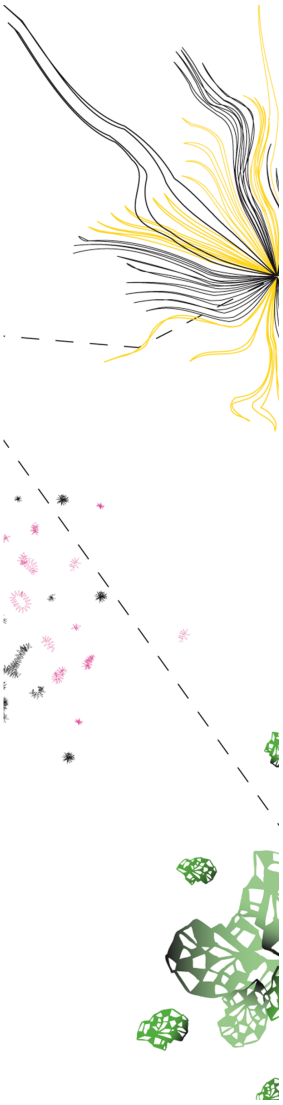

The creation of the Smart Interactive Mini Table

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Abstract

The Smart Interactive Mini Table (SIMT) graduation project aims to enhance and develop a tool that can be used for various on-table use cases. The SIMT is a variant of an existing bigger interactive dining table. Its hardware and software can be improved to develop a smaller, more practical, adaptable and internet-enabled smart interactive table. An literature review is done gain insight into the different connectivity methods with which the tables could be connected to each other. Wi-Fi together with MQTT were chosen as the most promising. Using the CreaTe Design Guide as a guideline for the design of the Smart Interactive mini table, it will guarantee that it not only meets the requirements that were gathered from expert interviews but also meets the needs of the users. A prototype was realized of the SIMT, that was tested and evaluated with users. The important requirements that were set for the SIMT were met, however the SIMT cannot yet be used as a tool by others in it's current state.

Contents

Acronyms

AC Access point.

AMQP Advance Message Queuing Protocol.

BLE Bluetooth Low Energy.

BSS Biomedical Signals and Systems.

coAP Constrained Application Protocol.

FDMA Frequency division multiple access.

HMI Human Media Interaction.

HTTP Hypertext Transfer Protocol.

IEEE Institute of Electrical and Electronics Engineers.

IoT Internet of Things.

LTE Long Range Evolution.

MVP Minimal Viable Product.

OSI Open Systems Interconnection.

SIMT Smart Interactive Mini Table.

SUS System Usability Scale.

TCP Transmission Control Protocol.

TDMA Time division multiple access.

TUI Tangible User Interface.

WAN Wide Area Network.

Chapter 1

Introduction and problem statement

A few years back, the University of Twente's Biomedical Signals and Systems (BSS) and Human Media Interaction (HMI) departments collaborated to develop an interactive table. There are 199 hexagonal modules on this table, each module consisting of one load cell and 42 LEDs. The individually controllable LEDs can function as a dynamic screen, and the load cells can be utilized to measure the distribution of weight across the table. [1]

1.1 Problem statement

The existing interactive table works well, however it does not have any remote applications and is too big to easily be moved. These limitations could be solved by having multiple smaller tables that have the ability to connect to each other.

Adding a feature to the smaller table which gives it the ability to communicate with other tables. This will be a new feature that is not part of the big table, and thus research needs to be done to find what the best communication method for this would be, which will be done in the form of a literature review. As the table is an instrument without a dedicated use case, it needs to work in various scenarios. Adaptability to different use cases is an important design factor because of this and should be considered when making the system design and software architecture. To ensure that the table can be applied in multiple scenarios, expert interviews will be carried out to find overlapping requirements in different use cases. Additionally, the hardware for the smaller table is being produced, however the software that was made for the big table cannot accommodate the new layout of the small table. The software will need to be modified in such a way that it becomes adaptable enough that it works on both the big and the small table which will be done in the realization.

1.2 Research question

How can the smart interactive dining table's hardware and software be improved to develop a smaller, more practical, adaptable and internet-enabled smart interactive table?

- 1. What methods prove to be the most effective for connecting multiple smart interactive tables?
- 2. What design considerations should be taken into account to ensure the system is applicable on different use case scenarios?
- 3. How can the system design and software architecture be designed such that interaction specifications can easily be used with both the existing big table and the new mini table?

Chapter 2

Background research

2.1 Literature review

2.1.1 Introduction

To answer the question of what method would prove the most effective for connecting multiple smart interactive tables, a literature review will be done. This is needed because there are a lot of different technologies that can be used, and they all have their own strengths and weaknesses. The connectivity methods that are chosen should make it possible for mini tables to communicate with each other. The selection of the connectivity method for the mini table will greatly influence for example the performance, reliability, security, or scalability of the tables. It is possible that one approach could be superior in one aspect but be lacking in another. For example, a method could be able to transfer data from one table to another very quickly, but also lose half of the data in doing so, making it not reliable. Thus, the purpose of this literature review is to gain insight into the different connectivity methods with which the tables could be connected to each other. Several connectivity methods will be identified, and their strength and weaknesses will be assessed, after which the best option will be chosen to use for the smart interactive mini table. This background research has taken from and based on the academic writing assignment from module 11 of the Creative Technology study. [2]

2.1.2 Study selection

For section 3.1 the literature review, Google Scholar, Scopus, and research rabbit were used as tools to find relevant articles in the field of connectivity methods. The search terms that were selected are synonyms and closely related topics of connectivity methods for connecting modules. The exact search terms that were used can be found in Table 1. For finding papers about lower level connectivity methods, a criterion that was used was that the articles had to be published between 2015 and now. For the higher level connectivity methods, that criterion

was limited to between 2020 and now to make sure the methods mentioned were not outdated as this type of technology evolves faster. All articles also had to be peer-reviewed as well as be written in the English language. Another softer criterion was that the papers had to compare or evaluate multiple methods in the research. Based on these criteria, ten papers were selected in total, of which six articles are about lower layer methods and four about higher layer methods. Two papers that do not fit the criteria above, but that were used to clarify some concepts, are the study explaining the OSI model [3] and the benchmark test by Fan and Kim [4].

Search term	**Similar terms**
Internet	Internet of Things, IoT
protocol	Framework, Technologies
Connectivity	Connection, Communication
Wireless	-

Table 1: Search terms used in literature review

2.1.3 Literature review

When choosing connectivity methods, it is important to know that several methods can be layered on top of each other. A model that explains the different layers on which connectivity methods can work is the TCP/IP model. The model is made up of four layers in total which can be found in Figure 1, but this literature research will mainly focus on the network access layer and on the application layer, as this is where the most impactful choices need to be made. As the model is a stack, the most logical way to choose a connectivity method is starting from the bottom. The bottom layer of the stack is the network access layer. This layer plays a big role in having a reliable link between the tables because the other layers will have to work on top of this layer. The network access layer technology will for a big part decides the efficiency, throughput, and reliability of the connection.

The application layer is where the format and structure of the data exchange is defined. It is the top layer of the TCP/IP model and serves as the layer between the application and the network. It also is the layer where authentication and access control is performed. [5] Because this layer is at the top of the stack, it is also the layer that users are the closest to. Choosing a fitting application layer protocol decides the compatibility, efficiency, and security of the communication between the tables.

The transport layer methods like UDP and TCP will also be mentioned when choosing an application layer technology. The application layer method can greatly influence the strengths and weaknesses of the transport layer protocol, which is why choosing a specific transport layer method is not very practical. The network/internet layer will not be mentioned in the literature review, as this would mainly consist of choosing the way the IP address is formatted. Evaluation of technologies and protocols for the application and network access

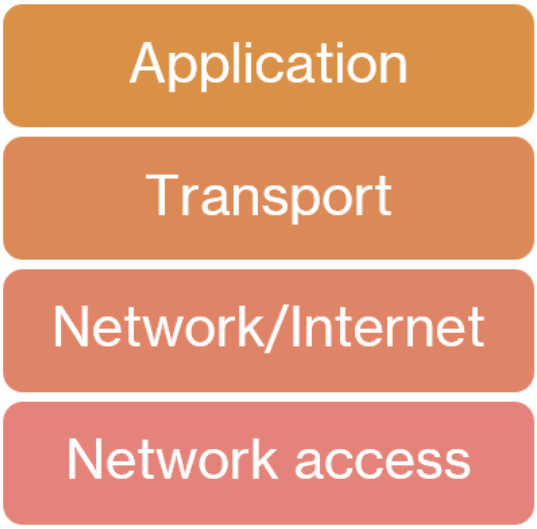

Figure 1: TCP/IP model layers

layers is needed to ensure an efficient and effective communication between tables, while the other two layers are less interesting because they have less impact.

Overview of existing methods for the network access layer

Starting at the bottom of the stack, a method for the network access layer will need to be chosen. Research by Ding et al. [6], Al-Masri et al. [7], Oliveira et al. [8] and Elkhodr et al. [9] provide valuable insights into the most widely utilized connectivity methods on this layer. Table 2 gives an overview of the methods that these four studies discussed. Two other studies by Cavalcanti et al. [10] and El Hassan et al. [11] are also included, as they discuss the more recent technologies in the field, including the newest Wi-Fi versions that are used nowadays that the previous four studies did not talk about.

Table 2 shows that one of the most well known connectivity method is Wi-Fi, as it is mentioned in all four studies as well as in the paper by Cavalcanti et al. [10]. LoRa, LTE, and Zigbee are also methods that are often mentioned in the field. Other methods that are often discussed are Bluetooth, NB-IoT, Sigfox and HaLow. A method that is also named is NFC, which is interesting as NFC only works when two devices are nearly touching. As evident by the table, there are various connectivity methods on the network access layer from which one can choose. The methods that are chosen to be further examined in the next subsections are those that are mentioned to most frequently, meaning the technologies in the table with the most X's. This is a practical choice, as it limits the scope to methods that are more widely known and used, meaning more information can be found on how to use and implement the method. This could

later make the process of implementing the method to the Smart Interactive Mini Table easier. So to gain insight into which method would be the most suitable for the Smart Interactive Mini Tables, in the next section investigation will be done to find out how some of the methods work and what their pros and cons are.

	Ding et al[6]	**Al-Masri et al**[7]	**Elkhodr et al**[9]	**Oliveria et al**[8]
WiFi	x	x	x	x
5G	x			
ZigBee	x	x	x	x
Bluetooth	x	x		x
BLE			x	x
ANT+		x		
NBIoT	x	x		x
ZWave		x		x
WirelessHart		x		x
Weightless		x		x
LTE	x	x	x	x
LoRa	x	x	x	x
HiperLAN			x	
HaLow	x		x	x
NFC		x		x
Sigfox	x	x		x
OWC				x

Table 2: Potential methods that could be used for connectivity on the network access layer

Wi-Fi

One of the most common approaches of connecting on the network access layer is by using Wi-Fi, which is defined as IEEE 802.11. Wi-Fi can be found in most homes and is a reliable, fast and secure connection method as explained by Elkhodr et al. [9]. They also mention the multiple drawbacks that Wi-Fi has. Because Wi-Fi is so fast, it also consumes a lot of power and when a lot of people are using it, there will be interference. Oliveira et al. [8] explain two ways in which Wi-Fi can communicate. One is between devices directly, creating an ad hoc topology, the other involves creating a star topology where one device becomes an access point. At this access point, data is collected, and the access point is often connected with a wire to a Wide Area Network (WAN). At some point, a version of Wi-Fi was needed that had a lower energy consumption. This is why Wi-Fi HaLow was created. In addition to reduced energy consumption, it also had a lower latency than the current Wi-Fi version at that time, and it can connect thousands of end devices. [8] As mentioned before, there are a lot of versions of Wi-Fi and Ding et al. [6] explain the differences between the version that were created, a, b, g, n, and ac. Almost all versions were created

because of the need for more throughput, except for Wi-Fi HaLow, on which Ding et al. [6] comment that it was created for the low energy consumption, its extended coverage and its bandwidth occupation. Ding et al. [6] however, stop at the ac version, after which two other versions have been released. Cavalcanti et al. [10] does talk about these newer versions and also how they can be combined with Time-Sensitive Networking (TSN) to allow for an even faster connection for application that require the latency to be lower than a millisecond. Collectively, the researchers all name Wi-Fi as one of the most used technologies for wireless communication, and its different versions allow for a diverse application.

Bluetooth

IEEE 802.15.1 also known as Bluetooth is a short range wireless network method that is a cheap alternative to Wi-Fi. Oliveira et al. (2019) [8] gives a very in-depth explanation about the evolution of Bluetooth up until version 5.0. It talks about how the different layers of Bluetooth relate to the OSI model and the different power classification. Oliveira et al. (2019) [8] also explain the topology of Bluetooth as a master-slave system where a master device can connect to a maximum of seven slaves, forming a piconet topology. This has a range of 40-100 meter depending on where it is used and data rate of about 1-2 Mbps. Piconets can overlap, creating a scatter-net topology, where a salve can communicate in different piconets by using in time multiplexing. Ding et al. (2020) [6] also gives an explanation of Bluetooth, but quickly goes into detail about Bluetooth Low Energy (BLE). As the name suggest, BLE was made for devices that cannot not meet the demand of the high power consumption of Bluetooth. Elkhodr et al. (2016)[9] talks about the applications BLE has for IoT devices because of its low power and low cost properties. Ding et al. (2020) [6] and Oliveira et al. (2019) [8] explain that BLE uses frequency division multiple access (FDMA) and time division multiple access (TDMA) based polling to reduce energy consumption. The slaves are put into sleeping mode on default and are only woken up through TDMA whereas in normal Bluetooth a stop-and-wait flow control is utilized. The papers describe Bluetooth as a cheap alternative for WiFi with a lower transmission range. BLE is a lower power consuming alternative, but also has a lower data transmission rate.

ZigBee

ZigBee is an technology built on IEEE 802.15.4, and is intended for short range wireless communication mostly used in IoT devices. ZigBee is very flexible and scalable, however BLE is often picked over ZigBee as they have similar traits but BLE has lower power consumption but also a higher data throughput. Oliveira et al. [8] talk about the underlying technologies of ZigBee which is mostly out of scope for this project. Al-Masri et al. [7] give a short overview of what ZigBee is, where they explain the different topologies ZigBee can be in. They also gives us some numbers on ZigBee, it has data rates of 20 to 250 kbps and there can be around 65000 nodes in a network. Ding et al. [6] explains these networks, where

there are coordinatios routers and end devices in a network. By linking these devices together the very large networks can be made. The enhanced version of ZigBee, called ZigBee IP is introduced to us by Elkhodr et al. [9]. This improved version offers better compatiblity between ZigBee and IP-vased networks and additionally it offers IPv6 end-to-end networking.

LoRa

LoRa and the LoRaWAN protocol offer a communication method that is long-range and low-power. Al-Masri et al. [7] and Elkhodr et al. [9] say to LoRa can support even more nodes than ZigBee, counting into the millions of nodes. Oliveira et al. [8] explains the technology behind the node networks. Sigfox is mentioned as a competing technology to LoRa by Ding et al. (2020)[6], Oliveira et al. [8] and Al-Masri et al. [7]. However SigFox will not be taken into consideration for the SIMT as Ding et al. (2020)[6] explain that Sigfox has a limit of 140 messages a day.

Evaluation of network access layer technology

Various wireless methods to connect the SIMT were discussed. These methods all meet different needs, where Bluetooth and BLE offer short range communication, LoRa offers long-range communication and both do not use a lot of energy. Wi-Fi offers high-speed reliable communication but costs more power. ZigBee then excels in flexibility for IoT networks. Understanding what the different methods excel in, makes it possible to choose a method to connect the SIMT tables as now an informed decision can be made based on the research.

The SIMT has some requirements that the connectivity method to be used will have to meet. The methods discussed above will be evaluated to see if they meet the requirements and the most suitable one will be chosen to be used for the SIMT. The SIMT will have a total of 19 load cells, when sending data, each cell will have to share 3 bytes. 3 bytes times 19 cells accumulates to 57 bytes for the entire table. The load cells measure at a speed of 72 HZ, as said by Haarman et al. [1]. This means that to capture all the data that is measured by the load cells the data transfer rate needs to be 57 bytes times 72 samples per second, is 4104 bytes per second that need to be transferred. We might also want to send and receive data on all the states of the LEDs. As there are 798 LEDs, most likely about 4 bytes are needed to determine the led number and state being on or off. When the color data also needs to be send and received, a total of 7 bytes is added on top of this. The total number of bytes accumulates then to 13 times 798 which is 8,777 bytes per second to transfer. To make the sending and receiving data process easier and more reliable, start and end characters can be added to the data. This would add some more bytes to the transfer rate.

Looking at the requirements above and comparing them with the findings from the research on the different connectivity methods, Wi-Fi seems to be the best option. Wi-Fi meets the required transfer rate of 8777 bytes per second easily, and is a reliable connection method. In addition to this it is also often

used and many other methods are compatible with it. The main reason however that Wi-Fi would be a better choice than the other methods, is that the infrastructure is in most places already there. Many places have Wi-Fi available so in many scenarios no extra infrastructure is needed and the SIMT can just connect to the nearest router. There are some drawbacks of using Wi-Fi such as that the transfer speed does rely on the Wi-Fi version and the type of router, as well as the strength of the connection which can greatly vary between places. The other big drawback of Wi-Fi consuming a lot of power compared to some other methods should however, in most use cases, not be a problem. This is because the SIMT will already need to be connected to a power socket for it to work, as the LEDs and load cells need this power too. When taking all these factors into account, Wi-Fi seems like a logical choice as a connectivity method for the SIMT.

Application layer

Now that Wi-Fi has been evaluated as the most promising connection method, application layer protocols can be investigated. Before a decision can be made on which method would fit the best with the SIMT, the protocols will need to be identified and evaluated. Hyper Text Transfer Protocol (HTTP) is the dominating protocol for data transport, however there are many other options such as MQTT. Four studies were selected to find the most used protocols to investigate, the chosen protocols can be found in Table 3.

	Puthiqidam and Shelbi[12]	**Ravuri et al**[13]	**Iqbal et al**[14]	**Sharma et al**[15]
HTTP/HTTPS	x	x		
MQTT	x		x	x
CoAP			x	x
XMPP			x	x
AMQP			x	x

Table 3: Potential methods that could be used for connectivity on the application layer

The study by Puthiyidam and Shelbi [12] evaluates different setups of an MQTT protocol and compares it to the HTTP protocol. MQTT work with publishers and subscribers, where a publisher can have multiple subscribers. The paper shows the more subscribers a publisher has, the longer it takes for a message to be delivered. However with the publisher-subscriber setup, a session is created that can be maintained, whereas, in HTTP each time data is accessed a three-way handshake needs to be done. Ravuri et al. [13] suggest using Dynamic Adaptive Streaming over HTTP (DASH) in combination with QUIC for media streaming. QUIC replaces TCP as the transport layer in HTTP/3 reducing latency but also reliability. Using this combination makes it possible to share large media files with very low latency. MQTT uses TCP as its trans-

port layer, allowing for reliable data transfers. It is very easy to set up and lightweight, making it a good protocol for IoT devices.

Advance Message Queuing Protocol (AMQP) is similar to MQTT in that it can use a publisher/subscriber architecture, but it can also use a request/response architecture. While MQTT is specialized for IoT devices, AMQP has a broader application range. Headers can have varying length and the protocol is reliable. [14] [15] Extensible Messaging and Presence Protocol (XMPP) is mostly used for real time communication and also offers both publisher/subscriber and request/response architectures. [14] Constrained Application Protocol (CoAP) like HTTP uses request/response architecture but uses UDP instead of TCP. CoAP can be seen as a more lightweight alternative of HTTP. Fan and Kim [4] did a benchmark test between MQTT, HTTP, CoAP and AMQP, the throughput, delay and security are summarized in table 4 to give a good comparison of the differences between protocols.

	Throughput (request/s)	**Delay (s)**	**Safetly level**
HTTP	443	1.2360	Good
MQTT	4106	0.1101	Poor
CoAP	1877	0.8661	Average
AMQP	217	0.1255	Excellent

Table 4: Comparison of protocols in throughput, delay, and security from benchmark tests by Fan and Kim [4]

As the SIMT will be used in a variety of use cases, the protocols on the application layer need to be versatile, to accommodate different scenarios. Because of this, choosing a protocol that is widely used and supported would be sensible. Taking this reasoning, choosing HTTP as the protocol to use for the SIMT could be a good choice. However, from the performance test by Fan and Kim [4], MQTT seems like the best choice in terms of throughput and delay. This is why, for the direct data exchange between tables, MQTT will, for now, be chosen as the application layer method to use for the SIMT.

2.1.4 Conclusion

In this literature review the most promising methods for connecting the Smart Interactive Mini Tables were found. This was done through first finding the most popular existing methods and evaluating them. The methods that were found, were further examined to find their pros and cons, as well as technical details such as throughput.

