring to the resonance shift, most assay developers will understand that as well. Furthermore, the fluidics on/off button is not needed, it might even be better to not have the user control this.

What do you think of the styling of the interface?
I like that it is simple and clean. I especially like the progress bars with priming fluidics and cleaning chip at the start. Be mindful that connecting the chip might also take significant time. It occurred to me that there is little space in your status bar, you would want to be as specific as possible with what the machine is doing and specify how long it will still take.

What features are you missing at the maintenance section? You should be able to check the alignment of the chip. If the reference ring is not getting a good signal it means that the alignment is wrong and someone should be able to check on said alignment.

Would you use this interface as inspiration when building an interface for your own product?

I have never thought how a point of care interface would look like, but I would definitely look back at this prototype. I think it is well thought out.

Appendix C

Research on data visualization

C.1 Data visualization theory

An important aspect of an instrument interface is to properly communicate the data acquired by the machine. The way Azzam [32], an authority on data visualizations, defines the term data visualization suits the project well:

"A process that (a) is based on qualitative or quantitative data and (b) results in an image that is representative of the raw data, which is (c) readable by viewers and supports exploration, examination, and communication of the data" (p.9)

For medical equipment it is first and foremost of importance that the visualization accurately represents the data, and that said data remains accessible. Thereafter, the main goal of the visualization itself is to make the data more accessible in a manner that allows for a more efficient analysis. Finding the suitable degree of simplification of the data will be discussed in a later chapter.

In this sub-chapter a range of fundamental topics in the field of data visualization will be addressed. In these sections, available literature is applied to the context of this project and will identify key metrics that define the data visualization that is to be designed. The topics are ordered such that they build upon one another. The conclusion of a certain topic will more or less define the direction of the next topic.

Brief context

As the field of data visualization is rather broad, the problem statement of the visualization is to be briefly defined ahead this sub-chapter. In this thesis, the problem statement is largely constructed through the interface requirements (CH 3). Nevertheless, only the most fundamental aspects of the requirements are needed to guide the upcoming literature research in the right directions.

- The data signal from the instrument is in the form of a frequency shift.
- The data is continuous, high sampling frequency.
- The data needs to be related to time.
- The data must be communicated in real time (live).
- There is a control measurement that produces the same type of data with a different signal.

C.1.1 Complexity

Using these aspects, the data can be attributed a certain complexity, there are X amount of data dimensions present in the problem statement [33][34]. A data dimension refers to a certain aspect of the entire data set. In this case, there are three dimensions: Frequency shift, time and the corresponding concentration of the target chemical. Only two of these dimensions are also present in the control measurement, as it does not test for the target chemical. Though it would be possible to include all data dimensions and data sets in one visualization, Brath and Evergreen[33][35] advice against doing so. They state that the comprehensiveness of a visual is directly linked to its complexity, where a more complex visual will be harder to understand. This view is supported by Midway [36], who suggests to divide a complex visual into small multiples (or panels). By using the same geometry, axes and scales, the relation between the different data dimensions becomes clearer than if all these dimensions were crammed into the same visual. Whether or not the measurement and the control should be separated depends on the details of the case, though aforementioned sources would generally advice against putting both in the same visualization.

C.1.2 Geometry

If the type of data that is to be represented is clear, the matching geometry can be assessed. Wilke [37] suggests that there are six types of data, each with their own respective choice of geometries: Amounts, Distributions, Proportions, X-Y relationships, geo-spatial and Uncertainty. Similarly, Ware [38] divides data in entities and relationships, where entities are objects of interest and relationships are the structure that relate entities. In contrast, Telea [39] takes a more mathematical approach, dividing data not to its application but to its definition, such as sampled, discrete or continuous data. Independent of the approach, each of these data types have several matching geometries [37] [36]. In the case of the established data dimensions, there are two entities and a relation. Both time and the frequency shift are entities that are measured, though they are closely related to one another. The target chemical concentration is entirely based upon the frequency shift at a different point in time and as such is a relation. Whether or not this relation shall be included in the visual is debatable and should be assessed with the requirements of the user.