There were several methods that were looked into, these are Wi-Fi, Bluetooth and BLE, ZigBee and LoRa. From these, the method that was seen as the most promising was Wi-Fi because of the infrastructure already being in place in addition to meeting the other requirements of the SIMT The application layer was also looked at. The connectivity protocols that were considered were

HTTP, MQTT, CoAP and AMQP. MQTT seemed the most promising and was chosen as a method with which to connect the tables.

A more practical test should be done to find if the selected connectivity method and protocol prove to work for the SIMT. However first it will be seen how other similar tables have been connected to each other in other studies.

2.2 Previous studies and works

An alternative method to finding connection possibilities is by looking at previous studies and works where tables or similar devices are used to connect people. The following works have been found.

In the field of tangible user interfaces (TUI) and interactive connected table systems, MIT's inFORM table [16] is a notable contribution. The inFORM table has a dynamic surfaces that can show three-dimensional shapes. Users can remotely manipulate the tables surface through digital and physical methods. Having multiple input methods expands the range of potential applications for the table. The SIMT could also potentially benefit from this where you can also interact with the table via a device that is not the table. There are a lot of applications for the inFORM table, including remote collaboration on 3d object, as well as showcasing them. The tables are connected to a computer and the communication has a total latency of 150 to 200ms, mainly cause by the camera and image processing. No further information could be found the connection.

Another noteworthy contribution in the field of tangible user interfaces is PlayTogether by Microsoft [17]. It allows for two users to play a board game together remotely. It uses a projector and cameras to turn a tabletop into an interactive play area. A player has their own physical pieces, while their opponents pieces are projected on the board. The two sides are connected together through a local gigabit network though nothing more is said about the connection. A drawback of this table is that shadows can obstruct the projected video. There are quite some systems that are similar to the PlayTogether table in terms of using a camera and projection to connect users via a table. A couple examples are IllumiShare [18], MirageTable [19] and IncreTable [20] Another interesting mention is the Actuated Workbench [21], which is a tabletop that can move physical objects on the table by the use of magnets controlled by a computer. It was designed to use together with existing interactive tabletops to provide additional tangible feedback. None of these however mention any technical details on how the tables are connected.

So it was decided to step away from tables and looking at projects that use a combination of LEDs and communication, in the hopes of finding more practical information on communication protocols, as no information can be found on how the tables above communicate. These projects are mainly Arduino instructables, DIY projects and YouTube instruction videos.

The first project is made by a YouTuber named Maker101 [22], who uses an ESP8266 (Wi-Fi microchip) and MQTT to display a text on the LED display that was filled in on an android device. This seems to work well, however they

use an app to communicate only a single message, so how fast messages can be sent remains unknown for now. Another project that uses MQTT uses a Raspberry Pi for communication. This project is by MickMake [23], where MQTT is used to send images and GIFs to a LED panel. From the video the delay seems noticeable but only barely, however there is a camera switch at that point of the video, so the delay could have been edited out. A project that uses almost the same method as Maker101 [22] is the project by Useful Electronics [24], the project involves a lamp that can be set to any color from a phone using MQTT. In this video, the response delay is not noticeable.

These DIY projects show that the information found in the literature also work on a more practical level. Wi-Fi and MQTT seem to often be used in project involving LEDs and communication which gives more confirmation that the choices to use these methods for the SIMT is a good one.

Chapter 3

Approach

An in-depth explanation of the methods that were used throughout the creation of the Smart Interactive Mini Table will be given in this chapter. By using systematic approaches, the project aims to ensure its validity and reliability. The project follows the guidelines set by the Create Design Process [25]. The project was started with a literature review to get a good understanding about the current knowledge on the topic. After, multiple expert interview are done to find where the SIMT can be applied, and to find requirements. These requirements are then given a priority so that an MVP can be made. Lastly, the MVP will be evaluated to find if all requirements are met. The details of all the methods mentioned and used during the creation of the SIMT are explained below.

3.1 Literature review

To get an overview of the current knowledge on the topic of connectivity methods, a literature review was done to identify methods that could be used for connecting the SIMT's. This was done in section 3.1, and more details on the systematic approach with which articles were chosen to review can be found in section 3.1.2.

3.2 CreaTe-Design-Process

The create design process is a design method made for the bachelor Creative Technology created by Angelika Mader and Wouter Eggink. The create design process is a spiral model that uses divergence and convergence. It consists of four phases, Ideation, Specification, Realization, and Evaluation. [25]

3.2.1 Aims

The CreaTe Design Guide will serve as a reference framework for the design processes. By following the four phases previously mentioned, the design pro-

cess will be done in a structured way. An overview of the model can be found in figure 2. The use of divergence and convergence during the design process will ensure that a board space of ideas are considered, which will then be systematically narrowed down to find the best solution for the problem. This will help with exploring many ideas but also with decision-making. The model being a spiral gives flexibility to the design process, allowing a more dynamic approach. Using the CreaTe Design Guide as a guideline for the design of the Smart Interactive Mini Table will also guarantee that it not only meets the requirements but also meets the needs of the users. This is because the design guide places emphasis on the user-experience by wanting the creator to make multiple prototypes that should be evaluated by users. [25]

3.2.2 Method

The project will be done with the structure described below, which can also be found back in the report structure.

Ideation

The ideation phase's goal is to come up with initial requirements and concepts. The project started with a product idea / order from the client. Doing interviews with clients, users, or experts can help in identifying requirements. [25] For this project, expert interviews will be done. Background research and brainstorming will also be done as part of the process of gathering ideas and requirements for the SIMT.

Specification

The specification phase has the goal of specifying the concepts that were come up with in the ideation phase. It uses the best ideas from the ideation to come up with early prototypes of the SIMT. The CreaTe Design Guide is different from the Engineering Design in that it wants creators to make multiple prototypes. [25] However, due to the fact that the hardware for the SIMT is already built, this phase will follow the Engineering Design guide of only having one prototype that is improved upon.

Realization

After the specification phase, the SIMT needs to be built in the realization phase. This is done by breaking down the specification, realizing the actual components, and integrating them. In this phase, a minimal viable product (MVP) of the SIMT will be build that has all the cire functions to be able to conduct a user evaluation in the next phase.

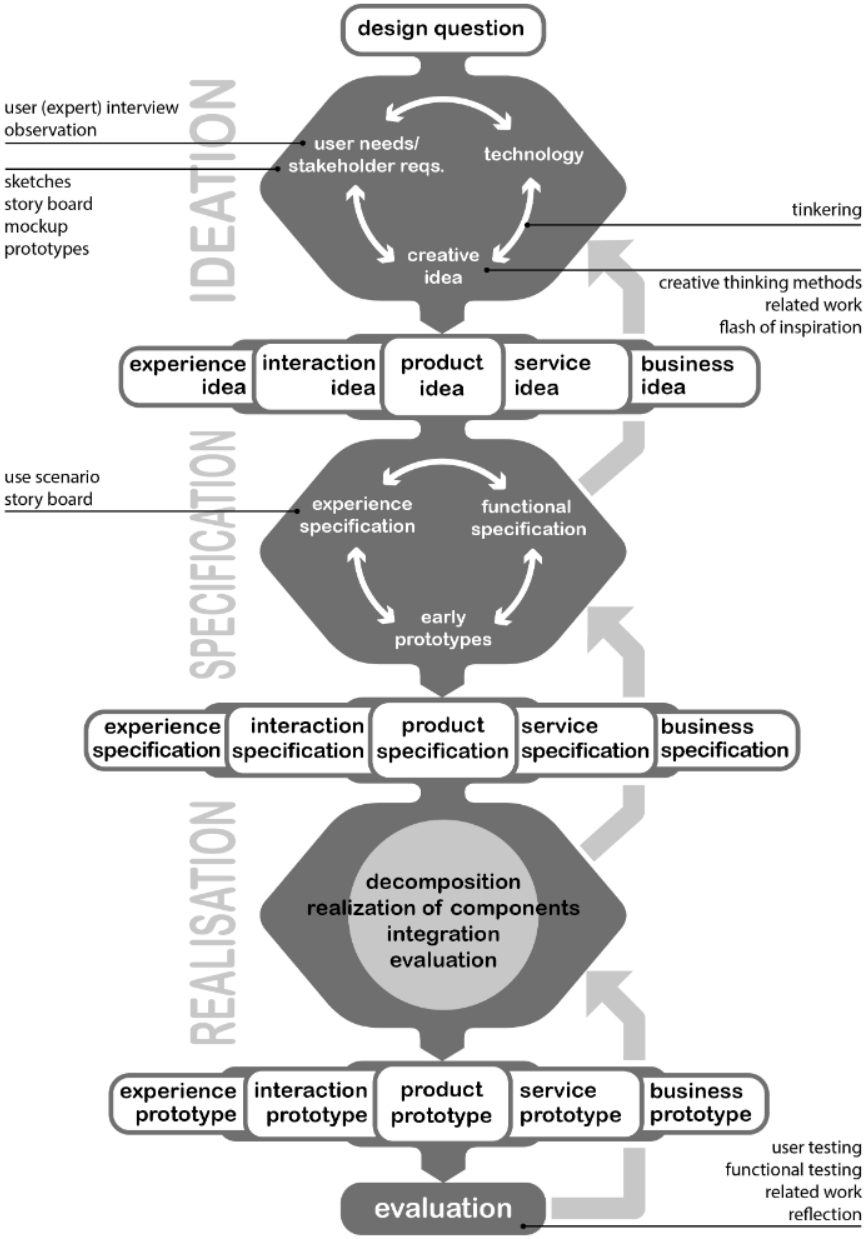

Figure 2: CreaTe Design Process model [25]

Evaluation

In the evaluation phase, it will be assessed if the MVP meets the requirements. A user evaluation on the MVP of the SIMT will be done in this project to establish if the prototype meets the requirements. After this, the product can be placed in the context of the related work.

3.3 Expert interview

In an expert interview, 'expert' individuals are interviewed about their knowledge or experience in their area of expertise. It is a qualitative research method with the purpose of gathering in-depth information about a specific area.

3.3.1 Aims

An expert interview will be done for this project to find in what use cases the mini table could be applied or help with research. From those cases, system requirements will be extracted. The interview will aim to exploring and collecting information about different kind of scenarios in which researchers would want to potentially use the mini table and what the table should be able to do, to be applicable in those use cases. The findings from these interview should contribute to the understanding of the system's functional and non-functional requirements. Some use case scenarios might need unique solutions tailored to the use case, but there might also be requirements that overlap between use cases that could be incorporated in the design to allow for a broader application.

3.3.2 Method

An interview will be held that is done by two people, one person taking notes, the other asking the questions, switching roles halfway through. The duration of the interview will be 20 to 30 minutes. Before the interview is started, the interviewee will be asked permission for recording the interview. This is done to ensure that if details are missed during note-taking, there is the possibility to listen to the recording and retrieve them. The interview will be a semi-structured interview that will start off with an introduction where the mini table is explained. After, the interviewee will be asked to think of scenarios in their field where this table could potentially help them with research or solve a particular problem. Depending on the scenario the interviewee describes, follow-up questions will be asked to dive deeper into what the table should be able to do for it to be effective in those situations and what could potentially limit the usefulness. The interview will end with a short summary to verify the interviewer interpreted the information correctly. A more complete overview of the interview setup and question can be found in Appendix A.

3.4 Requirement Prioritization

In a project with limited time, it is important to prioritize some requirements over others. This ensures that time is spent wisely and keeps the product within a manageable scope.

3.4.1 Aims

Requirements will be prioritized based on which requirements are essential for the products to work and which requirements a not necessary for the basic functionality of the product. This is done so that a working prototype can be made within a limited time span. By doing this, a minimal viable product is created, which allows for feedback from users early on in the development process.

3.4.2 Method

MoSCoW

The MoSCoW method will be used for requirement prioritization. [26] MoSCoW is an acronym that stands for the following:

1. (M) Must have – These requirements are critical for the product's base functionality and should be met for the product to be considered working.
2. (S) Should have – These requirements are desirable but not critical, they are still high priority requirements, but the product would still work without them.
3. (C) Could have – These requirements would be nice to have, but only if the time permits it.
4. (W) Won't have – These requirements are not within the scope of the product. However, they could be implemented when the product is further developed.

All requirements will be placed in one of these four categories. In the evaluation phase, if all the must-have requirements are met, the prototype will be considered successful.

Functional and Non-functional requirements

Functional requirements are requirements that the product should have for it to function. They are requirements that are observable by a user, the user gives an input and expects an output. Non-functional requirements are not directly observable by the user and can be roughly categorized in requirements that deal with portability, security, maintainability, reliability, scalability, flexibility, re-usability, and performance. The requirements for the SIMT will be placed into one of these categories and based on this some categories can have a higher

priority than others. For example, flexibility will be a high priority category in this project, as is it is part of the problem statement.

3.5 User evaluation

3.5.1 Aims

The purpose of the user evaluation will be to test the MVP that was creating to see if all the core features are working and to get feedback and insight to improve the design. By doing a user evaluation, assumptions could be validated, and some usability issues could be identified.

3.5.2 Method

The user evaluation will start off with the user being given a set of instructions. The user will be asked to perform certain tasks with the table, which will be observed as unobtrusively as possible by an observer with a checklist if actions are successfully performed and comments on how it was achieved. The user will also fill in a post-test questionnaire to get a deeper insight into the usability and the overall satisfaction. For this, the System Usability Scale (SUS) will be used with some additional questions added in the same format that apply to the context of the SIMT. Four to seven people should be part of the user evaluation based on the research by [27] to effectively find most of the usability problems.

Chapter 4

Ideation

In this chapter ideas will be generated and developed, however as the Smart Interactive Mini Table (SIMT) is a variant of an existing bigger interactive dining table part of the ideation is already done. However, the SIMT has additional features that the big table does not have, and should also include solutions for some fault that were found with the big table. In this chapter, expert interviews are done and the requirements from the expert interview and the background research will be gathered, as well as some general requirements that were already present in the big table. These will then be combined to make a full list of requirements, divided into functional and non-functional requirements. At the end of this chapter, some initial concepts will be suggested and a roadmap to guide the development of the SIMT will be presented.

4.1 Requirements from expert interview

Three expert interviews were carried out, using the method described in section 4.3, to answer research question 2. What design considerations should be taken into account to ensure the system is applicable on different use case scenarios?. The requirements that were gathered from the expert interviews and have been categorized in functional and non-functional requirements. These categories should make it easier to understand what the system should be able to do for the functional requirements and how the system performs these functions for the non-functional requirements.

The first interviewee suggested the integration of the SIMT with smart devices, such as smartwatches and other IoT devices. Aspects such as timely feedback and resolution were mentioned, as well as how the visual feedback should be tailored for specific purposes. The second interviewee suggested several possible applications within their research, such as the analysis of writing patterns to detect neuropathy. She also suggested that the tables could be a good way of unobtrusively monitoring the weight of patients. Some examples for how accurate the data should be, were given as well. The last interviewee

suggested that the tables could encourage social interaction and healthier eating habits in elderly people. They highlighted points such as user experience, learning curves and maintenance issues of the big table. The learning curve and user experience for the table should be such once the table is set up, there does not need to be any instructions to get started using the table. The full list of requirements from each individual interview can be found in Appendix B.

As, in the expert interviews, the experts were asked to come up with a use case in which the table could be used, the requirements are tied to the use cases they came up with. The table has as an objective to be adaptable to various use cases, this means that the requirements have been combined and generalized so that the table could work within any of the use cases mentioned. These requirements can be found in Table 5 and Table 6.

Functional Requirements
A.1. The tables should efficiently and effectively communicate with other tables/smart devices
A.2. The tables should be able to offer visual feedback in various ways
A.3. The tables should support interactive games and experiences regardless of a user's demographics
A.4. The tables should be able to gather and analyze data captured by the load sensors
A.5. The tables should give users timely feedback through the LEDs
A.6. The tables should provide a multisensorial experience for impaired individuals
A.7. The tables should be intuitive to use and not need any instructions
A.8. The tables should have a one-time setup
A.9. The tables should support remote updates to its software

Table 5: Generalized functional requirements from expert interviews

Non-Functional Requirements
B.1. The tables should display information in a way that is easy for users to understand
B.2. The tables should have a reliable connection to other tables/devices
B.3. The tables should be user-friendly for users on varying levels of digital literacy
B.4. The tables should be accessible to all user groups, including those with visual impairments
B.5. The tables should have a minimal learning curve
B.6. The tables should ensure that collected data is secure
B.7. The tables should look robust and durable and not fragile
B.8. The tables should be compatible with existing technology/infrastructure
B.9. The tables should not pose any risks or distractions to a user that can lead to harm
B.10. The tables should be adaptable for use in different settings such as homes, hospitals, and other settings
B.11. The tables should accommodate various group sizes

Table 6: Generalized non-functional requirements from expert interviews

4.2 Additional requirements

Other general requirements that make sense for the tables to have can be found in Table 7 and Table 8.

Functional Requirements
A.10. The brightness of the table could be adjustable
A.11. The table's Wi-Fi setup could be such that the inner workings of the table do not need to be accessed
A.12. The table could be capable of running multiple applications at once
A.13. The table could have cybersecurity features to prevent unauthorized access

Table 7: Additional functional requirements

Non-Functional Requirements
B.12. The table could store user preferences such as how much data will be stored
B.13. The table's interface could support multiple languages
B.14. The table could have energy usage optimization
B.15. The table could comply with industry standards for this type of product

Table 8: Additional non-functional requirements

4.3 Implementation requirements brainstorm

Besides the expert interviews, background research was done and from the evaluation section, several requirements can be extracted. The background research provided a logical choice for a connecting method for the SIMT, namely Wi-Fi. An obvious requirement should thus be that every table has the means to connect to a Wi-Fi router for internet access. The table also needs a way to know which router to connect to and a way to fill in a password, as most routers are password-protected. An additional requirement could then be that the table should remember this and automatically connect after the first time. This would help fulfill the requirement from the expert interview, A.8. "The tables should have a one-time setup".

Specific requirements for throughput and data size are harder to establish. The minimums were calculated in the evaluation section of the background research, however realistically these numbers could be very different. Something that needs to be taken into account is a scenario where, because of for example

a bad connection, the throughput is not high enough. The table should know how to regulate itself in this scenario, ideally in a way that minimal data is lost and use of the table is still somewhat possible.

The requirement, B.11. "The tables should accommodate various group sizes", and the requirement B.10. "The tables should be adaptable for use in different settings such as homes, hospitals, and other settings" in addition to the requirement A.1. "The tables should efficiently and effectively communicate with other tables/smart devices" from Table **??** suggests that there is a way to configure table groups. When there are multiple tables, a useful feature might be, being able to select to which other tables you want to connect or maybe even to other smart devices. For this to be possible, there needs to be some sort of interface where you can see every what other tables or devices are available to connect to. Possible ways to do this could be using the table's LEDs to create an interactive screen or through a web interface.

There is also the scenario where multiple tables are in use, but not every table is used with the same purpose. So one table could run an application meant to help older people eat, and another table could run an application that lets you play a game. These two tables should then not be able to connect to each other to exchange data, as that would not make any sense. Another thing that needs to be considered is if there will be dedicated tables for a single application, or if tables also need the ability to switch between application. This would make tables with different application not connecting to each other slightly harder. If tables can switch what application they are running, an interface where you can select what application you want to run is also needed.

In one of the expert interview, it was mentioned that keeping the big table updated and programming new software for it was difficult. A great additional feature could be that the tables can be updated remotely, and a clear explanation is added that tells people how to make and add a new application to the table. An approach to this could be taking advantage of the internet connection that the SIMT's have by connecting them to a GIT repository. Then every time the table starts up, the table can look for any changes and do an update if needed. Combining this feature with tables being able to run multiple application, a rudimentary form of an "app store" could potentially be created, where the table only fetches application data when it is told to do so in the interface.

Some of the feature mentioned in this section, while conceptually good, will most likely be logistically unattainable during the given time frame. In the next chapter, prioritization of requirements will be done to ensure that at the end of the project a working prototype is created. However, first, some concepts for the SIMT will be explored in more detail and visualized to get a better overview of how some of the requirements could be incorporated.

4.4 Concepts

Multiple requirements or proposed features are visualized in either diagrams or concept pictures. Especially when there are multiple ways to do something, a

visual concept generation or diagram can help better understand what the final product would look like or what would be the most logical choice.

4.4.1 Visualization

The first thing that was created was a visualization of what the table would approximately look like in Blender, as can be seen in figure 3. This was made to get an idea of the scale of the table, as well as to give the experts that were interviewed an idea of what the table would look like if they did not understand the concept completely from the explanation.

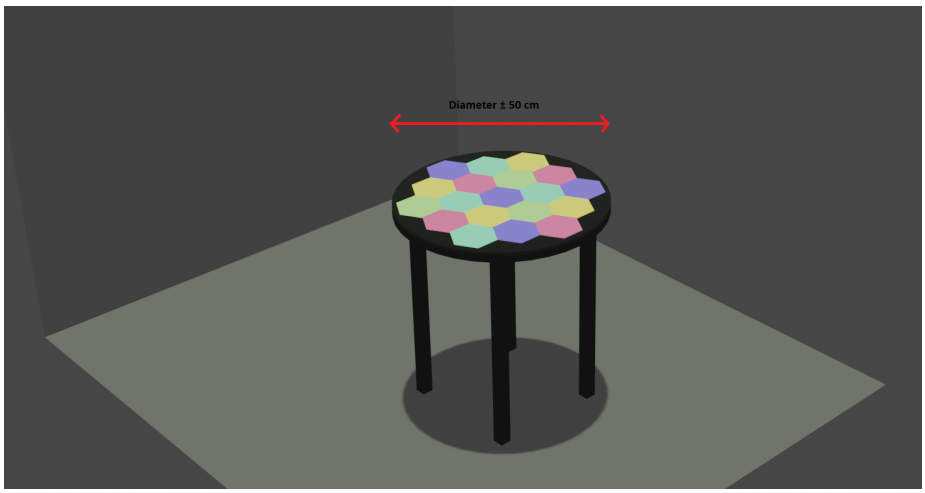

Figure 3: First visualization of a Smart Interactive Mini Table

4.4.2 Connection

Wi-Fi connection

A requirement that was put forth, was that the table should have a one time setup. In addition to that, ideally, the person setting up the table should not have to touch the hardware of the table. A proposed solution to this can be found in Figure 4. The idea is that when the table turns on, it tries to connect to the Wi-Fi with the details and password that it has saved, which the first time would be nothing, resulting in it failing. When it tried and failed, a technique that is also used to set up IoT devices is employed, where the table becomes a soft access point. It should then be possible to connect to the table from a device, fill in the details somewhere and close the access point. The table will overwrite the password etc. with the one that was filled in and then try to connect to the Wi-Fi again. How this is all done exactly will be worked out further in the next chapter, if this idea is chosen.

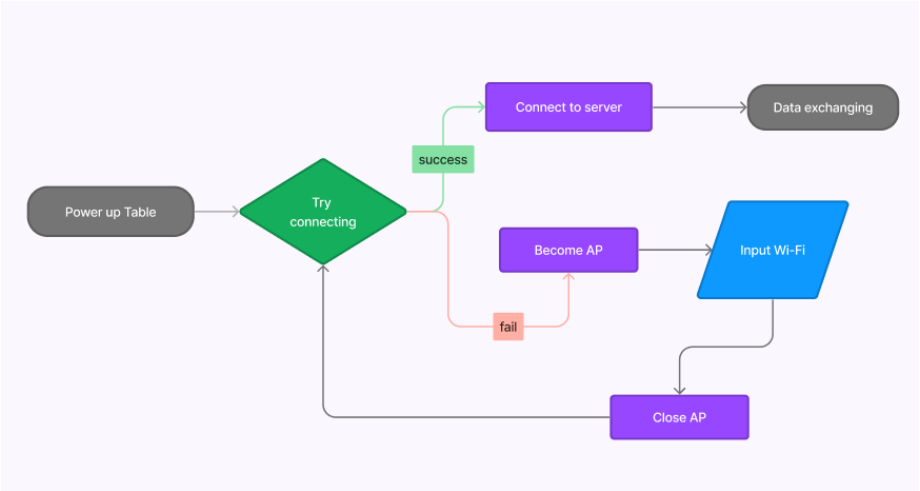

Figure 4: Wi-Fi input idea flow diagram for the Smart Interactive Mini Table

Communication

Most features and requirements assume that the tables are connected to a central server, as depicted in Figure 5 which was the first idea on how to connect the tables. However, there is also another possibility where one of the tables becomes the server, if it does not detect a server that it can connect to, to which other tables can then connect. A diagram of how this would work can be found in Figure 6. This however does have the drawback that when the server table disconnects, the other tables that are connected will lose their connection too. It does not look like a perfect solution, but it would pose a good alternative if the first idea does not work out.

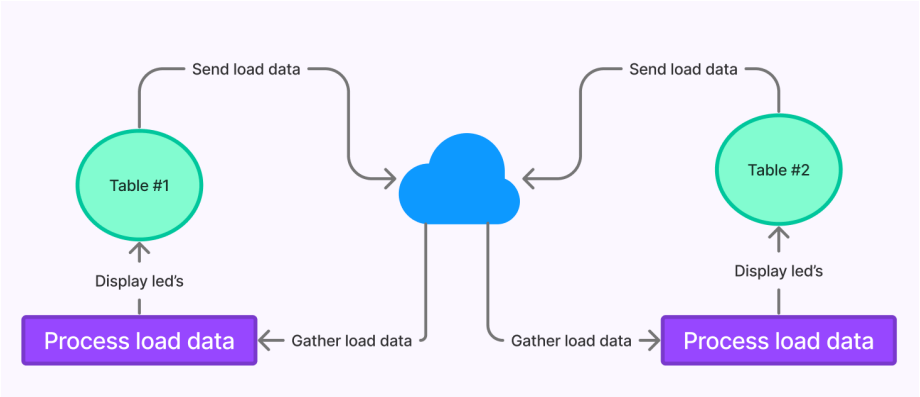

Figure 5: Connection idea diagram for the Smart Interactive Mini Table

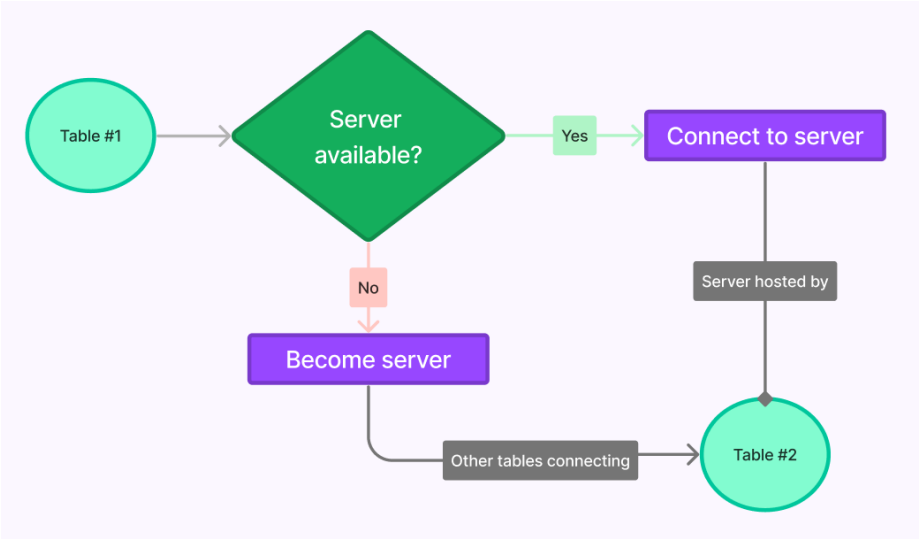

Figure 6: Connection idea 2 diagram for the Smart Interactive Mini Table

MQTT broker

Another reason why a client server setup is preferable is because MQTT needs a broker, and there is only one broker that can do p2p. This would severely limit the options for a MQTT broker. MQTT needs a broker to take care of the message transmissions. A broker is among other things responsible for identifying to which topic a subscriber is listening and sending the correct messages. There are a lot of option for client server MQTT brokers, all slightly different. As setting up a basic MQTT message exchange system is quite easy, multiple MQTT brokers were identified that can be tested in the specification phase. The first broker that will be tested and seems the most promising is RabbitMQ, this is an open source MQTT broker, that offers many options such as streams and filtering. It has a decent throughput and delay, as well as very good flow control. There is also clear documentation available, a discord where people help each other with question, as well as it being completely free to use. Other brokers that were identified and could be tested if RabbitMQ does not work in the context of the SIMT are, hiveMQ and MQTX as they are some of the biggest most used MQTT brokers, however they are paid.

4.4.3 Roadmap

From the requirements and the ideation, a rough overview of what needs to be done is approximately what order was made. 7 It gives an overview of the implementation of the basic function of the SIMT. The colors in the diagram represent the expected feasibility when looking at the time limit. This diagram will be expanded on in the specification chapter, where the requirements will be prioritized.

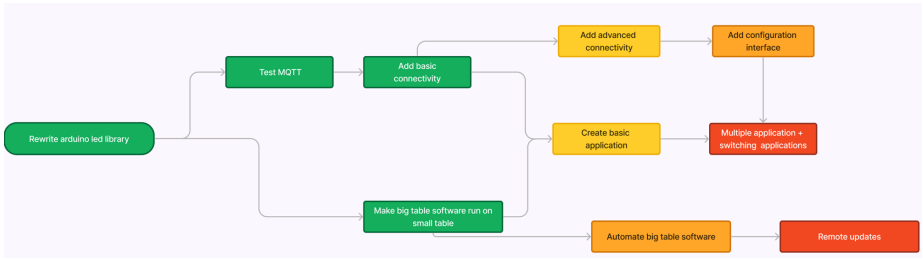

Figure 7: Rough overview of feature implementation for the SIMT

4.5 Ideation conclusion

The ideation has outlined the ideation process for the Smart Interactive Mini Table. The expert interviews helped with finding requirements so that the second research question of how the table can be used in various use cases can be answered. A list of requirement was made that can be used in the next chapter for the development of the SIMT. For some of the requirements, solutions on how to implement them were suggested, which will be further specified and decided upon in the next chapter.

Chapter 5

Specification

In this chapter, first, the requirements will be specified and prioritized. Currently, for the requirements that were gathered during the ideation phase, a lot of qualitative terms are used to describe the SIMT and multiple requirements could be split up to be more concise. The requirements will also be divided into the MoSCoW categories to get an overview of which requirements are more important than others. After this, for each requirement it will be described as to how it should be implemented, creating a full overview of how the prototype should function.

5.1 Requirement splitting

There were requirements that were two requirements in one, which could be split. The following requirements were split up, to make them focus on a specific feature so that they could be specified and prioritized better.

- A.1. The tables should efficiently and effectively communicate with other tables/smart devices
  - A.1.1 The tables should efficiently and effectively communicate with other tables
  - A.1.2 The tables should efficiently and effectively communicate with other smart devices such as phones and wearables
- A.4. The tables should be able to gather and analyze data captured by the load sensors
  - A.4.1 The tables should be able to gather and store data captured by the load sensors
  - A.4.2 The tables should be able to analyze data captured by the load sensors
- A.7. The tables should be intuitive to use and not need any instructions

  - A.7.1 The tables should be intuitive to use
  - A.7.2 The tables should not need any instructions for users to use it
- B.2. The tables should have a reliable connection to other tables/devices
  - B.2.1 The tables should have a reliable connection to other tables
  - B.2.2 The tables should have a reliable connection to other devices

5.2 Requirement prioritization

The requirements will be prioritized based on if they are necessary to answer the research question and the general do-ability of the requirements. For the first research question, it was found that Wi-Fi and MQTT are most likely the most effective way to connect the SIMT's. These two methods will be implemented, and are a big part of the mini tables functionality. This is why, for example, requirements A.1.1, *The tables must efficiently and effectively communicate with other tables, ensuring a data transfer rate of at least 8777 bytes per second* and B.2.1, *The tables must have a reliable connection to other tables with less than 1% packet loss and be able to recover automatically from connection loss* are in the must category because they ensure a fast and reliable connection between tables. The second research questions, of what design consideration should be taken into account to ensure the SIMT's are applicable on different use case scenarios, is arguably the hardest to answer. The requirements were gathered from overlapping requirements of multiple expert interviews on different use case scenarios to try to ensure the SIMT's are applicable in different use case scenarios. However it is impossible to ensure that the SIMT will work in every scenario. Examples of must requirements that try make the SIMT applicable in most scenarios are requirements A.5, *The tables must give users feedback through the LEDs within 1 second* B.1, *The tables must display information clear and concisely, in a way that is easy for users to understand* and B.9, *The tables must not pose any risks or distractions to a user that can lead to harm.* These requirements are example of requirements that can be implemented to make it easier to use the SIMT in most use case scenarios.The last research question on how the system design and software architecture can be designed such that interaction specifications can easily be used with both the existing big table and the new mini table will be found out through implementing requirement B.8, *The tables must be compatible with the existing technology/infrastructure of the big table, meaning all software for the small table can run on the big table as well.*

The should and Could requirements have been prioritized similarly to the way the must requirements have been prioritized. In addition to being categorized. The requirements were also specified so that they can be measured. This means that words like 'timely' have been replaced with a specific amount of seconds for example. The full overview of the specified requirements can be found in the following sections.

5.2.1 Must

The list of requirements that will determine if the table is functional, these requirements are the top priority.

- A.1.1 The tables must efficiently and effectively communicate with other tables, ensuring a data transfer rate of at least 8777 bytes per second
- A.2. The tables must be able to offer visual feedback through color variation, intensity variation and or pattern changes
- A.5. The tables must give users feedback through the LEDs within 1 second
- B.1. The tables must display information clear and concisely, in a way that is easy for users to understand
- B.2.1 The tables must have a reliable connection to other tables with less than 1% packet loss and be able to recover automatically from connection loss
- B.8. The tables must be compatible with the existing technology/infrastructure of the big table, meaning all software for the small table can run on the big table as well
- B.9. The tables must not pose any risks or distractions to a user that can lead to harm

5.2.2 Should

The list of requirements that should be implemented for the table, but that the table does not absolutely need for it to function.

- A.3. The tables should support interactive games and experiences regardless of a user's demographics
- A.4.1 The tables should be able to gather and store data captured by the load sensors with a sampling frequency of 72hz
- A.7.1 The tables should be intuitive to use so that 80% of the users can use the table effectively without prior experience after a basic explanation
- A.8. The tables should have a one-time setup, that should take no longer than 20 minutes
- B.3. The tables should be considered user-friendly by 80% of users on varying levels of digital literacy
- B.5. The tables should have a minimal learning curve, where users can do basic actions within 3 minutes of them using the table for the first time

- B.10. The tables should be adaptable for use in different settings such as homes, hospitals, and other settings
- B.11. The tables should accommodate various group sizes, varying from 2 to 10 tables that can interact together

5.2.3 Could

The list of requirements that could be implemented if there is time, but do not have a high priority.

- A.1.2 The tables could efficiently and effectively communicate with other smart devices such as phones and wearables, ensuring a data transfer rate of at least 8777 bytes per second
- A.7.2 The tables could not need any instructions for 80% of users to use it effectively
- A.9. The tables could support remote updates to its software
- A.10. The brightness of the table could be adjustable
- A.11. The table's Wi-Fi setup could be such that the inner workings of the table do not need to be accessed to set it up
- A.12. The table could be capable of running multiple applications, between which the user can switch
- B.2.2 The tables could have a reliable connection to other devices with less than 1% packet loss and be able to recover automatically from connection loss.
- B.7. The tables could look robust and durable and not fragile with 70% of the users agreeing that they are not afraid to break the table from normal use
- B.13. The table's interface could support multiple languages

5.2.4 Won't

The list of requirements that are not in the scope of the current project, but that could be implemented in the future.

- A.13. The table should have cybersecurity features to prevent unauthorized access
- A.4.2 The tables should be be able to analyze data captured by the load sensors
- A.6. The tables should provide a multisensorial experience for impaired individuals

- B.4. The tables should be be accessible to all user groups, including those with visual impairments
- B.6. The tables should ensure that collected data is secure
- B.12. The table should store user preferences such as how much data will be stored
- B.14. The table should have energy usage optimization
- B.15. The table should comply with industry standards for this type of product

5.3 Implementation specifications

5.3.1 Must requirement implementation

A.1.1, The tables must efficiently and effectively communicate with other tables, ensuring a data transfer rate of at least 72.462 Kbps. This requirement will be implemented by using the Wi-Fi of the laptop to connect via a router to the internet. This will enable the laptop to communicate through MQTT. The system will be both a publisher and subscriber, meaning it will both send and receive data from and to other tables. This will be done through a MQTT Broker. Multiple scripts will ensure that the right information gets sent and that the table reacts accordingly to incoming data.

A.2, The tables must be able to offer visual feedback through color variation, intensity variation and or pattern changes. This requirement will automatically be implemented when requirement B.8 is implemented, as requirement B.8 requires the demo's from the big table to work on the small demo. The demo's let you interact with the table and gives you visual feedback in various ways based on weight distribution.

A.5, The tables must give users feedback through the LEDs within one second. What is considered 'timely feedback' is dependent on the use case scenario. The faster it is, the more use case scenarios in the tables could be used in to a certain point. For now, the aim will be to get the response to be under a second.

B.1, The tables must display information clear and concisely, in a way that is easy for users to understand. Shneiderman's rules [28] are a good example of rules that can be followed to make sure the information displayed is clear. These rules can also be applied to any interfaces the table might have and to the system as a whole.

B.2.1, The tables must have a reliable connection to other tables with less than 1% package loss and be able to recover automatically from connection loss. The basics of a reliable connection is to make sure that data loss is minimal, and that in case it happens, the table's software knows how to handle the situation. An auto-reconnect function for both the Wi-Fi and the MQTT would also make sure that in case something goes wrong, it tries again.

B.8, The tables must be compatible with the existing technology/infrastructure of the big table, meaning all software for the small table can run on the big table as well. To make sure the table is compatible with the existing table, the software should be able to recognize if it is running on the big or small table and change parameters accordingly. This could be done through recognizing differences in hardware. Ideally, this could be done in a way that any table of any size could be compatible, but the way the software is currently set-up does not allow for this because of LED and module mapping.

B.9, The tables must not pose any risks or distractions to a user that can lead to harm. A situation where the table poses risks to the user, is very much undesired. During the making of the SIMT, any potentially risks that are discovered will be addressed and solved.

5.3.2 Should requirement implementation

A.3, The tables should support interactive games and experiences regardless of a user's demographics. For the table to be applicable in various use case scenarios, it is important that different types of users are able to use the table. The most important one being people with varying levels of digital literacy, requirement B.3.

A.4.1, The tables should be able to gather and store data captured by the load sensors with a sampling frequency of 72hz. To be able to do something with the data, it should first be stored somewhere. This should be done in a manner that makes sense, e.g., adding timestamps to the data, not storing null data when nothing happens, and in an easily accessible manner.

A.7.1 The tables should be intuitive to use so that 80use the table effectively without prior experience after a basic explanation. Intuitively is an important factor to make the table more accessible to various user groups. Not every user group can or wants to invest time in learning how to use a system. Following Shneiderman's rules [28] or other design guidelines will help with this. One of the most important things in this case would be to be consistent and use standards.

A.8, The tables should have a one-time setup, that should take no longer than 20 minutes. This requirement is mostly concerned with the connection set-up. The SIMT will need to know the Wi-Fi password of the user's router before it can connect, but after filling this in once, it should remember it and automatically connect the next time.

B.3, The tables should be considered user-friendly by 80% of users on varying levels of digital literacy. Same principle as requirement A.3.

B.5, The tables should have a minimal learning curve, where users can do basic actions within 3 minutes of them using the table for the first time. Not every user group can or wants to invest time in learning how to use a system. Following Shneiderman's rules or other design guidelines will help with this. One of the most important things in this case would be to be consistent and use standards.

B.10, The tables should be adaptable for use in different settings such as homes, hospitals, and other settings. Different settings bring different users. In addition, some features might be useful in one setting but not in another. It might be useful if certain features could be turned on or off depending on the situation.

B.11, The tables should accommodate various group sizes, varying from 2 to 10 tables that can interact together. With different settings and user demographics comes the need for varying group sizes. In some settings, one might want a one on one connected between two tables. In other situation, a big group of tables that are all connected could be better. Using MQTT, different publish and subscribe topics can be made. However, to join a specific topic, some sort of interface would be needed where the user can select which topic to join.

5.3.3 Could requirement implementation

A.1.2, The tables could efficiently and effectively communicate with other smart devices such as phones and wearables, ensuring a data transfer rate of at least 8777 bytes per second. In addition to communicating with other tables, the tables could also have a function where you can communicate with other devices such as a phone or a smartwatch. To realize this, an app or web page needs to be created where the device can communicate with the MQTT broker.

A.7.2, The tables could not need any instructions for 80% of users to use it effectively. Ideally, the table is so intuitive that user do not need any extra information to be able to operate the table. By following Shneiderman's rules and testing different interactions or interfaces, the best designs could be found to minimize the instructions needed.

A.9, The tables could support remote updates to its software. Being able to update the tables software or add additional demos without having to access the hardware inside the table would make keeping the table up to date a lot easier. As the table has access to the internet, this could for example be achieved through connecting the system to GitLab. The table could, for example, every time it starts up look if any changes have been made to the repository, and if so, update its software. A drawback of this would be that if someone uploads any code that is not working or makes changes that break the system, the table could potentially not work anymore.

A.10, The brightness of the table could be adjustable. Different scenarios may have different levels of light. The table could be outside in the sun or in a dim room. It could be useful to be able to change the brightness of the LED's according to the setting. This would be most easily accomplished through an interface where the color intensity is a parameter that adjusts the color. However, in reality, this might be somewhat difficult to achieve because of the different color formats that are used throughout the code.