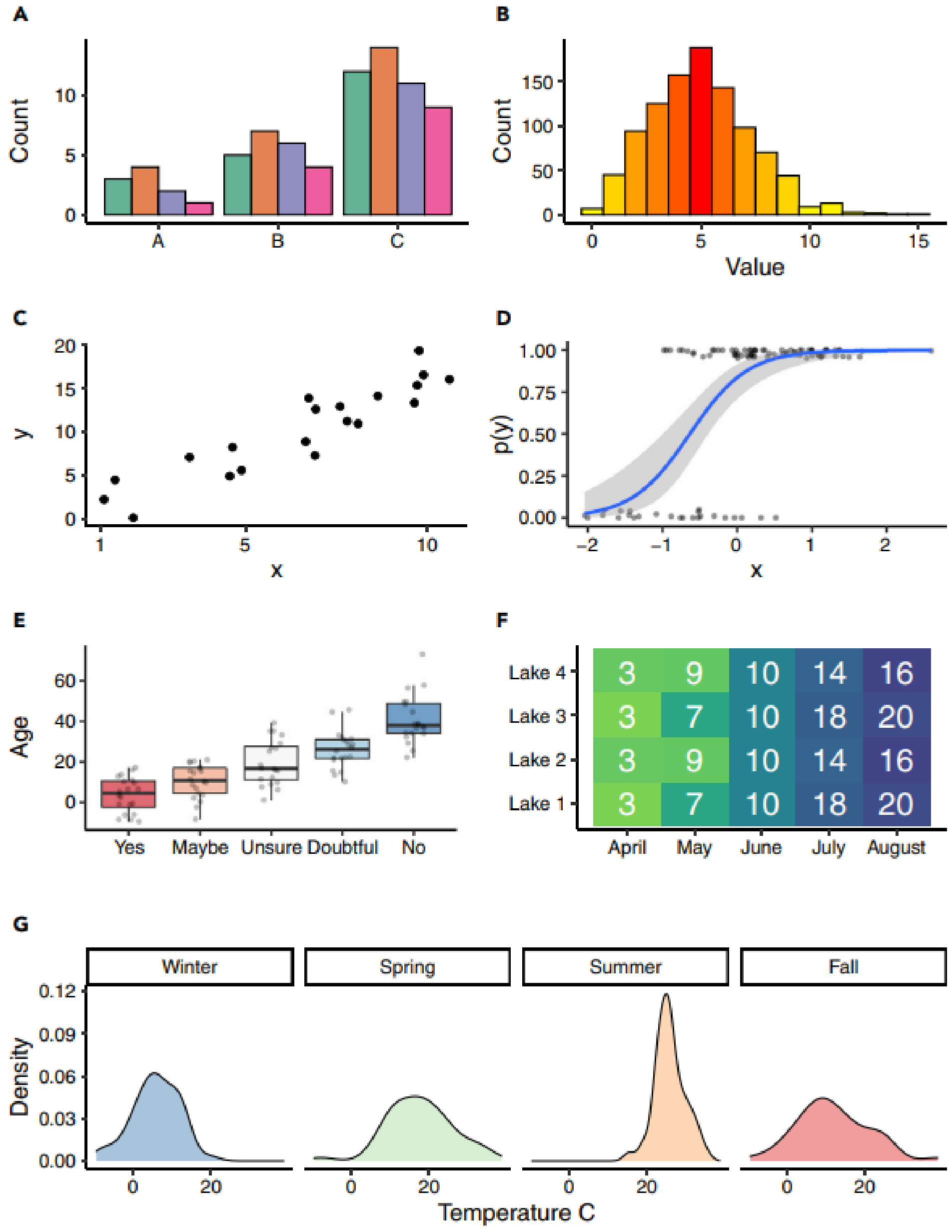

Figure C.1: Various geometries for data visualization (Midway 2020 [36])

There is a vast amount of different geometries that can be applied to a certain data set. It is important to note that an inappropriate geometry might not only make the visual less readable, it can lead to misrepresentation of the data[36][34][38]. Especially when multiple data points are clustered for the sake of readability, the visualization must reflect that the data is processed as such [40]. Therefore, it is justified to put a significant amount of effort into determining the right shape of the visualization. Furthermore, these geometries can be modified to fit the needs of its application. An important aspect of a geometry is its data-ink ratio, referring to the amount of ink is used as context for the visualization and how much ink represents the actual data [36][37]. There is certain balance to be made between providing the user with enough context to show what the data means, and keeping the data itself as the main point of attention. Both the geometry and its modifications are heavily dependent on the exact purpose of the visualization and the needs of its user. As such, the process of shaping the geometry for the product that is to be designed is discussed in a later chapter.

C.1.3 Color

On top of the information provided in the geometry of a visualization, color can provide a whole new dimension on which to put details of the data that is to be represented. However, color does not only provide a new avenue to carry information. There is an entire field dedicated to the interaction humans have with color called color psychology. There have been numerous studies relating colors to certain emotions, both in the psychological field [41] and in the field of design [42][35]. Whilst, the psychological field focuses on the reasoning behind the impact that color has on us as people, its implications are an important tool used in the field of design. Additionally, Midway [36] suggests that colors can provoke certain associations with the world. Such as, blue being perceived as water on a geo-spatial geometry. In short, the color that is being used has a meaning to the viewer. In the process of designing a visualization, color must be purposefully used to enhance the experience of the user.