A.11, The table's Wi-Fi setup could be such that the inner workings of the table do not need to be accessed to set it up. When setting the table's connection up, as explained in A.8, you need to fill in a password for the Wi-Fi most likely. Ideally, this would be done without accessing the system directly, e.g., filling it

in on the laptop. This might be possible through using access points. The table would detect that it has no password yet or the password is wrong, and become an access point. The table will then become a sort of router, to which the user can connect from their phone or other devices. This will then direct them to a web-page, where they can fill in the Wi-Fi password, after which the table will reset and try to connect again with the password the user just filled in.

A.12, The table could be capable of running multiple applications, between which the user can switch. The ability to easily switch between different application would make it easier to use the table in different settings. This could be achieved the same was as A.10, by having a parameter that sets the application.

B.2.2, The tables could have a reliable connection to other devices with less than 1% packet loss and be able to recover automatically from connection loss. Same principal as B.2.1.

B.7, The tables could look robust and durable and not fragile with 70% of the users agreeing that they are not afraid to break the table from normal use. Having the table look robust, makes people more likely to use it, as they will not be afraid of breaking it. This could potentially be achieved by hiding the many electronic details of the table.

B.13, The table's interface could support multiple languages. Different users speak different languages. The table will be programmed in English, so other researchers can understand and develop it further. However, as the table will most likely be used solely in the Netherlands, it would be good to add an option for Dutch, especially for use cases involving elderly.

5.4 Specification conclusions

In this section, the requirements from the ideation were specified and prioritized. Now that the requirements have a priority, the general order in which they should be implemented is clear. Also, the general idea on how they should be implemented has been worked out. In the next section, this will be used to realized and actually implemented the requirements.

Chapter 6

Realization

In this chapter, the prototype as described by the requirements and ideas in the ideation and specification chapters will be build. First the changes in hardware will be described as this is the foundation that the tables runs on. After the changes to the code of the big table to ensure that it works on both tables will be explained. Finally the additional features such as the connection that were added will be described.

6.1 Hardware

To ensure that that interaction specifications can easily be used with both the existing big table and the new mini table the hardware should ideally be as closely related as possible. Most hardware of the SIMT has stayed the same as the big table, however some changes were made that will be discussed below.

6.1.1 Teensy

The big table makes use of the Teensy 3.6. This Teensy version is no longer in production and thus a replacement component was needed. It was determined that the Teensy 4.1 would replace this component. The Teensy 4.1 is much faster and has more memory than the Teensy 3.6. This new version of the Teensy however has different internal clocks. This made it so that the library called MultiWS2811 that was made for the big table did not work anymore. This library was made for a multiplexer controlled by the Teensy 3.6 to access all the led panels. As the big table had 199 modules, and the Teensy 3.6 could only control LED's on 8 channels with the OctoWS2811, this was needed. However the Teensy 4.1 is not limited to only 8 channels, and can use any digital channel. This in combination of the SIMT only having 19 modules made it so that the library was not technically needed anymore. At first it was still attempted to rewrite the MultiWS2811 library to work on the Teensy 4.1 but after some testing, it was found that this was quite difficult, as it could not simply be done

by renaming the names of the clocks. Because of this it was decided to leave out the multiplexers and the OctoWs2811 is now used to control all the LED's. In the software modification section it will be described how this change affected the software.

6.1.2 PCB

A PCB was designed for the Smart Interactive Mini Table using EasyEDA. This PCB was based on the big table and connects all the components together in a neat way. However as it was decided to leave out the multiplexer, this PCB had to be redesigned. The multiplexer chips were taken out and instead 19 Teensy 4.1 channels were directly connected to the LED panels via a buffer chip (SN74HCT245PWT) and some resistors (a 100 Ohm placed close to the Teensy 4.1 and a 0 Ohm resistor before the led panel to ensure a stable signal with the buffer chip in between). See figure 8 for an overview of the connections. The 0 Ohm resistors were put into place as a safety precaution because they would allow for manually routing to the Teensy if mistakes were made in the design of the PCB. This PCB was then ordered with most parts already mounted. Some parts such as the buffer chips and the headers that hold the boards in place still had to be manually soldered on. Multiple mistakes were found on the PCB, the most important one being that the PCB does not have a TX RX connection between the Teensy 4.0 and 4.1. This connection is arguably one of the most important connection as it will transfer all the values collected by the Teensy 4.0 to the LEDs. Another mistake was one of the module's LED panel not being correctly connected to the Teensy 4.1. This problem was easily solved by soldering a connection between the wrong and the right pin. The first problem will for now be solved by adding a some jumper wires between the Teensies. The design for the PCB has been updated to fix these mistakes, however this iteration has not been made or tested yet. Another big problem that was found was that the power system of the PCB could not handle the required amperage that LEDs needed. This caused some parts of the PCB to break and some of the LEDs as well. The consequences for the prototype of this will be discussed in the evaluation.

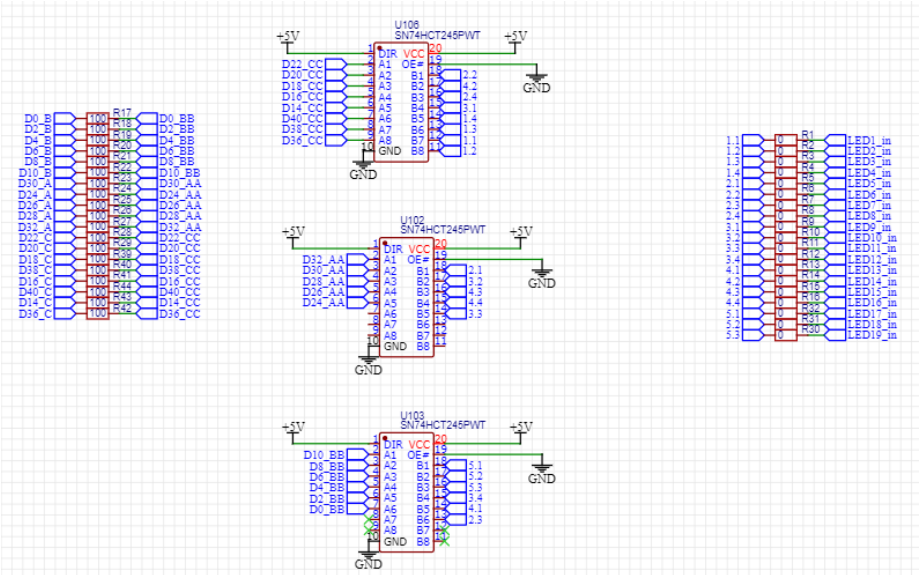

Figure 8: Buffer chips and resistor connections overview

6.2 Software modification

To ensure that that interaction specifications can easily be used with both the existing big table and the new mini table both the big and small table should be able to run from the same code. To do this, the original code for the big table was modified.

6.2.1 PixelPusherDemo

There are two main variables in the code that are different between the big and the small table. The first is the number of modules, for which there is a global variable. Changing this to work on the small table means changing 199 to 19. It was contemplated to make this change dependent on the Teensy version that is detected by the port, however this would mean that if the big table would ever be updated to work on a Teensy 4.1 or other iterations of tables would be made with a different number of modules it would not work. This is why the number of modules was kept as a global variable that manually needs to be set by the person uploading code to the table. The number of modules changing also meant that a new mapping of the table needed to be made. This is needed for the table to know which led number is it's neighbour across modules, see figure 9 There are now two version of the led mapping and every time the led-map is mentioned there is an if statement for how many modules there are that then points to one of the maps. This works, however there is a lot of duplicate code, so there is definitely room for improvement here. The issue currently is that both maps are arrays, but of different sizes. The second variable is the library

used, the big table with the Teensy 3.6 uses the MultiWS2811 library and the small table with the Teensy 4.1 uses the OctoWS8211 library. Only one of these two libraries needs to be loaded, which is done by first looking what version of the Teensy the port sees, and based on that loading the correct library as well as setting a variable that indicates the version for ease of use in the code. After this the LED's are set up in the correct way based on this variable.

Another thing that had to be changed was the code for the Teensy 4.0. For the big table the Teensy 4.0 had to collect data from three Arduino Megas, however for the small table only one is needed. This makes much of the code redundant, and it might even be possible to remove the Teensy 4.0 in it's entirety.

The way the PCB was designed has the LED's connected to the Teensy leaving a pin in between. This seemed like a good idea to keep the connection a little further apart, however it turns out that that was an not as smart as initially thought. The connection skipping every other pin means that there is no pair of TX Rx pins available on the Teensy 4.1. As mentioned before in the PCB section, a RX TX connection is needed between the Teensy 4.1 and 4.0. This is now done by using the RX pin of Serial7 and the TX pin of Serial 4 to read data on the Teensy 4.1. This works, however it is very inelegant and should be changed in the future.

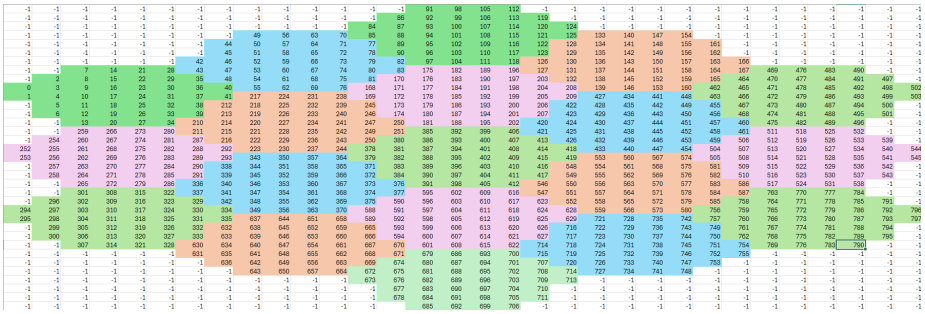

Figure 9: LED numbering map

6.3 Software additions

6.3.1 MQTT

For connecting multiple smart interactive tables, MQTT is used. From the specification RabbitMQ was chosen as a possible candidate to use as an MQTT broker. RabbitMQ has a web interface where useful statistics about the connections can be found. This was used during testing to determine among other things the speed at which messages where send. basic publisher and subscriber scripts where written in python that could connect to the broker. The subscriber script also passes the values to the Teensy. The first test that was done was one where a single LED panel would get commands over this connection. It was quickly found that sending individual messages for each led was not a

viable option as it was very slow. Sending a single message containing all LED information for one panel is a lot quicker. However there is still a maximum to how fast it can go. A test was done where 100 messages where send and consumed per second.

Now this all worked fine for a test script, but when trying to implement it within the pixelPusherDemo, it was quickly realized that the serial messages were getting mixed up. Both the Teensy 4.0 and the Python script are sending messages over Serial without knowing what the other is sending and when. This was solved by moving the serial communication between the Teensy 4.0 and 4.1 to a Tx Rx connection. After, an Arduino script was written that would read the data send by the python script and decode the messages. Messages can be send with different prefixes to indicate if a led needs to be on, off and what color, or if an entire module needs to be on. All this data is stored in two arrays that store a boolean if a led is on or off and what color it is. The same script also can send data to the python script when a module is pressed so that it can send that data to another table. With this addition to the code, tables can now communicate with with each other.

6.3.2 Web interface

In addition to communication between tables, communication between table and web interface was added. A website was made using HTML, Flask, and Ajax. The web page features buttons for each led, that the user can turn on and off. The user can also pick the color they want the led to be and the buttons, as well as the leds on the table will change to that color. All the tables that are connected are listed at the top, and the user can choose which table to send their commands to. There is also a reset function, which turns all the leds off. Together this makes it so the user can 'draw' on the table using the web interface. There are also buttons to switch between modes, this makes it possible to switch all the demos of the PixelPusher and the drawing mode. This works both on a desktop and on a touch screen device, however on touch screen devices, the server that handles the input is prone to crash when drawing. This is because of issues with threading. It was tried to solve this and while it works better after implementing some checks, it can still crash. However a reconnect function has been implemented, so even if the connection is closed, it will automatically try to reconnect.

The buttons on the web page send post request and uses Ajax so the states can change without having to refresh the page to see the changes. The buttons all have a id attribute that is then send with information on the color and on which table the change was made to a python script. This python script is what actually runs the website using Flask. Flask is a web application framework that combines multiple libraries to make creating a responsive website easier. Whenever the user clicks a button, the python script requests the button id from the website and uses this with the information on the color and the table to string together a messages that is send to the RabbitMQ broker in much the same was as was done in the test publisher script. The subscribe script

is still used as in the same way as testing, as it only passes the message from RabbitMQ over to the Teensy 4.1. The complete overview of the data flow can be found in figure 10. An overview of all the use cases for users and the relations between users both with and without table can be found in figure 11.

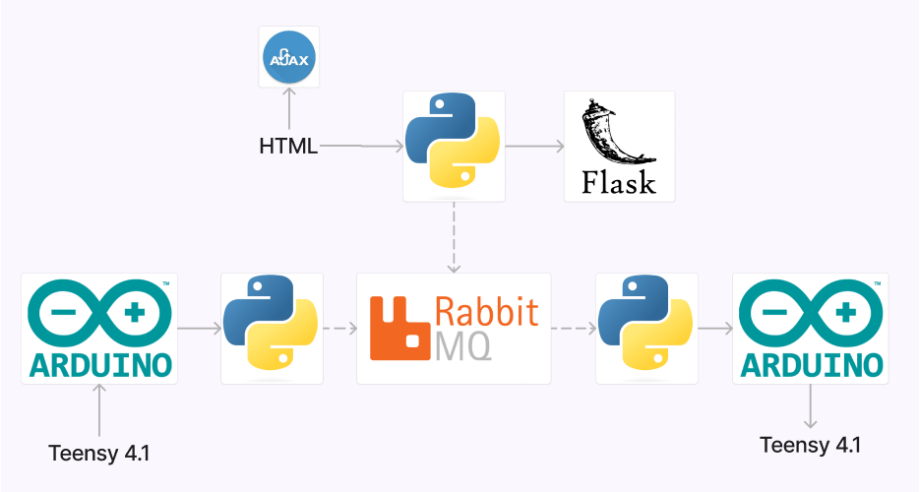

Figure 10: Overview of programs used for communication and data flow

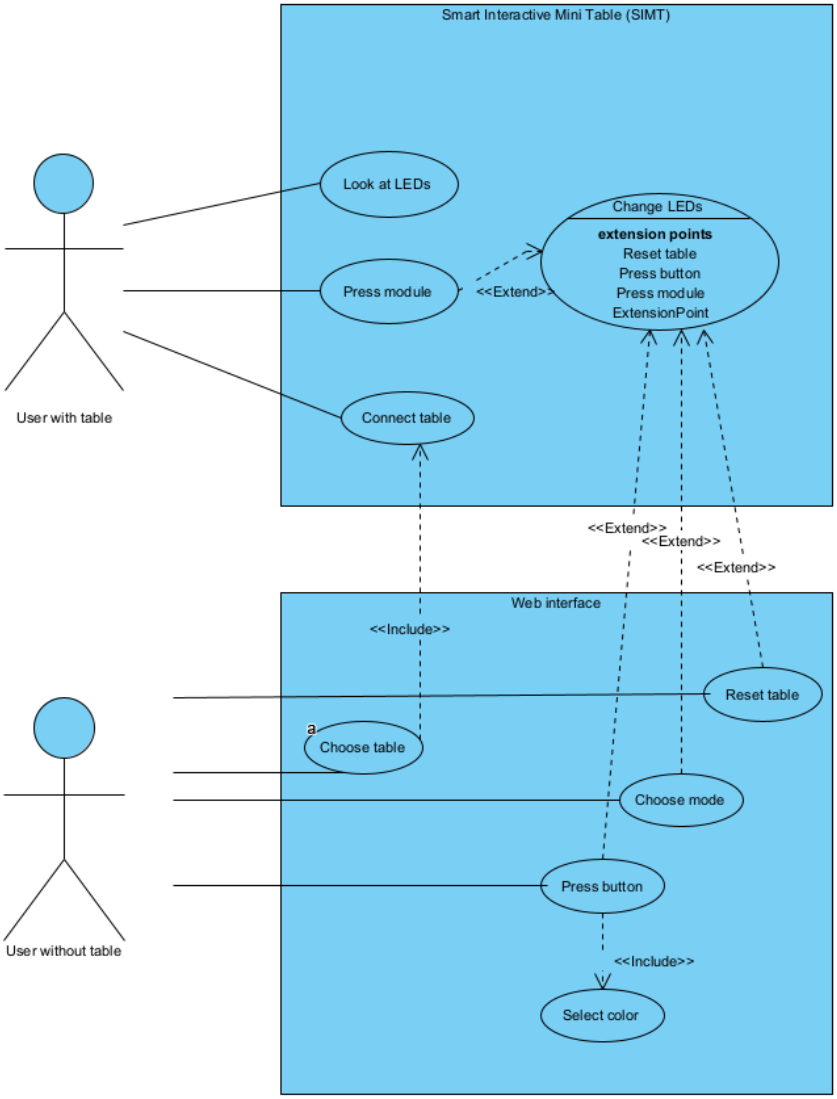

Figure 11: UML use case diagram of user interaction with systems and relations

6.4 Prototype

As the power system of the PCB does not work, a prototype could not be made that included all 19 modules. Instead of 19 modules the prototype that will be used in the evaluation is a single modules. This includes a sin-

gle load cell and 42 LEDs. This setup can be powered via a regular USB cable. Figure 12 and figure 13 show the setup. The software modifications and additions together still make for a prototype with a single module that the user can interact with. The user can use all the demos that were already available on the big table in the PixelPusher code and they can easily switch modes now by using the web interface. A new mode was included that allows the user to draw on the table using the web interface as well as interact with other tables that are connected. All code for the SIMT can be found on https://gitlab.utwente.nl/bss_development/ehealth/sensory_interactive_table/mini-sit. In the next section, the functionalities and usability of the table will be tested to see how well the prototype works.

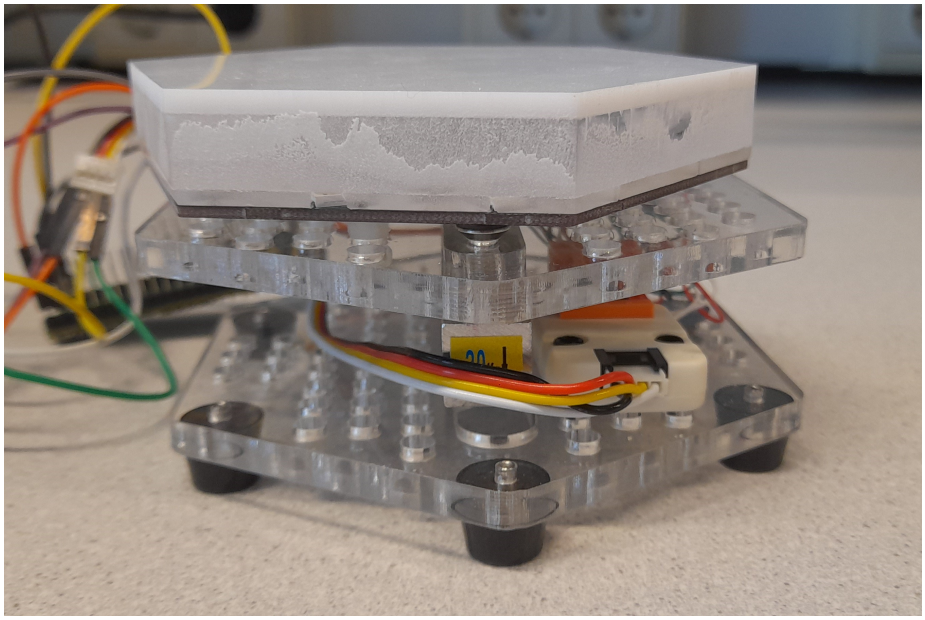

Figure 12: Prototype setup, LED panel on load cell, side view

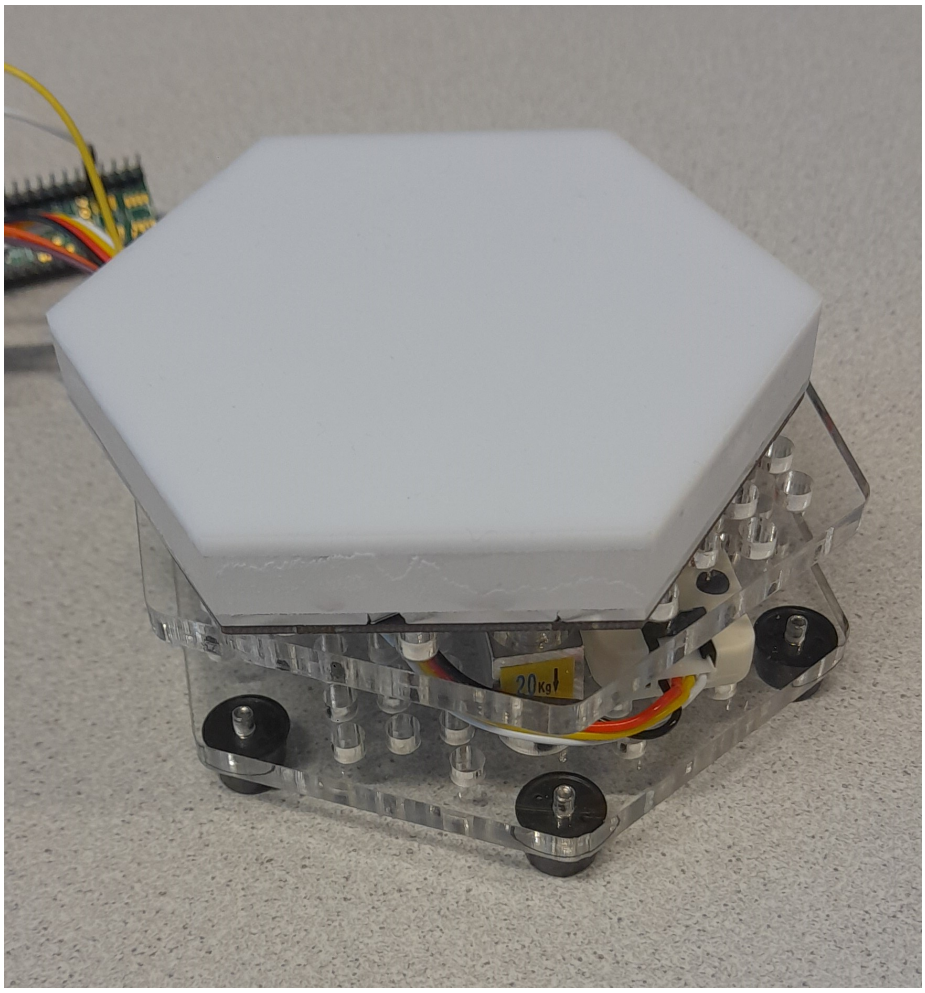

Figure 13: Prototype setup, LED panel on load cell, top view

Chapter 7

Evaluation

Now that a prototype has been realized, it has to be evaluated to see if all the requirements are met. This will be done in two ways, one being a technical test and the other evaluation will be with users testing out the device. For both evaluations, two laptops with each one modules connected were used.