Figure C.2: Color wheel (October 12, 2016 by dzbiro)

In addition to viewers having certain responses and associations with color, the usage of color is subject to a few technical issues. Color blindness (Color Vision Deficiency) is a common impairment in the general population [43]. Midway [36] suggests it is good practice to accommodate for the color blind in visualizations. While Evergreen [35] takes an even stronger stance, saying that color combinations that are difficult to differentiate between for the color blind should be avoided entirely. In the context of an interface used to diagnose patients it is essential that all the available information is provided to any medical worker. It is a requirement that the information can only be perceived in a single way, and is not up for interpretation. If due to a variance in color perception of an individual the visualization's data is altered, it could lead to unforeseeable consequences.

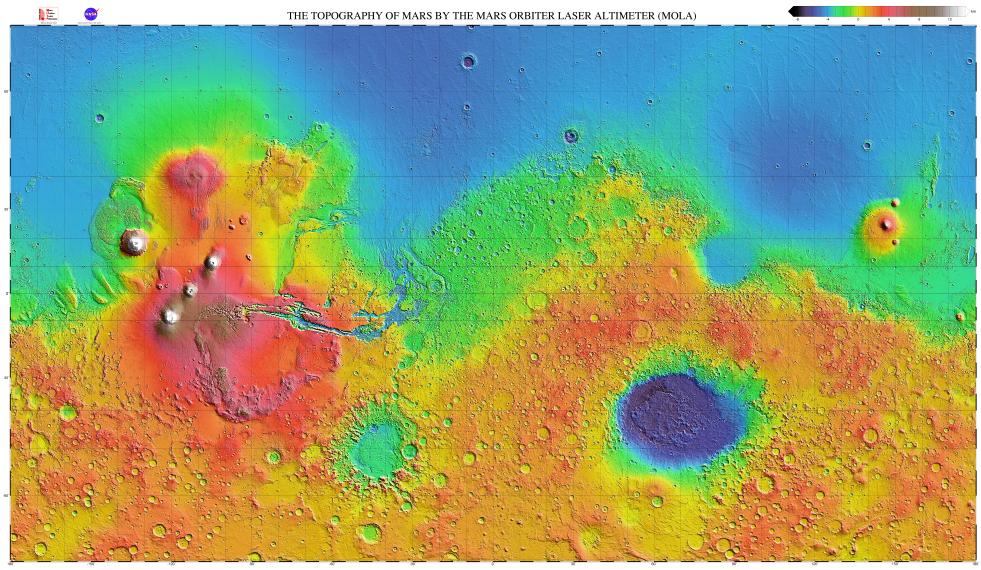

Figure C.3: Rainbow mapped martian surface (NASA, 2000)

Having considered the implications of using certain colors, they must be applied properly in accordance with the data. A categorical data set needs its colors to be easily differentiated between. Gramazio [44] explains the concept of 'palette discriminability', which refers to mapping a color palette in such a way that the ability of a person to differentiate between the colors is maximized. In contrast, if a continuous data set is to be coded in color, the range upon which the data is coded must be perceived as linear. A pioneer in this train of thought is Rogowitz [45], they declare the end of the rainbow in their paper. Which refers to using the entire color spectrum (or the entire wheel) as a range to map data on (figure C.3). They we're successful, in later literature the rainbow palette is no longer even mentioned[36][46][37]. The ineffectiveness in this approach lies in the fact that we as humans are far better at differentiating between different colors than we are in shades of the same color, creating a segmented image rather than a continuous one[45].

Therefore, nowadays most opt for one of three palettes: sequential, diverging or qualitative. Sequential palettes usually transition from light (low value) to dark (high value) within the same color or are a transition between two colors[36][37][35]. Diverging palettes use two 'one color sequential palettes' meeting with a neutral color in the middle[36][37]. A qualitative palette is used to differentiate between different categories and aims to be segmented [36][37][46]. Sequential palettes are most useful in one dimensional visualizations, such as the height of a map. Whilst diverging palettes are commonly used to display between two extremes, where there is a neutral middle point[47]. Qualitative palettes are more often used to divide the data in a number of categories, such as in a bar graph with multiple dimensions. The choice of palette is closely connected to the purpose of the data dimension that is represented through the palette. As such, the choice of palette will be further discussed in a later chapter.

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