7.1 User testing

As said before, four to seven people will be part of the user evaluation. All participants must be adults without impairments that are able to understand the English language. Other than this, there are no inclusion or exclusion criteria. Recruitment will be done through convenience sampling. The requirements that will be tested during the user testing are:

- B1, The tables must display information clear and concisely, in a way that is easy for users to understand
- A.3, The tables should support interactive games and experiences regardless of a user's demographics
- A7.1, The tables should be intuitive to use so that 80% of the users can use the table effectively without prior experience after a basic explanation
- B.5, The tables should be considered user-friendly by 80% of users on varying levels of digital literacy
- B.7, The tables could look robust and durable and not fragile with 70% of the users agreeing that they are not afraid to break the table from normal use

B1 is from the must requirements, A3, A7.1, B3, B5 are from the should requirements and B7 is from the could requirements. These requirements were chosen to be tested with users as they contain the word user in the requirement.

7.1.1 Setup

As explained in the approach, the evaluation will start off with a short introduction, where after the users are asked to perform some tasks with the SIMT to the best of their ability. All tasks are about operating the SIMT and these tasks should not be harmful in any way, and the users are free to refuse any task given. There are also no consequences for not being able to complete a task. The full list of tasks can be found in Appendix C.1 After the tasks are performed, they will be given a questionnaire which they can fill in. The questions all concern the usability of the table and how you feel about certain aspects of it. For this, the System Usability Scale (SUS) will be used with some additional questions added in the same format that apply to the context of the SIMT. The full list of questions can be found in Appendix C.3.6. The total duration of the evaluation will be about 15 to 20 minutes.

7.1.2 results

Now that the user evaluation has been conducted we can take a look at the results. The SUS has a calculation for the results to see if the design is satisfactory. The score is calculated by summing all the scores of questions, with all questions ranging from 0 to 4 points. For the uneven questions the points minus 1 is the score, and for the even questions it is 5 minus the score. All the scores are summed and multiplied by 2.5 to get a number between 0 and 100, however this is not a percentage.

The overall result of the first part from all the questionnaires, that can be found in Appendix C.3.6, when taking the average of all the six individual that participated, amounts to 76.25. Using the interpretations presented by [29], the usability of the SIMT can be considered good and acceptable. See also figure 14 for the complete range of rankings. The second part of the questionnaire is harder to interpret. This part was five extra questions added to the questionnaire that were specifically added to try and answer some of the requirements for the SIMT. For the question "I was able to complete the tasks given quickly using the tool", the common answer was somewhat agree and for the question "I thought the tool responded timely to my inputs", the general answer was agree. The question of if the tool looks durable ranges from strongly disagree to neutral. The last questions on if the tool would easily break however have very mixed answers ranging from one end to the other. These results will later in this section and in the next section be used to determine if requirements have been met. It was also recorded if the participants could complete all the tasks correctly. The results can be found in table 9. Task 7 could not be completed by 4 participants without help. The main problem here was that they did not switch back to their own table after completing task 6 and where thus still interacting with the other table and not their own. Task 2 was also failed by 2 participants, as they did not get the starting mode correct. Other observations where that people found the 'reset' button confusing, and it was proposed by a participant to change this to 'clear' and that the reset button was too close to

the color picking button.

Figure 14: Grade rankings of SUS scores from [29]

Task	Tester 1	Tester 2	Tester 3	Tester 4	Tester 5	Tester 6
#1	x	v	v	v	v	v
#2	v	v	x	x	v	v
#3	v	v	v	v	v	v
#4	v	v	v	v	v	v
#5	v	v	v	v	v	v
#6	v	x	v	v	v	v
#7	v	v	x	x	x	x

Table 9: Task completion by testers

With these results, the requirements are judged to see to degree they have been fulfilled.

- *B1, The tables must display information clear and concisely, in a way that is easy for users to understand.* The SUS-questionnaire includes question like, "I thought the tool was easy to use" and "I was able to complete the tasks given quickly using the tool". These questions are a good indication that the information that was displayed was clear and that the user understood what to do. This requirement will be seen as fulfilled.

- *A.3, The tables should support interactive games and experiences regardless of a user's demographics.* Not a lot can be said about this requirement, except that the table support interactive games and experiences for some user. More user evaluations with many different users need to be done before an indication can be made if this requirement is fulfilled.

- *A7.1, The tables should be intuitive to use so that 80% of the users can use the table effectively without prior experience after a basic explanation.* The tasks the users were given contained basic explanations on how different features worked. All user could use almost all of the features correctly after the explanation with succession rates of a 100% and 83%. The exceptions are task 2 with a 67% succession rate and task 7 with a 34% succession

rate. The average succession rate for all tasks is 83%. This requirement will be seen as mostly fulfilled.

- *B.8, The tables should be considered user-friendly by 80% of users on varying levels of digital literacy.* The SUS-questionnaire's overall result of 76.25 indicates that the user-friendliness of the table is acceptable and or good as seen by the user. (The 76.25 is a score, not a percentages) However not users from all level of digital literacy were included in the evaluation. This requirement will be seen as partly full-filled.

- *B.7, The tables could look robust and durable and not fragile with 70% of the users agreeing that they are not afraid to break the table from normal use.* The result from the questionnaire strongly indicates that all participants think the table does not look robust and durable. This requirement will be seen as unfulfilled.

7.2 Technical testing

To test the technical aspects of the design such as the speed at which the data is transferred, some tests were done. The requirements that are tested in this section are requirements:

- A.1.1, The tables must efficiently and effectively communicate with other tables, ensuring a data transfer rate of at least 8777 bytes per second

- A.5, The tables must give users feedback through the LEDs within 1 second

- B.2.1, The tables must have a reliable connection to other tables with less than 1% packet loss and be able to recover automatically from connection loss

- A.1.2, The tables could efficiently and effectively communicate with other smart devices such as phones and wearables, ensuring a data transfer rate of at least 8777 bytes per second

- B.2.2. The tables could have a reliable connection to other devices with less than 1% packet loss and be able to recover automatically from connection loss.

A.1.1, A.5, B.2.1 are from the must requirements and A.1.2, B.2.2 are from the could requirements.

7.2.1 setup

The main tool that was used to find the numbers for throughput and packet loss, comes from the MQTT rabbit web interface. For requirement A.1.1 and A.1.2, tests were setup where 8777 bytes of data was send every second by another

table or the web interface, and it was seen if the receiving table could keep up with consuming the data. This was done in two ways, first sending the smallest possible message of 4 bytes, as fast as possible to seen if it could accumulate to 8777 Bps. Secondly, for requirement A.1.1 a single message of 8777 bytes was send every second. For requirement A.5, there are 3 ways to get feedback, directly from the load sensors to the LED's which will be measured by a timer in the code, from the interface to the LED's and from another tables load sensor to the LED's which both will be measured by recording. In addition, during the user evaluation, participants were asked if they though the table responded "timely" to their inputs. For requirement B.2.1 in the subscription script the connection was purposely closed to see if it would automatically reconnect. For requirement B.2.2, the server connection was tested, by purposely closing the connection and seeing if it automatically reconnected. For both requirements packet loss was tested by sending and receiving a 1000 messages, and seeing how many of them are received first by RabbitMQ and then by a table.

7.2.2 Execution notes

All tests are done running the server on the local Wi-Fi network. Different Wi-Fi networks can generate different results. At the time of testing the Wi-Fi speed was approximately 130.0 Mbps for both downloading and uploading.

7.2.3 results

Now that the technical evaluation has been conducted we can take a look at the results. For requirement A.1.1, the transfer rate was about 20 messages of 4 bytes in total, amounting to a total of 80 bytes per second. This is way less than the required 8777 bytes. The bottleneck here is the Arduino code not being able to send the data over the serial connection fast enough. Next a single message of 8777 bytes was send every second. The results can be seen in figure 15, the messages are consumed at the same rate as they are send. However, while the data is received fast enough, extracting the led information from the data and actually turning the LEDs on takes quite a while. While these numbers nowhere near the once that are required, when testing with one module, no negative effect is experienced from this. This requirement will be seen as almost fulfilled because of this but should be tested again once all 19 modules work.

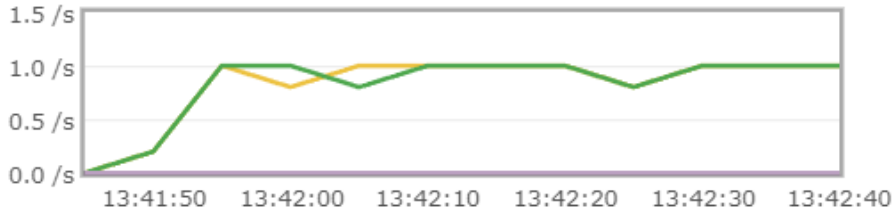

Figure 15: Message deliver/consume rate from Teensy to Teensy, green line is delivered, yellow is published

For requirement A.1.2, the input rate is dependent on how fast the user can move the mouse over the buttons. An auto clicker set to 100 clicks per second was used to determine the throughput. As seen in figure 16 the throughput is limited to 20 messages per second, or with each messages being 4 bytes, 80 bytes per second in total. As seen in figure 16 this limit is imposed by the publishing side. When stopping with clicking, the interface would still show the button changing for a while after. The bottle neck here would be the Flask code publishing the data from the web interface. This requirement will be seen as almost fulfilled.

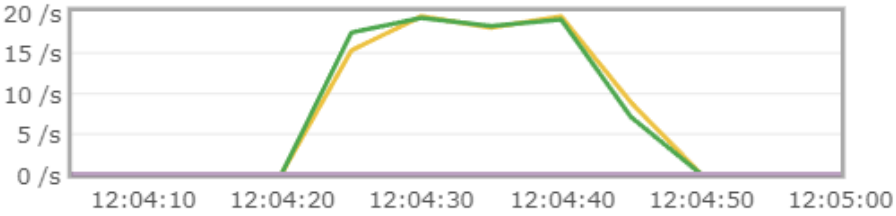

Figure 16: Message deliver/consume rate from web interface to Teensy, green line is delivered, yellow is published

For requirement A.5, the tables must give users feedback through the LEDs within 1 second. The first test of responding to the load sensors with the LED's takes less than a ms, so well under a second. The second test, was response time from an input on the interface. The interaction was filmed in slow motion with 240 fps or a frame every 0.035 seconds. Both the interface and or the "other table" were filmed next to each other so that the video showed both the in and output. When testing the time between the LED turning on and clicking the button on the interface, the led updates faster than that the interface updates. The time it takes between clicking and the LED turning on is approximately 50ms. The last test, of the time between a load sensors input and the output on another led, is approximately 99ms. This was measured by the LED's of the input module to turn on when the modules is pressed, and the LED's turning on on the other modules. The time in between the LED's of the different modules

lighting up was measured. Also, from the user evaluation, the user agreed that the SIMT responded timely to their input. This requirement is seen as fulfilled although the time between two tables communicating could be decreased.

For requirement B.2.2, the main errors that occur are:

- AMQP Connection Error: Stream connection lost
- AMQP Connection Error: Stream connection lost: IndexError('pop from an empty deque')
- AMQP Connection Error: Stream connection lost: ConnectionResetError('An existing connection was forcibly closed by the remote host')

After one or more of these errors occur, the script closes any connection that is still there and reconnect again. It also reconnects as soon as it cannot send a message to RabbitMQ. This requirement will be seen as fulfilled

For requirement B.2.1, to test the packet loss, 1000 messages were send to the RabbitMQ broker. In figure 17 it is seen that all 1000 messages have made it to the queue. Next, the messages were retrieved from the queue and checked if the original messages was intact. All 1000 messages were correctly retrieved from the queue and send over the serial to the Teensy 4.1. For the automatic reconnecting, the script automatically tries to connect again as soon as an error occurs. This means that you can disconnect the Teensy 4.1, which crashes the script, and plug it in again, and the script automatically reconnect to the Teensy again. This requirement will be seen as fulfilled.

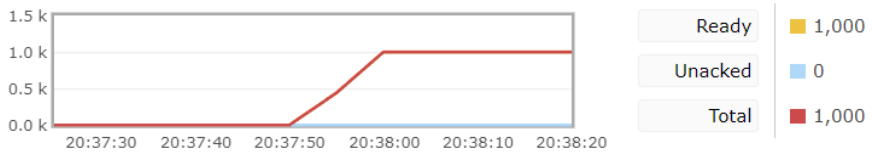

Figure 17: Packet loss test sending

7.3 Remaining requirements

The remaining requirements are features that are either there or not, so for example multiple languages being implemented, or have not been implemented and thus cannot be tested. This encompasses requirements A2, A.4.1, A.8, B.10, B.11, A.9, A.10, A.11, A.12, B.13.

7.3.1 Not tested requirements

- *A2, The tables must be able to offer visual feedback through color variation, intensity variation and or pattern changes.* The demos from the original code of the big dining table all work on the small table as well as a new

mode that allows the user to turn on and change the color of each individual led. This allows for visual feedback to the users actions implementing color variations as well as intensity. The Demo code also shows varies patterns and using the draw mode the user can create patterns themselves. This requirement is seen as fulfilled.

- *A.8 The tables should have a one-time setup, that should take no longer than 20 minutes.* Currently, the SIMT does not have a one-time setup but steps have been taken to make it. A single python script needs to be activated manually before the SIMT starts works. However this could easily be started automatically if a dedicated devices was used, the file could be run on startup and the table would work with as soon as you plug in the power. This requirement is seen as partly fulfilled because of this.

- *B.11. The tables should accommodate various group sizes, varying from 2 to 10 tables that can interact together.* Currently, the SIMT can theoretically connect tens of thousands of tables. This requirement is seen as partly fulfilled however, as there can still be a lot of improvement on how groups are managed.

- *A.11. The table's Wi-Fi setup could be such that the inner workings of the table do not need to be accessed to set it up.* The SIMT uses the Wi-Fi of the device (in this evaluation a laptop was used, however in the future this could be substituted by for example a raspberry pi), so it has a one time setup as long as you do not move the table and select connect automatically on the Wi-Fi settings but when the user does move it the inner workings do need to be accessed. This requirement is seen as mostly unfulfilled.

- *A.12. The table could be capable of running multiple applications, between which the user can switch.* Via the web interface the user can switch between the different demos, and new demos can easily be integrated. The draw demo also does not reset if you switch back and forth to it. This requirement is seen as mostly fulfilled as they do not technically run concurrently.

7.3.2 Not implemented requirements

- *A.4.1 The tables should be able to gather and store data captured by the load sensors with a sampling frequency of 72hz.* While the SIMT does gather data from the load cells this data is never stored. Because of this, this requirement is seen as not implemented.

- *B.10. The tables should be adaptable for use in different settings such as homes, hospitals, and other settings.* No specific steps or actions have been taken to fulfill this requirement. First it should be investigated what

each setting needs, before the SIMT can be made adaptable to them. This requirement is seen as not implemented.

- *A.9. The tables could support remote updates to its software.* No specific steps or actions have been taken to fulfill this requirement. This requirement is seen as not implemented.
- *A.10. The brightness of the table could be adjustable.* No specific steps or actions have been taken to fulfill this requirement. This requirement is seen as not implemented.
- *B.13. The table's interface could support multiple languages.* No specific steps or actions have been taken to fulfill this requirement. This requirement is seen as not implemented.

7.4 Discussion and conclusion of evaluation

Figures 18, 19 and 20 show to what percentage requirements have been met and implemented. 1% means the requirement has not been implemented, 10-40% means some steps were taken but not implemented, 50% means implemented, but could be improved a lot or needs to be tested more, 60-90% means mostly fully working and 100% means fully implemented. In total 86% of the must requirements, 75% of the should requirements and 22% of the could requirements have been met. It does however is important to keep in mind that only 1 modules per table was used for the evaluation and not 19. While using 1 module for the evaluation gave a good indication on if it would work for the full table, the PCB should be fixed so that the evaluation can be done on all 19 modules to verify the result and this would also give more interaction possibilities.

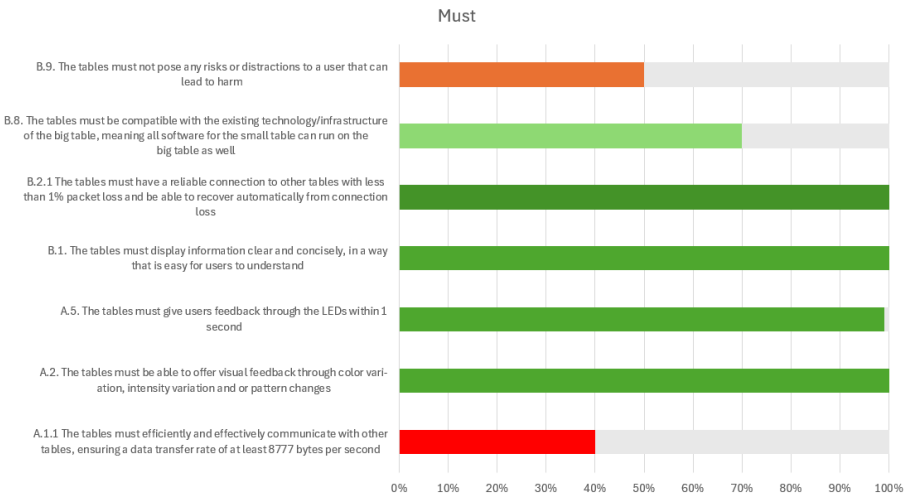

Figure 18: Must-requirements implementation percentage

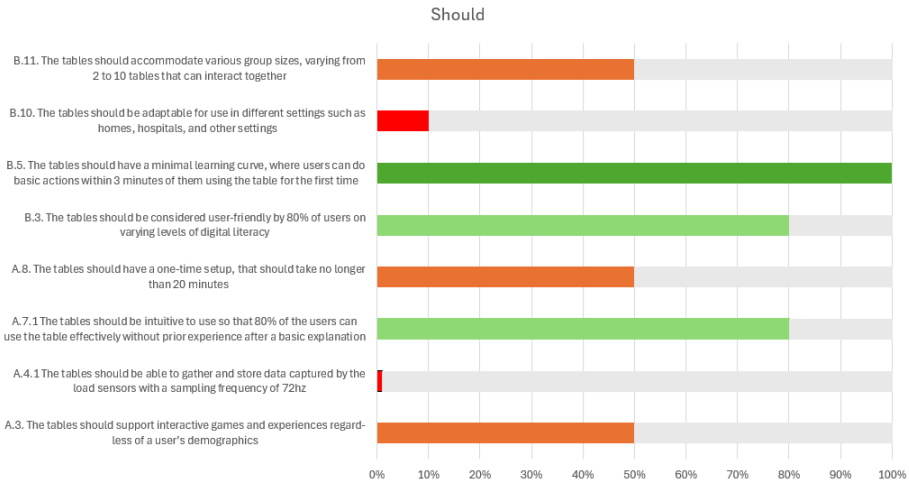

Figure 19: Should-requirements implementation percentage

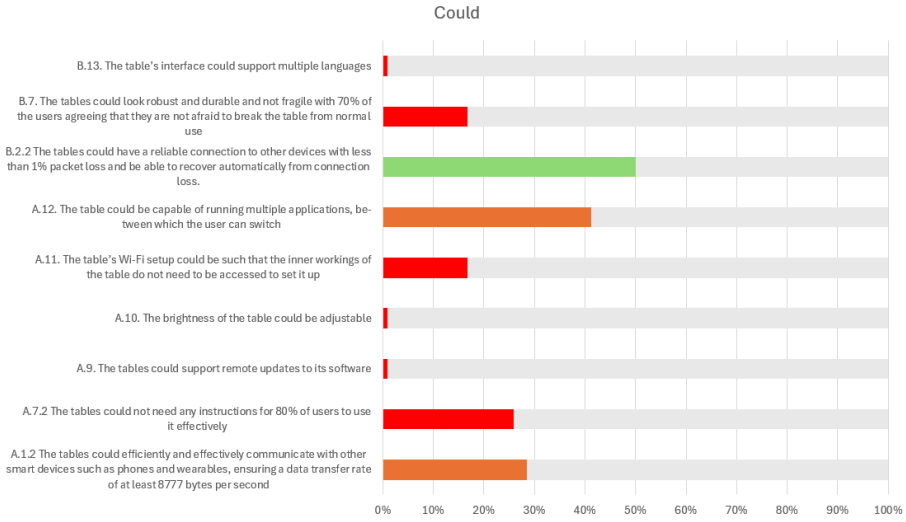

Figure 20: Could-requirements implementation percentage

Chapter 8

Discussion and Recommendations

In this chapter, the choices that were made will be looked upon and limitations will be addressed. It will also give ideas for further works and recommendations on how to further develop the SIMT.

8.1 Key findings

The realization of the Smart Interactive Mini Table involved both changes in hardware and software. A transition from the Teensy 3.6 to the Teensy 4.1 was necessary as well as a change in library. The PCB for the SIMT was redesigned to adjust to this, however errors such as incorrect pins being connected or not connected at all were made. Temporary solutions were implemented to solve these issues. In addition, the PCB had errors in it's power systems which made it unusable for the evaluation. The adjustments to the PixelPusherDemo code make the code theoretically compatible with both tables, however it also resulted in multiple instances where there is quite some duplicate code, which indicates a potential for optimization. The addition of connection of table added significant functionality to the table, however it also introduced some problems such as problems with the serial communication and threading. While currently the code reconnects after the connection has crashed, the crashes could be altogether prevented by implementing a thread safe call back function. The choices made in the literature review on using Wi-Fi and MQTT however did prove to be good choices. The MQTT broker rabbitMQ could handle messages very fast, and was never the bottleneck in the communication. The evaluation of the SIMT shows that the prototype meets 86% of the must requirements, 75% of the should requirements, and 22% of the could requirements. This means that there is a functional prototype, but there is also room for improvement. The main issue is the data transfer rate. However it was also found that users generally thought that the table is user-friendly and responses timely. The prototype however,

is still far from an actual product and has to be further developed and tested. The evaluation however was a good proof of concept, it was learned that the user could easily interact with the prototype and that they had no problem navigating it. If the prototype is further developed the Smart Interactive Mini Table that was envisioned at the start of this project should become a reality.

8.2 limitations

There are several limitations that were found during the realizations and evaluation of the SIMT.

The main and biggest issue being that testing could not be done with the PCB and all 19 modules. The power system of the PCB could not handle the required amperage for the LED's and broke multiple times. So it was decided to do the evaluations on a single module that could be powered via USB directly. The full Mini Table has never worked. The evaluation gave a good indication of if the full table could work, but further evaluation should be done with all 19 modules to verify the results.

Another limitation is that the evaluation was done using convenience sampling meaning there is a risk that the researcher has personal relationships with the participants (e.g., friends or classmates), this gives the limitation that some users could have provide responses that they believe the researcher wanted to hear, rather than honest ones.

Another limitation is that the SUS-questionnaire has limited depth. There are only 10 question on the SUS-questionnaire, and the overall score was taken. There we also only 6 test person. This means that while some testers could give a high score on usability, it doesn't mean that that is the same for all users.

8.3 Future Research

Further research can be done in removing the Teensy 4.0 in its entirety. As the SIMT is much smaller than the dining table, it does need three Arduino Megas to function. The Teensy 4.0 that previously collected the data from these, now only does so from one. This makes it so that for the SIMT the function of the Teensy 4.0 is only to propagate and encode the data. These functions could also be done between the Teensy 4.1 and the Arduino Mega, making the Teensy 4.0 potentially unnecessary. Further research can also done in making the unity program work on the small table. Currently only the low level coding for the SIMT was touched upon. There is also a unity project for the big table with which a user can interact with the table. This unity project could potentially even be implemented within the web interface of the SIMT. In addition to this, a more diverse group of people could be involved in testing the SIMT, to further evaluate the implementation of certain requirements. This would give a better comprehension of the tables overall usability for people with various backgrounds.

8.4 Recommendations

Based on the findings and limitations, some recommendations can be made.

- The next iteration of the SIMT should implement the updated version of the PCB, as well as an improved power system.
- The code should be refactored to reduce the amount of duplicate code.
- Evaluation should be done with a more diverse group of testers as well as the evaluation using all 19 modules.
- The remaining requirements that have not been implemented in the current version could be implemented in the next version.

With these recommendations the SIMT can be developed further into a product that will meet all the needs of the users, and be used as a tool by researchers and students to do projects with.

Chapter 9

Conclusion

This graduation project shows the development of the Smart Interactive Mini Table. The challenge was to make a smaller more practical version of the Smart Interactive Table that also could connect to other tables over the internet. A main research question and three sub questions were formulated. The questions were as follows:

How can the smart interactive dining table's hardware and software be improved to develop a smaller, more practical, adaptable and internet-enabled smart interactive table?

- What methods prove to be the most effective for connecting multiple smart interactive tables?
- What design considerations should be taken into account to ensure the system is applicable on different use case scenarios?
- How can the system design and software architecture be designed such that interaction specifications can easily be used with both the existing big table and the new mini table?

The first sub question was answered in a literature review, where multiple methods where investigated and WiFi and MQTT were chosen as the candidates with the most potential to implement during the realization. The second sub question was answered by doing expert interviews in which experts described different use case scenarios in which they though the SIMT could be used. From these use case scenarios requirements were extracted that matched between the scenarios. The last sub question was tried to answer during the realization as it was found that some parameters could be adjusted based on what hardware the software detected. However the code was never tested on the big table as it was in use. Together these sub questions resulted in a prototype being made which was evaluated on different aspects to ensure that the main research question of how the smart interactive dining table's hardware and software can be improved to develop a smaller, more practical, adaptable and internet-enabled

smart interactive table could be answered. The evaluation was subdivide in user and technical testing and the conclusion of these tests were that most of the important requirements have been met for the prototype. The project does however have as an important limitation that the evaluation was done on a single module, and that the full mini table never worked.

Appendix A

Expert interview

A.1 Interview #1

Interview on the 27th of march with Annemieke Witteveen, associate Professor at the Biomedical Signals and Systems (BSS) group and the Personalized eHealth Technology (PeHT) research program. Permission to record the interview was requested and granted before the start of the interview. Below, the transcript of the interview can be found. The transcript was edited slightly to make a more readable text but remains mainly a verbatim transcription of the interview.

Ruumpol, J.W. I'm Janine and this is my partner Thirsa, and we're currently doing our graduation project on the Smart Interactive mini table with supervision of Frodo and Juliet. I'm gonna to personally do the technical aspects of the table and Tirsha will come up with possible use cases for the tables. And the goal for this interview is basically to find good use cases for the tables within your area of expertise. So we thought we could maybe begin with you explaining. Your area of expertise, what you're doing researching currently. So would you like to tell us about that?

Witteveen, A. Yeah, sure. So my research is on a personalized e health technology for oncology and in one sentence more specifically you could describe it as developing dynamic models for personalized predictions, monitoring, and recommendations for patients, mostly after having had cancer. So, for example, for the late effects after cancer. An example project would be in cancer related fatigue. So, many people are affected by cancer related fatigue after having had cancer there is a large number of people that are affected, but it's not your regular fatigue that we might experience, but it's really unrelated to activities. For example you have done. And there the idea is to make based on holistic patient profiles so not just medical data. So provide optimal treatment recommendations for cancer related fatigue as not every treatment works for everyone. You should tailor there, so that's that's one of the projects. A larger, broader pro-

gram is a collaboration with the four technical universities in the Netherlands. So I'm leading the RECENTER program. There the focus is also on late effects after cancer, but also more specifically, the added effect of lifestyle. Many of the lifestyle factors also influence, for example. Of recurrence, your risk of cardiac complaints after cancer. So again, can we, you know, predict the risk of these complications and more specifically also the added risk for your lifestyle gives you and then do targeted monitoring to see if you're developing complications or if they are worsening and then tailored recommendations for, yeah, what we should do? Yeah. So. That was it in a nutshell, I can talk more.

Ruumpol, J.W. No, this is fine for now. We're working on the smart interactive dinner table. It was displayed in the design lab. Have you seen it?

Witteveen, A. I only saw it in the E Health house, not in the design lab. But yeah, I'm familiar. I also know Juliet.

Ruumpol, J.W. Yeah. OK. So you kinda know what's what it is about?

Witteveen, A. Yeah.

Ruumpol, J.W. OK. So, we're making a smaller version of this interactive dinner table, and it will have a diameter of roughly 50 centimeters, because, you've seen the big table, it's very big, very impractical to move. The small table will consist of 19 LED panels. So there will be about 800 LEDS. And, they have the load sensor still so they can measure weight distribution over the panels and so it's very similar in this respect to the big table, however there will be multiple small tables, and they will be connected to each other so they can share data between them. OK, so I have a couple of pictures to make it a little more clear. On the left is a 3D model of what the table will sort of look like and then on the right upper corner is how the LED panels look and under that is a single module. So do you have any questions so far about what the table is or how it works? No. OK, then Tisha can ask her questions now.

Chin-A-Kwie, T.L. So do you have any ideas on how the mini tables could be used within your research?

Witteveen, A. Yeah. Maybe I do have a question then, so is it also possible to use it more to give feedback also, not necessarily related to the table itself, but suppose you also have like a smart metrics or the chair you have next to the table you have some sensor mats in there that you also display if you've been sitting you know for half an hour stand up that you have some form of feedback. By combining also with different things, you're sensoring in the home.

Ruumpol, J.W. Oh yeah, that would be very possible if that is something you think would be very useful. Then give us ideas.

Witteveen, A. So I don't know whether there are more companies, but for example Luxysends is a company making mattresses. Smart mattresses, but you can also do it with smart chair. That doesn't really matter. So if you combine it, if you have a side table and a chair, then I guess you could combine the two and use the table to give feedback based on the signals you get from the smart well chair or couch or whatever. Because a small table is something in a seating arrangement. I can imagine that's a more general setting if you have communicating tables is something for loneliness. So I can imagine there are applications there, but those are not really. I don't see a direct relationship

with the cancer use cases, so I could talk about it, but I'm not sure if you really want to keep it to preferably you know the the cancer or late effects after cancer setting.

Ruumpol, J.W. I think it's a good idea that it could also communicate with like other smart devices, that would be a very good idea. We hadn't come up with that ourselves. But please, continue on that idea.

Witteveen, A. Yeah, I think it also then depends on the opportunities or the possibilities you have in giving feedback. Using the table itself, so I'm not, I mean I have seen the table. I'm not super familiar, but I know you can also give like lines et cetera. But can you also give the numbers or a bar that's becoming more or less full, or you know, flowers opening up or other visuals instead of.

Ruumpol, J.W. Yeah, it's basically a screen with 800 LEDs. So while you can't really like display videos or like small text on it, numbers would definitely be possible.

Witteveen, A. Yeah. Then I would see some added benefits of, you know, using it to give, well, not necessarily numeric feedback, but some feedback on, I don't know activity or other tasks. I think the easiest is always activity. I could also imagine that for some elderly people it might be a better way to provide feedback instead of doing it on a smartphone because it's just bigger. So if you have a certain smartphone application or monitoring well with the smart watch or smartphone that you use the table to provide the feedback. But then again, it's either a metrics or a wearable or something else that you combine it. So it's pretty much the same idea I guess. Same direction. It might be nice if you have some, if you combine it with like a weather forecast and seeing like, your opportunity for going out is diminishing. So take a walk now or it will start raining.

Ruumpol, J.W. That's a fun idea. I like that. Would you maybe see a way to incorporate the weight sensors in some way that those are used?

Witteveen, A. Yeah, maybe very specifically, if you do it for like if it's like your medication table and if you interacted with it, then you have taken your medicine.

Chin-A-Kwie, T.L. Do you think that's two tables being connected with each other would add into this, or is it mainly just a table with something else instead of the other table?

Witteveen, A. Yeah. I only think the connecting with each other it's like for, you know, having contact with your grandma or peer contacts or I think there are many opportunities to stay connected with people. I don't know if I wanna ask my mother something. I use WhatsApp quickly or something so it needs to make sense to do it in that way, and I think it just makes the most sense in elderly, yeah, digibetes not very digitally advance or yeah, low digital literacy setting. Because otherwise start to. Yeah, so many other applications that make more sense to you so, but yeah, for loneliness. Or, yeah, it might be helpful. But also if you put it more on like children, if you combine like children and their grandparents or something that you would make it really more into a game or like getting points or whatever. But in a very low-key, easy way. You also have something called overtaxle I think. That probably has already

some of these elements and I think for children. I know in the past they were talking about collaborations with Doffer Darfur as well. I don't know if you'll yet was one of those people or a different post doc back in the day. So if you have to, yeah, two connected tables. But are you also talking to Femke Nijboer? Because she's really also into elderly and loneliness, and also she's very active and creates a curriculum, so I can imagine that she has a lot of ideas. She would definitely be on my list for uh people to talk to. Yeah. So that's I guess my thoughts on the two connected tables.

Ruumpol, J.W. Okay, and like what would limit the usefulness of the table? So you think for example of the delay between the feedback being like 10 seconds or more, something like that.

Witteveen, A. I think it depends if you have. If you're aiming more at children, then you want more direct feedback because it if it takes a long time, they will be distracted and start doing something else, but if it's giving some other type of feedback, for example, like on the activity, well, the 10 seconds is really nothing.

Ruumpol, J.W. And any other things that would limit the usefulness?

Witteveen, A. Yeah, if you use it for feedback then I don't know if the resolution will be an issue at some point, so it really determines on what you would like to display. I think the limitations depend on your, on your target group also.

Ruumpol, J.W. Okay, so if you could add like an additional feature to the table, what would you add?

Witteveen, A. Yeah, I think for me again that something with visualizations or maybe if you do for the medication then. Each of the hexagons is like something you can open up, then if it's like a medication thing then it's not lighted anymore. If you'd already taken it or something, or if you connected to a certain task or the connection to other devices. I know that the main aim of the big table was for like also well happy eating or also including you know the broader setting of eating and eating behavior. But I think that's much more difficult in the smaller one. Because if you have a more social setting then some people may hold their cup and the others are too far away and put it on the window sill. So it then maybe yeah, maybe that's again part of a limitation that it is a smaller one, it depends on its place in the surroundings how well you can capture the behavior that's going on around it.

Ruumpol, J.W. Yeah, that makes sense. Thirsa, do you have any questions that you want to ask?

Chin-A-Kwie, T.L. How long do you feel like the interaction with the table would be?

Witteveen, A. Depends very much on this setting. If you use it to give feedback on stimulating activity the interaction could be 2 seconds in which a person you know flicks away a pop up or whatever or it can be if you have a child with a grandparents then something going back and forth and can take. I don't know, 30 minutes or. So I don't think there is. Yeah, it really depends on the setting.

Chin-A-Kwie, T.L. And could you identify any risks or challenges that the table could have?

Witteveen, A. Yeah, again setting dependent. So if, if you lose the signal on the grandparents, doesn't receive anything anymore and thinks and nobody's thinking about me or llike with the medication adherence, if you have, if you're not lighting it up and someone doesn't take their medicine, it's a whole different kind of risk. Or if you predict the weather incorrectly. So you send someone outside, in the rain, and the next time you someone doesn't want to follow it anymore. So again, I would say depends on the use case you're looking at.

Ruumpol, J.W. Can you maybe also, can you come up with a use case where you could use like data that you got from the table for? Your specific research or, changing behavior, is there anything especially like that in your area of expertise?

Witteveen, A. I think that the closest connection is with a promotion of physical activity, and then you have data whether a person becomes more active.

Ruumpol, J.W. And how? Because the table basically captures data from the weight distribution. So say you have an application that says. Now go outside or something and move this so the table knows?

Witteveen, A. I'd yeah. I'm not sure whether I see a use for that weight distribution data in that setting. You can then the data then would be in activity patterns from a wearable or something else instead of directly from the table. So then the table would be a display more or less.

Ruumpol, J.W. OK. Yeah, I'm through my questions here. Thirsa do you have any questions?

Chin-A-Kwie, T.L. I think you answered most of it.

Witteveen, A. And if you think of some other, I can always answer through e-mail. If you come up with some later, perhaps.

Chin-A-Kwie, T.L. I just have one more question: what is currently being done for the people within your area of expertise? Like what technology is being developed?

Witteveen, A. That's a very broad question. So yeah, in one study for the cancer related fatigue, we're using wearables, smartwatches. I'm also looking at digital phenotyping using your smartphone. Smartphone data and that's logs and other things also GPS some activity. Then I also have sensors for vital sign monitoring like plaster like sensors. Yeah. So. Different things.

Ruumpol, J.W. I guess that was it then.

Witteveen, A. Okay, goodluck

Ruumpol, J.W. Thank you for your time and for doing this with us.

Witteveen, A. Alright, good luck. Bye bye.

A.2 Interview #2

Interview on the 2nd of april with Arlene John, Assistant Professor at Biomedical Signals and Systems (BSS) at the University of Twente. Permission to

record the interview was requested and granted before the start of the interview. Below, the transcript of the interview can be found. The transcript was edited slightly to make a more readable text but remains mainly a verbatim transcription of the interview.

Chin-A-Kwie, T.L. So we are Janine and Thirsa and we are currently doing our graduation projects on the smart interactive mini tables under supervision of Frodo and Juliet, and Janine will focus more on the technical aspects and I will explore the possible use cases for the table.

Chin-A-Kwie, T.L. The goal for this interview is to find good use cases for the smart interactive mini tables within your area of expertise. So maybe you could explain briefly what your area of expertise is so we have that clear.

John, A. Yeah. OK, so my area of expertise is uh, signal processing and machine learning for data that you obtain from variable devices. So any kind of variable devices that from which you get data based mainly for Health like your oxygen saturation, ECG etcetera, but also data that you can obtain from other sensors that are placed in your environment like camera for example. So any kind of data that gives you information about your environment or or your person or Health which can be used for health inferences, that kind of data I work with and I mainly focus on signal processing and machine learning for inferences from that data. So I mainly focus on developing algorithms that can do this.

Chin-A-Kwie, T.L. OK. Thank you. So the smart interactive dining tables currently in the design lab, I don't know if you've seen it there?

John, A. No.

Chin-A-Kwie, T.L. That's OK. It was being used for measuring eating behavior, and we are making smaller version of these tables so it will have diameter of roughly 50 centimeters and have 19 panels with each 42 LEDs so about 800 LEDs in total. And all that will be individually controllable, and all each of the panels will also contain a load sensor. So you can measure weight in the tables, put on the tables and similar to the big table, but it's just a smaller scale and another feature that small table have is that the big table does not have is that there will be multiple tables which will be connected over the Internet. So we can exchange data between them. Do you have any questions about this?

John, A. And how many small such tables are you planning to connect to each other?

Chin-A-Kwie, T.L. I think the main idea is two right now.

John, A. OK.

Chin-A-Kwie, T.L. The tables still need to be made, so we're just sticking with two.

Ruumpol, J.W. Or it could be more. It depends on the situation we want to use them in, but we're going to find out.

John, A. OK, cool.

Chin-A-Kwie, T.L. And do you have any ideas on how the mini tables could be used within your research? Or a good use case.

John, A. Yes. So the sensor that you mentioned is like a load sensor so that measures weight I guess. Yes. So I was, uh, at one point looking into whether you can recognize neuropathy, that is, you know, when you have numb numbness or tingling on your fingers because of as a side effect of some treatment on whether and when you type a message on your smartphone and the patterns of how you type, whether it will change if you have tingling in your fingers. Uh, but I don't know whether that can be connected to eating patterns or like how someone's probably going to grab their spoon, or whether that can be detected with the load sensors. No, I don't think it can be measured with load sensors, but maybe writing patterns can be measured, for example. So if it's a study table like the new interactive table could be a study table and someone's writing, and how you write or the tremors, and like maybe moving from 1 panel to another and could be an interesting thing to look at for example.

Chin-A-Kwie, T.L. OK, so for what specific user group would this be?

John, A. Yes, and this is for uh.So I was looking mainly into patient groups that have been treated for cancer, but as a side effect of the treatment, a neuropathy is a side effect of the treatment and like not everyone gets it like a small population of the people would get it, but it would be good to know beforehand that they are developing this so that you can already start with an intervention treatment for that.

Chin-A-Kwie, T.L. OK. Uh. And so it would mainly be used for like the research behind it wouldn't actually or would there be an actual way for it to help also with the neuropathy? Would it just be used for measuring the tables?

John, A. I think it would mainly be used for measuring. I don't know whether it would be helpful for any kind of treatment unless it's for like some kind of rehabilitation of the muscles in your hands like maybe a task is still probably do something like OK, drop certain objects into a box in like very little time, and then you have to really focus on doing that. But I don't know whether you can use a smart table for that.

Chin-A-Kwie, T.L. OK. And so what's currently being done for these people already here? Is there something that's already there or?

John, A. No, it's mainly based on the patient themselves report that they are feeling loss of sensation in their fingertips, so it's not, uh, these people are not monitored to do any kind of early detection. So it's at the stage, really depends on the patient. If they are very proactive about conducting their GP, we get to know about it early, but otherwise, like it's much later, and it's probably at the end stage where you can't do any kind of therapy to solve it.

Chin-A-Kwie, T.L. OK, so is it true that if you catch it earlier, there's something you can do about it. But later on it just kind of stays, or does it still go away?

John, A. Uh. Very unsure, really depends on the patient, I guess.

Chin-A-Kwie, T.L. OK. So what kind of interactions would they have with the mini tables?

John, A. Just writing on the table, but I think that that's the entire idea is probably not very useful, but I do work with a lot of patients who have had treatment, not like work with the patients directly, But like in the group

that have had treatment for obesity. But that's like bariatric surgery. So they have been surgically well, uh there's been a surgery to reduce the size of their stomach or directly connect the top of their stomach to the intestine so that they don't eat a lot. But then what happens is they start losing weight, but after some time they start regaining the weight again, but obviously to keep the weight off they have to eat healthy and not eat a lot and things like that. But then it would really be very similar to the original interactive table topic on like monitoring, eating patterns and things like that I guess. But it would be nice to also measure the weight of these patients in an unobtrusive manner. So if someone pressed their hands on the table, can you say anything about their weight whether it's increasing or decreasing?

Ruumpol, J.W. Yeah, that's kinda interesting. Now I'm wondering if you could.

John, A. And also under the group that I just remembered because I was talking about placing your hand on the table. So some patients who have been treated for breast cancer, which has been surgically treated. So that means that their breasts have been removed, as a side effect, their lymph nodes are also removed and their lymph drainage doesn't happen properly. So that means their arm will start swelling. Uh, because the limb drainage is not happening properly, so there's like one arm which is bigger than the other, and it's called lymphedema. So it could also be used to see if your one arm is heavier than the other. Would it be possible to measure that? But it's pretty the patient themselves will know if they're having lymphedema, and it's like, uh, kind of, you could treat it using physiotherapy. So it's not a problem of whether the patient would know or won't know, but it would still be nice to like measure or figure out if someone's getting it by just placing their arm hand on the table, and if there's a difference in the weight.

Chin-A-Kwie, T.L. OK. And do you have any idea how to incorporate like the interconnection between different tables into this idea?

John, A. Are you talking about the technology or are you talking about okay, one table does one thing and the other table does another thing and then they can communicate.

Ruumpol, J.W. No basically within the same patient group like could it add something if the tables are connected like uh, Could we connect like patients to each other and something do with that?

John, A. Umm, unfortunately not, because I'm a huge proponent of using one table for everything. So like 1 table should be able to measure everything that you need to know of the situation going on. So I am blacking out on how to connect.

Ruumpol, J.W. Okay maybe from a previous interview we got the idea of that the table would also connect to like wearable devices for example. Maybe a connection in such a way? Do you have any ideas for that?

Chin-A-Kwie, T.L. It can also just be for fun or something like it. The table will itself will just measure everything and then for fun it can also send things to other people, and you have a way of interacting with other patients in a way.

John, A. Yeah, maybe for the patient groups with obesity for example, like. When they're eating habits like hey, today I had so much broccoli. Like, and somebody else would be like, yeah, today I had so many, so much amount of protein or something, but I don't know whether that would be really healthy. What if it leads to more eating disorders in the population that is already struggling with obesity. So I don't know. I would not recommend that.

Chin-A-Kwie, T.L. Uh. Could you identify any risks or challenges that could come up as the mini tables are being used within this user group?

John, A. I think I did mention one difficulty. Yeah, I don't know, especially with patients who have been treated for obesity like they are probably obsessed with their weight a lot. So if every second they're being notified of their weight, or they're looking into their phone to see how heavy are, how much heavier they are, maybe it's not a good idea to have such a table because you will use a table more than you would use a weighing scale in your house, right? Yeah, mainly that. Like that's what I could think about. Yeah.

Chin-A-Kwie, T.L. And for like the writing with the neuropathy?

John, A. For writing with neuropathy? I do not, I do not foresee any risks. As long at least as long as the table, unless it leads to some kind of paranoia, then everyone's like watching how they write. Maybe don't tell patients that the table measures neuropathy.

Chin-A-Kwie, T.L. OK. And so in what kind of setting or space would this be used? So would it be at home or like in a certain research area?

John, A. Uh. I think it should ideally be used at home, but I'm not completely sure whether the cost of having such a table installed in every home would outweigh the benefit of detecting these problems early on. Uhm, but maybe they can be used, at least for the obesity population, it makes sense to use them in the home setting because it's for more long term monitoring. But for the people who might develop neuropathy, it could be that they're going for some kind of follow-up treatment at the hospital, and they have to fill out a form or something. Tell them to go and sit at that specific table to fill out that form, and that probably the form also has a similar structure every week, so you have to start writing out your name and your patient number anyway, so that would give like good data on analyzing whether the writing patterns have changed. So maybe that in the hospital setting. And what else did I talk about? Neuropathy, obesity, and lymphedema. Yeah, lymphedema. Lymphedema also can be with in the hospital or the GP, because that group is constantly, they do have a lot of follow-ups. Uh, but lymphedema develops very quickly, so sometimes it might be beneficial to have it at home also.

Chin-A-Kwie, T.L. OK. And do you think like the LEDs would still give any feedback during the time the patients are using it, or would the LEDs not really be incorporated?

John, A. In these three scenarios for the lymphedema and the patients with neuropathy, I don't think the leads would give any kind of feedback. But maybe for the patients with obesity. Yeah, there might be like it would be good to have some feedback like you have been sitting here for so long. So this is a dining table you're supposed to leave now or like stop eating or something like that?

Yeah, or even like for. It really depends on what kind of table it is. It's if it's like a laptop table where someone's watching a movie or something. Then you could say if a person has been there sitting like this for a really long time, that maybe you should like get moving or exercising or something like that. Also, would affect both groups like the lymphedema group and the neuropathy group, because fatigue is also a side effect of cancer treatment. So if someone's just sitting there, it can indicate that they're fatigued, or they're they don't have enough physical activity and tell them to be more active and get out of the house. But really depends on the purpose of the table as well.

Chin-A-Kwie, T.L. Well, the tables will be like smaller, so it will be more of a... eh.

John, A. Like a coffee table?

Chin-A-Kwie, T.L. Yeah.

John, A. OK. I don't know. Some people have their smartphones on a stand, and they leave it on their coffee table, and they just, like, watch things on it. So if there is a smartphone on the coffee table for a really long time, they have not left the house.

Chin-A-Kwie, T.L. Yeah. OK. Uh, what would be the key performance or success indicators that would prove the effectiveness?

John, A. Umm for the group with lymphedema, it would be on accurately identifying patients who are developing lymphedema in probably a large group of patients. Same for the people with neuropathy. So it would be like good sensitivity to neuropathy, good sensitivity towards detecting lymphedema. For patients with obesity it will probably be on, if they were able to keep their weight off by using this table, but I am not completely sure how you could directly make a correlation. It could simply be they were doing other things correctly, and so I'm not very sure how to go about measuring the key performance indicator for that scenario.

Chin-A-Kwie, T.L. OK. And would the mini tables add anything to your research that you are currently doing?

John, A. Umm. The three things that I mentioned right now, even though they're connected to my research, I do not think, uh, I have the opportunity or. or the patient groups or the cohort studies in place to actually start doing these measurements because they're all connected directly to the patients. So it's all the examples that I mentioned did not have like healthy people or healthy lifestyle monitoring in it. So no, I wouldn't say it's directly connected to my research at this point.

Chin-A-Kwie, T.L. Okay. Umm. And how long do you think the table would be used before reaching a desired effect?

John, A. Now for the patients with lymphedema or patients who have been treated for breast cancer, it should be within the first six months after breast cancer treatment, for patients with obesity within two years to see how whether they have been successful in keeping their weight off. And for people with neuropathy also, like within one to two years after treatment.

Chin-A-Kwie, T.L. Okay.

Ruumpol, J.W. I guess I'll be asking some questions now. So yeah, I'm specially interested in the writing idea. So if you wanted to do that, how accurate should the data be that you collect before you can actually Yeah Identify that?

John, A. Umm. I think it should be pretty accurate. Because it's like very minor change in the writing style like, so it's like small tremors in your fingers and things like that. And then you place your hand on it. Whether it creates any new vibration, so if it's like more noisy than before. So it would be a good idea to have some kind of baseline measurement of a patient before they have been treated for any condition, and then they compare how it changes with the baseline and it. I think it should be, as I think it should be wonderful for it to work. It's not. I wouldn't say it's an easy task, but definitely something that you can do.

Ruumpol, J.W. And for the breast cancer patients, you said they could measure like the difference between like their hands. Is that like how big is the difference? Do you know that?

John, A. Yeah, it would be. So if it's like a fully set and lymphedema like, it could be really a big difference because there was another Create Student working on developing a sock that could like I think it was a sock in the end. It was like you could put it on one arm and then put it on the other arm and see how much it stretches and both arms. To be fair, all humans have asymmetry in their arms. So like both arms are not the same, but there is a limit to how much of a difference is normal. So if someone's like sitting with two arms on the uh table and there is a significant difference between these two arms like, I don't know, half a kilo difference or half a kilo or more of a difference than it big, yeah.

Ruumpol, J.W. Pretty big difference, OK. So yeah, with the data, the table will store it. So if you had to like access all the data, do you personally have a preference of how the data would be stored?

John, A. As in the format of the data storage or where it is going to be stored?

Ruumpol, J.W. Yeah, yeah. Doesn't matter anything, Anything you have to say about it?

John, A. Umm, I don't know. Like some kind of CSV files or E.D.F. Files and yeah, probably should be stored in a safe, accessible environment so that it won't get leaked or something.

Ruumpol, J.W. Yeah, because I can imagine, especially for the like the noise data of the tremors like that would be like a lot of data. And like very specific data. So yeah, a good way to access that would be pretty important, I think, And also like would you want to analyze that yourself? Or do you think that you should already have a build in like analysis?

John, A. Uh, as in OK, if this table is final product and is being used, then the table should have it built in. But like when you're developing algorithms, you can just collect the data, send it to a researcher, and they can make an algorithm, and then you can put it back into the table. Because I don't think anyone at the hospital or at the GP is going to get the data and be like, oh, this patient is going to have neuropathy like they just want like neuropathy? Yes,

or neuropathy? No right?

Ruumpol, J.W. I mean, I do not know. I don't have the knowledge. Yeah. So. For like all three users, what would be the like are there any special learning curves, or are there any groups that you think have a bigger learning curve or?

John, A. Umm, so all the things that I mentioned are not things that they need to do differently, right? So I don't think there's going to be any learning curve involved, so it's not an intervention. So nothing really to be done.

Ruumpol, J.W. OK. Can you think of anything that we could add to the table that would make it easier or more accessible to use with any of the user groups? So they can more readily use it.

John, A. Yeah, I was just thinking about the LED's and then that means the blind patient groups can't really use to use it to have any kind of interaction. So I don't know, maybe it should have like also a sound thing that can speak to you or something saying like you have been at this table for a really long time. Please leave or something. Umm. More accessible to users. Umm. Yeah, I mean like, only rich people have coffee tables, right? So maybe it shouldn't be a coffee table.

Ruumpol, J.W. Hmm, right. Umm, I mean we can use it as a placemat or something very thick one but. Okay So yeah, we talked about this in the beginning like there only being 2 tables. But like if that could be like 100 like would that be like better in the use cases or how many tables do you think there should be?

John, A. Yeah, at least for the Obesity Group 1 table is fine, because mostly people do sit at a dining table to eat, unless they're watching TV then maybe it would be nice to have like a table near the TV on which they can keep their food or something. But for the patients with lymphedema or neuropathy like, you can't really limit people to say that, OK, you have to write only on this table. Yeah, that's in the home environment, that is. But uh, if you're talking about the GP case, you can be like every table that is accessible to the patient at the GP has this cool thing that can see if someone's having neuropathy or if they have lymphedema. Things like that.

Ruumpol, J.W. So if you can make her like a rough estimate of how many tables will be used in that case.

John, A. OK, yeah. So how many will need to be produced? I think on average like yeah like maybe like 300 people in 300 women per year do get treated for obesity in the Netherlands. So in a year 300+ for people with obesity, if they are going to use it in their home setting, but for these tables placed in the GPs, I would say it would be safer to take a count of how many general practitioners are there in the Netherlands. And then you can get like the number of tables, which would be a lot I think.

Ruumpol, J.W. OK. So do you. Is there something that would like really limit the usefulness of the table or anything you can think of, like the weighting will be like accurate enough? Something like that?

John, A. I have never actually seen the table, so I'm not completely sure how durable it is like is it like, would people want to use it or would people look at it and be like I don't want to damage that expensive piece of thing, so I'm

not going to use it. And so if it's that scenario, then like obviously it's limiting the usefulness of the table because it's going to limit how much data you're able to collect from the table. So I would say it should look like a normal table. And I don't know the LED feedback thing may or may not affect that the feeling of whether it's safe, it's safe to like just rest your hands on it or something. So maybe the LED could be like around the edges of the table or something like that. I don't know.

Ruumpol, J.W. OK. Yeah, I mean, it was not something I would have thought of honestly as a thing. But it makes sense. It makes sense.

John, A. I haven't seen the table, so I have no idea what I'm talking about.

Ruumpol, J.W. Yeah, but we want you to be as creative as possible. Don't be limited by what it already is. So you already mentioned the sound thing, are there any additional features you could think of that would be useful, like something completely different?

John, A. Would it be possible to have a hologram come out of the table?

Ruumpol, J.W. Maybe. Do you think that would be useful?

John, A. I was thinking for the patients with obesity, like sometimes there was this one study on showing their future selves to motivate them to continue a healthy lifestyle and things like that. So like you could show like a hologram of this patient, how she would look two years down the line or one year down the line if she follows the plan for the diet and plan for the exercise and everything is so healthy, so happy, running around with joy or something like that.

Ruumpol, J.W. Yeah, but like that, like, could that maybe you should be done with like the LEDs or on? Does it need to be like very detailed because like the LED panels I mean, there are obviously some LEDs, but they will probably be more like cartoonish.

John, A. Oh yeah, I think that should be OK as well. Like, maybe as part of the study. Like you could before the patient is given this particular method of following a diet or study or an exercise plan, you could do a caricature of this patient as a healthy person and that then they make the connection. OK, this is me. This cartoon character is me, and then if you show it on the table then there's that connection like ohh this is me in the future, if I do what I am supposed to do or something like that.

Ruumpol, J.W. OK. Do you have any questions Thirsa?

Chin-A-Kwie, T.L. No.

Ruumpol, J.W. Uh, yeah.Then I think we're done with our questions. Do you have any questions or remarks?

John, A. Umm, no, I'm very curious about like the idea of like having the two tables and they communicate with each other and like how it could probably improve some kind of collaboration between patients. If, for example in the hospital or something, and whether this collaboration would be would lead to better outcomes or better health outcomes for the patients like I'm, I would be very curious to know what you find.

A.3 Interview #3

Interview on the 8th of april with Femke Nijboer, assistant professor in the Biomedical Signals and Systems (BSS) group at the University of Twente. Permission to record the interview was requested and granted before the start of the interview. Below, the transcript of the interview can be found. The transcript was edited slightly to make a more readable text but remains mainly a verbatim transcription of the interview. Some parts at the end of the interview are left out of this transcript as the interview went of topic.

Chin-A-Kwie, T.L. We are Thirsa and Janine and we are doing our graduation project on the Smart interactive mini tables under the supervising of Frodo and Juliet. And yeah, the purpose of this interview is kind of to find a good use case for these tables within your area of expertise. So maybe you could explain a little what your area of expertise is. So we have that clear.

Nijboer, F. Yeah, good question, so at the moment I work in the field of E health and I mostly work on the prevention of disease, so not so much in the medical domain where people are already ill, and you want to cure them. But I would like to keep them healthy so that there's lifestyle related diseases are prevented and for this and the reason years we've looked on older adults on how we can make them move a little more, eat a little healthier and mostly more because malnutrition is a big problem in the older adult. And also to do coaching that is fun and meaningful to people.

Chin-A-Kwie, T.L. OK. Thank you. So you have seen the big table in the design lab. So we are basically making a smaller version of that with a rough diameter of 50 centimeters and with an additional feature. That's there will be 2 tables connected with each other. So you can select it information between the tables. Do you have any questions about this?

Nijboer, F. Maybe you have to help me a little bit. So what does it do then? What kind of information can be shared, for example?

Chin-A-Kwie, T.L. You have the input from the table, so it has load sensors in them, so it measures weights on the table. Because it also has LED panels on top, you can for example send information about where somebody has placed the glass on the table or something like that.

Nijboer, F. Yeah. OK.

Chin-A-Kwie, T.L. And so do you have any specific user group or where this could be used for?

Nijboer, F. It was very general question. Uh.

Chin-A-Kwie, T.L. Within your, your area of expertise, you have any use case for these tables. Do you just have an idea of what the tables could add in your research or for some people that you are working with?

Nijboer, F. Well, but maybe I could. It makes me think of an experiment that the Interactive media group once did. They had a table that encourages play and working together. Because the plates on top of the table would disappear within the table, but you had to play a game with the rest of your dinner party in order to make the plates appear again. So everybody could eat and in

that sense it would stimulate working together or playing together. So a happy atmosphere at the table and I think that's that could be a nice idea for two such tables that you use it in a way that you make more social connection between the tables or something. So for example, with the elderly, with the malnutrition, or maybe they could have a do tables connect thing and they would did not weigh be stimulated to eat more. Because we've noticed, especially with older adults, is that they don't for themselves. They don't really have a reason to eat more because they they maybe don't take good care of themselves, but they still want to take care of other people, so if you give them kind of an assignment, that by eating themselves. They also stimulate others to eat more. This could be an encouragement to increase all of them, to eat a little bit more. There's also with older adults in lifestyle intervention and in lifestyle interventions in general people, if if it's a scientific study, they don't really participate for themselves, but just to contribute to science. This is a big motivator for a lot of people to enter such lifestyle interventions so they know I don't really need it. I already know to take care of myself, but I want to advance science. For example umm, you can use that also as a little bit and to if if that's an important motivator for them, then somehow you should include another person in the lifestyle intervention that you connect them. And I think that's why 2 tables is easier than one to do this. And could the tables also be distant from each other, like in different locations?

Ruumpol, J.W. Yes, that's the general idea.

Nijboer, F. OK. Because then I also think of the hospital in Deventer where I want was and where the geriatrician told me that she has 2 problems and the first is that when the older adults are at the department in her ward, it's very difficult to motivate them to go to the joint dining room. I mean they really want them to go out of the bed for the movement, but also go into the dining area. So they have some social interaction and they eat more when they're present with other people. So an interactive table could be a means of going there and having fun there or something. But she also says she doesn't have the ability to monitor them at home anymore. Like if you could have a program which you say OK, we learn, we teach you to eat a little bit more during the hospital and then you go home. And we also monitor your you for a couple of weeks. If you maintain weight, or if you continue this new eating behavior, then I think the risk that they reenter in the hospital again is lower. So I think this could be something she would want to use as well.

Chin-A-Kwie, T.L. OK. And do you think then the tables would just be at home with all these people, like with the elderly, they would just all have one table. So they kind of Join eating in.

Nijboer, F. No, this I see the problem. They can't take it home, of course. No. Hmm.

Chin-A-Kwie, T.L. I think it did. The end goal is kind of to make tables they could use at home, right? I mean I don't know what it would cost for you, but we're not at that stage yet, so.

Nijboer, F. Maybe then it's more of a retirement home thing that you place the persons who have difficulty eating at the same 2 tables and through

an interactive nice. Stimulation, something that you have to invent. You make them eat a little bit more.

Chin-A-Kwie, T.L. And do you have any idea on what kind of interactions would be helpful for these people?

Nijboer, F. This I don't know so well. Umm. It depends a little bit what their cognitive function is. If they're, you know, with people who are maybe a little bit more dementia or have cognitive problems sometimes they also use. Like pictures or sounds, or even smells or music from their and childhood or teenage years when they were 20. Umm to project this as kind of a yeah. Say material or something that can help them interact or something. So maybe it's something like you're eating and you're getting rewarded with a picture of the past or something. But then it's an experimental question whether this material which could be displayed on the table is in the way of eating, because it distracts them or it actually stimulates them, or they're willing to work for it. But that's an experiment, yeah.

Chin-A-Kwie, T.L. Just then, what's kind of interaction towards there be between the the two different people eating at the same time with the different tables?

Nijboer, F. I don't know. I think not everything has to be done by the table, right? There can also be a human instruction next to it, or a volunteer who eats with them, but who monitors the table. And if the table says OK, you should. You have eaten enough or you have eaten as a high enough frequency. Then you get a reward and I don't know the volunteer facilitates the conversation with the other person or something so that the interaction might be between the humans and the table and the volunteer or something. But we know for eating behavior that it's frequency, right, so it's it's the speed with what you eat is important for, especially for people with overweight, they eat too fast. They need to take slower, have slower of bytes. And people who don't eat enough, I don't know if they also eat slower or just not enough. Yeah, I've seen forks as well. That's give feedback every 10 seconds to time your your the the frequency with which you take a bite to remind you the table could also. I don't know if the table vibrates or the chair can vibrate. Or maybe this fork in combination with visuals on the table?

Chin-A-Kwie, T.L. So just includes other things as well together with the table.

Nijboer, F. Yeah. And for older adults, you always have to be extra careful that their sensory because they have sensory impairments. So maybe their vision is less or even textile. Maybe they feel a little bit less. They smell less, they taste less. So all of these things contribute to them eating also less so that could also be a case that you with a multi sensorial experience, you enrich their eating experience a little bit. So you compensate for the loss of smell and taste by giving a grand disco show or something.

Chin-A-Kwie, T.L. And do you think the sound would add something to the table then?

Nijboer, F. I don't know. Maybe that's an experimental question.

Chin-A-Kwie, T.L. And and do you think there would be any risks

included with this user group and and if they also?

Nijboer, F. With the older adult I know well the the risk is always that you have the opposite effect of what you intend to have, that it distracts so much that they eat less. I'm worried, I don't know about choking. But this is maybe more for people with swallowing problems if they get distracted and choke on something. What if somebody sues you for this? I don't know. Otherwise, I don't see a lot of risks, yeah.

Chin-A-Kwie, T.L. Uh, yeah, that's that's good. And do you think then that the tables would be useful within the research? Or would even more just before the adults to eat more.

Nijboer, F. I think it's mostly useful for research. First to understand better how how we can enrich the experience while eating and what people find important. Yeah, you can ask a lot of research questions with this table, I think and how it can be made useful. I don't know so well, but I think there will be a lot of interest for it. Not not so much in the table. Maybe because it's too costly, but I think if you can find a way to to change eating behaviors of people with the table that's there could be very interesting. Maybe also for other groups like Autistic Children or something. This is a bit speculation. Thisd is not my research area, but maybe they could benefit from a more structured pacing of of a meal, maybe also Parkinson patients who have trouble starting a movement. So if the if the table could dictate you or to queue you to start eating, then maybe people start to eat again.

Chin-A-Kwie, T.L. Well, that is quite interesting. OK. Umm, you have kind of answered the interaction questions, that I wanted to know.

Ruumpol, J.W. You have answered most of my questions already but one question, what do you think would like really limit the usefulness of the table? You could think for example it looking like it would break any moment.

Nijboer, F. Yeah. So the older adults that we studied were really careful with the equipment, more so than the young people. And if they felt they could break it, they wouldn't use it. We have this with the sensor that they wouldn't wear because it was too fragile and they were afraid they would lose it and they're very, very careful and conscientious about other people's stuff, right? So that could be a problem and I think for the stakeholders like like we when we were planning an experiment in the Deventer Ziekenhuis the problem was how large the table is and how bulky it is. There was a big problem, but you notice already. It's difficult to move. Uh, and maintenance. It has been a big problem over the last years of this interactive table. It's Frodo and Juliet trying to update the table and keep it fresh a bit. And nobody knows how to program it. I don't know if that's been solved already, but so it makes for a bit of a a not very usable table at the moment.

Ruumpol, J.W. So it would be like very useful to be able to update the tables and maybe like remotely even.

Nijboer, F. Yeah.

Ruumpol, J.W. So one concern I also see with using the tables for the elderly people is the learning curve. How do you think like can you guess the learning curve, if we use the table in the way you like described.

Nijboer, F. Uh, I don't know, but we, I do know that we have a tendency to underestimate older adults in terms of what they can learn and especially the Dutch older adults that we studied have a lot of technologies at home. They use iPads, they have smartphones, they most of them had an email address. Umm, so they're pretty up to date with most things. Nevertheless, uh, if we instructed them on a lifestyle intervention or something, we really needed to have good instructions or sit down with them one on one to explain how something should work. But I think the table itself should be so intuitive that you just sit on it and the experience starts. So I don't think there's any reading involved. Or are you having to connect as a wearable to a a laptop for example, like we had to, you had to connect your wearable to a computer at home. This was a bit tricky. But I think the table should be. You sit down. Something happens and then maybe by learning you by doing, you learn how to interact with the table like you understand if I see a red light, I have to touch it or something or I don't know.

Ruumpol, J.W. You know, because I was thinking like a when it's actually used like at home for the user. Like there will always be like a setup cause like it needs to be connected to like some form of Wi-Fi for it to work remotely There is an issues thinking along those lines however.

Nijboer, F. That that needs uh, that needs somebody to do that for everything. So you should think also of who is going to distribute the tables. What is it going to be like? Or would you call this company? We have a lot of care companies that give technologies to other adults and they come to your house and they set up the device. They give you a short instruction and they leave again. And then in the Netherlands. This is really well arranged, so there is a reimbursement scheme for that. The insurance will cover it or sometimes not. Sometimes they're like family pays for it, but then like me with my mother, I say, OK, this cost us €30 per month, but we pay for it because it's security. So then the company comes to your house and sets it up.

Ruumpol, J.W. Yeah, that would solve that problem.

Nijboer, F. So if you are designing a concept, I would include that in your concept of the table that there is. How the service is going and who does what and what kind of puppets and people do you need to make this happen?

Ruumpol, J.W. Yeah, yeah, that makes sense. So, like you said, we have the use case where the elderly people use the tables to like sort of eat together on help each other. How many tables or how many people do you think should be connected together? Would it be one on one or maybe like a small group or?

Nijboer, F.

That depends on the context where you place it. So if it's a retirement house, then I don't know the answer. You should go to the retirement house and study what the context is like. Are people eating together with four on four on a table? Umm, you know, some people prefer to stay on their room. Those are probably more the target group. So how do you get them out of the room? And the table could actually be a nice thing to try out.

Ruumpol, J.W. So my idea is that for those people that stay in their room maybe like a step like in between going to the dining area and like staying

in a room and don't at least like eating with the table so they're sort of still connected and sort of can communicate with like other people that also stay in a room and you should table like that maybe.

Nijboer, F. Yeah, like you could log on to the table or something and I think what also would help is if your grandchildren or something could log on to the table and it could be a way of getting more contact to your grandchildren because now you have a super cool, innovative game that they can also use when they eat dinner with grandmother. So it's a way of luring your grandchildren to you and and you want to do it because you have extra time with your grandchildren. I think maybe that's the trick with the table to try to make win, win, win situation somehow, yeah.

Chin-A-Kwie, T.L. I have a random question, but how old would you say these people are like, what ballpark are the people that you were studying?

Nijboer, F. The older adults that we were studying were average of 80 years old, but I think I don't know, in the geriatric hospital. I think maybe after 70. And the group of 72, I mean most people who are obese or overweight, they don't become really old, right. And the the rest that's is left is usually a bit thinner and also has the risk of malnutrition. And once, once they are malnourished, this is also when problems start to arise with wound care or frail, or they break stuff because their bones are not so good anymore. So it's it's more more older adults, I think older, they call them I think the to older old people, yeah.

Chin-A-Kwie, T.L. Yeah, I'm through my questions. So OK, I think that was it done to you have anything to add still?

Nijboer, F. Maybe tonight, when I thinking again of it, I don't know.

Chin-A-Kwie, T.L. Or you can you can always email us.

Nijboer, F. Another use case would be overweight I think. And my students are working on that a little bit, so maybe they can provide a use case as well. I'm not sure we target especially males with overweight and then with a kind of a persona in mind of the soccer club. Fans, umm, and especially in the region they have maybe a little bit lower health literacy and also. Less literacy in general, so they can't read and write so well. Not all of them, but some of them. And so lifestyle interventions, especially given by females, are very intimidating to them and they really would like to have a fun activity with men attending there. And I don't know if it table could help there, but at least it's not a female, so that's good. Yeah, they're really concerned about feminized spaces and and we should be really careful of that. So that's a different use. And maybe there's a bad case because they want they don't want lifestyle intervention to focus on weight or food. It should really be about physical activity and fun, yeah.

Chin-A-Kwie, T.L. I don't think the table is a good solution then.

Nijboer, F. A table is very often about food, right? But maybe the most boring use case, but could be a proof of concept. Is this maybe the frequency of biting? Because I think that has been studied very extensively that this is related to overweight and if you have a table who can monitor your frequency and coach you in the frequency that you eat. Maybe it feels like a bit of boring concept, but it could be a first proof of concept that you can coach people

through a table.

Chin-A-Kwie, T.L. Thank you very much for this interview, and for the opportunity.

Appendix B

Requirements

Requirements gathered from expert interviews, for the transcripts of the interviews see appendix A

B.1 Requirements

B.1.1 Requirements from interview 1

Functional requirements

- The table should be able to communicate with other smart devices
- The table should support various forms of visual feedback, such as numeric or bars charts
- The table should make interaction like games possible between for example family members
- The table should be able to collect data such as weight distribution and activity patterns

Non-Functional requirements

- The table should provide feedback timely, especially in use cases involving children
- The table's visualization should display information clearly
- The table should have reliable communication between tables
- The table should be user-friendly, especially in use cases involving people with low digital literacy.

B.1.2 Requirements from interview 2

Functional requirements

- The table should be capable of integrating algorithms for data analysis
- The table should provide timely feedback to users with LED's or sounds

Non-Function requirements

- The table should be accessible to all user groups, including visually impaired individuals.
- The learning curve of the table should be minimal
- The data the table collects should be sufficiently secured
- The table should be durable, and not look fragile.
- The table should be made such that it can be used in different settings such as at home or healthcare centers

B.1.3 Requirements from interview 3

Functional requirements

- The table should provide a multisensorial experience to compensate for any impairments of user groups
- The table should be intuitive to use and not require any instruction
- The table should only have to be set up once
- The table should support remote updates and maintenance.

Non-Function requirements

- The table should encourage social interaction by means of games or activities that focus on cooperation
- The table should be durable and reliable
- The table should not be distracting in a way that could lead to risks
- The table should be compatible with existing technology
- The table should accommodate different group sizes.

Appendix C

Evaluation

C.1 Task list Smart Interactive Mini Table

Try to complete the following tasks (in order). If you cannot figure out how to do a task, you can ask for help. As the table is still being developed, some things may not work as expected, this is not your fault. If you think something is wrong or not working correctly, please speak up.

Task #1 Connecting the table

1. On a laptop/smartphone, open your internet browser and go to _____:5000
2. The resulting screen should show a webpage saying Welcome to the smart interactive table. From here, try and connect the table.

Task #2 Modes Now that the table is connected, you can interact with it through the webpage!

1. Go back to the beginning screen and click start.
2. The table has five different modes, write down the mode that you think the table started in.

   The table started in a mode called:

   _____
3. Now try and switch between modes and observe the effect on the led module.

Task #3 Drawing Basics

1. Switch to the "Draw" mode.
2. Turn on a LED.
3. Change the color and turn on another LED.

4. Turn both LEDs off.

Task #4 Drawing figures

1. Draw a square by turning on LEDs.
2. Turn all the LEDs off.
3. Draw a smiley face, with 1 green eye, 1 blue eye and a red mouth.
4. Change the color of one of the eyes to yellow.
5. Turn all the LEDs off.

Task #5 Interacting with others Ms. Smith, living in the retirement home down the road, also has a table. You are now going to interact with her!

1. Select Ms. Smith her table.
2. Set the mode to draw.
3. Draw something on Ms. Smith her table.

Task #6 Receiving a reply Ms. Smith is very thankful for your drawing and is sending you something back!

1. Set the mode to receive.
2. Write down what Ms. Smith has sent you:

Task #7 Knock Knock

1. Place your hand on the LED module, once the LEDs turn on, lift your hand again.
2. Try the different modes again and observe the effects.

This in another way to interact with the table. The table measures the pressure put on the surface.

Good job on completing all the tasks!

Now please finish your participation by filling in the survey on the next page on the usability of the Smart Interactive Mini Table.

C.2 Blank SUS-Questionnaire

This part is a standard questionnaire that measures the overall usability of a system. Please select the answer that best expresses how you feel about each statement after using the Smart Interactive Mini Table today.

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
1. I think I would like to use this tool frequently.	◯	◯	◯	◯	◯
2. I found the tool unnecessarily complex.	◯	◯	◯	◯	◯
3. I thought the tool was easy to use.	◯	◯	◯	◯	◯
4. I think that I would need the support of a technical person to be able to use this system.	◯	◯	◯	◯	◯
5. I found the various functions in this tool were well integrated.	◯	◯	◯	◯	◯
6. I thought there was too much inconsistency in this tool.	◯	◯	◯	◯	◯
7. I would imagine that most people would learn to use this tool very quickly.	◯	◯	◯	◯	◯
8. I found the tool very cumbersome to use.	◯	◯	◯	◯	◯
9. I felt very confident using the tool.	◯	◯	◯	◯	◯
10. I needed to learn a lot of things before I could get going with this tool.	◯	◯	◯	◯	◯

Smart Interactive Mini Table Specific Questions

This part is a questionnaire with specific questions to evaluate certain non-functional requirements of the Smart Interactive Mini Table. Please select the answer that best expresses how you feel about each statement after using the Smart Interactive Mini Table today.

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
1. I think the tool looks durable.	◯	◯	◯	◯	◯
2. I was able to complete the tasks given quickly using the tool.	◯	◯	◯	◯	◯

3. I thought the tool responded timely to my inputs.	◯	◯	◯	◯	◯
4. I think that the table will easily break.	◯	◯	◯	◯	◯
5. The tool has all the functions and capabilities that I expected it to have.	◯	◯	◯	◯	◯

C.3 Filled SUS-Questionnaire

C.3.1 Tester 1

Total score: 72.5

	Strongly Disagree	**Somewhat Disagree**	**Neutral**	**Somewhat Agree**	**Strongly Agree**
1. I think I would like to use this tool frequently.	◯	◯	◯	x	◯
2. I found the tool unnecessarily complex.	◯	◯	x	◯	◯
3. I thought the tool was easy to use.	◯	◯	◯	◯	x
4. I think that I would need the support of a technical person to be able to use this system.	x	◯	◯	◯	◯
5. I found the various functions in this tool were well integrated.	x	◯	◯	◯	◯
6. I thought there was too much inconsistency in this tool.	x	◯	◯	◯	◯
7. I would imagine that most people would learn to use this tool very quickly.	◯	◯	◯	◯	x
8. I found the tool very cumbersome to use.	◯	x	◯	◯	◯
9. I felt very confident using the tool.	◯	x	◯	◯	◯
10. I needed to learn a lot of things before I could get going with this tool.	x	◯	◯	◯	◯
1. I think the tool looks durable.	◯	◯	◯	x	◯

2. I was able to complete the tasks given quickly using the tool.	◯	◯	◯	x	◯
3. I thought the tool responded timely to my inputs.	◯	◯	◯	◯	x
4. I think that the table will easily break.	◯	x	◯	◯	◯
5. The tool has all the functions and capabilities that I expected it to have.	x	◯	◯	◯	◯

C.3.2 Tester 2

Total score: 85

	Strongly Disagree	**Somewhat Disagree**	**Neutral**	**Somewhat Agree**	**Strongly Agree**
1. I think I would like to use this tool frequently.	◯	◯	x	◯	◯
2. I found the tool unnecessarily complex.	◯	x	◯	◯	◯
3. I thought the tool was easy to use.	◯	◯	◯	◯	x
4. I think that I would need the support of a technical person to be able to use this system.	x	◯	◯	◯	◯
5. I found the various functions in this tool were well integrated.	◯	◯	◯	x	◯
6. I thought there was too much inconsistency in this tool.	◯	x	◯	◯	◯
7. I would imagine that most people would learn to use this tool very quickly.	◯	◯	◯	x	◯
8. I found the tool very cumbersome to use.	x	◯	◯	◯	◯
9. I felt very confident using the tool.	◯	◯	◯	◯	x
10. I needed to learn a lot of things before I could get going with this tool.	x	◯	◯	◯	◯

1. I think the tool looks durable.	◯	x	◯	◯	◯
2. I was able to complete the tasks given quickly using the tool.	◯	◯	◯	x	◯
3. I thought the tool responded timely to my inputs.	◯	◯	◯	◯	x
4. I think that the table will easily break.	◯	◯	◯	◯	x
5. The tool has all the functions and capabilities that I expected it to have.	◯	◯	◯	x	◯

C.3.3 Tester 3

Total score: 72.5

	Strongly Disagree	**Somewhat Disagree**	**Neutral**	**Somewhat Agree**	**Strongly Agree**
1. I think I would like to use this tool frequently.	◯	◯	x	◯	◯
2. I found the tool unnecessarily complex.	x	◯	◯	◯	◯
3. I thought the tool was easy to use.	◯	◯	◯	x	◯
4. I think that I would need the support of a technical person to be able to use this system.	◯	◯	x	◯	◯
5. I found the various functions in this tool were well integrated.	◯	◯	◯	x	◯
6. I thought there was too much inconsistency in this tool.	x	◯	◯	◯	◯
7. I would imagine that most people would learn to use this tool very quickly.	◯	◯	◯	x	◯
8. I found the tool very cumbersome to use.	◯	◯	◯	x	◯
9. I felt very confident using the tool.	◯	◯	◯	x	◯

10. I needed to learn a lot of things before I could get going with this tool.	x	◯	◯	◯	◯
1. I think the tool looks durable.	◯	x	◯	◯	◯
2. I was able to complete the tasks given quickly using the tool.	◯	◯	◯	◯	x
3. I thought the tool responded timely to my inputs.	◯	◯	◯	◯	x
4. I think that the table will easily break.	◯	◯	◯	x	◯
5. The tool has all the functions and capabilities that I expected it to have.	◯	◯	x	◯	◯

C.3.4 Tester 4

Total score: 80.0

	Strongly Dis-agree	**Somewhat Dis-agree**	**Neutral**	**Somewhat Agree**	**Strongly Agree**
1. I think I would like to use this tool frequently.	◯	◯	◯	x	◯
2. I found the tool unnecessarily complex.	x	◯	◯	◯	◯
3. I thought the tool was easy to use.	◯	◯	◯	x	◯
4. I think that I would need the support of a technical person to be able to use this system.	◯	◯	◯	x	◯
5. I found the various functions in this tool were well integrated.	◯	◯	◯	◯	x
6. I thought there was too much inconsistency in this tool.	◯	x	◯	◯	◯
7. I would imagine that most people would learn to use this tool very quickly.	◯	◯	◯	◯	x
8. I found the tool very cumbersome to use.	x	◯	◯	◯	◯

9. I felt very confident using the tool.	◯	◯	◯	x	◯
10. I needed to learn a lot of things before I could get going with this tool.	◯	x	◯	◯	◯
1. I think the tool looks durable.	◯	◯	◯	x	◯
2. I was able to complete the tasks given quickly using the tool.	◯	◯	◯	x	◯
3. I thought the tool responded timely to my inputs.	◯	◯	◯	x	◯
4. I think that the table will easily break.	◯	x	◯	◯	◯
5. The tool has all the functions and capabilities that I expected it to have.	◯	◯	◯	◯	x

C.3.5 Tester 5

Total score: 75.0

	Strongly Disagree	**Somewhat Disagree**	**Neutral**	**Somewhat Agree**	**Strongly Agree**
1. I think I would like to use this tool frequently.	◯	◯	x	◯	◯
2. I found the tool unnecessarily complex.	x	◯	◯	◯	◯
3. I thought the tool was easy to use.	◯	◯	◯	◯	x
4. I think that I would need the support of a technical person to be able to use this system.	◯	◯	◯	x	◯
5. I found the various functions in this tool were well integrated.	◯	◯	◯	x	◯
6. I thought there was too much inconsistency in this tool.	◯	x	◯	◯	◯
7. I would imagine that most people would learn to use this tool very quickly.	◯	◯	◯	◯	x

8. I found the tool very cumbersome to use.	◯	x	◯	◯	◯
9. I felt very confident using the tool.	◯	◯	x	◯	◯
10. I needed to learn a lot of things before I could get going with this tool.	◯	x	◯	◯	◯
1. I think the tool looks durable.	◯	◯	◯	x	◯
2. I was able to complete the tasks given quickly using the tool.	◯	◯	◯	x	◯
3. I thought the tool responded timely to my inputs.	◯	◯	◯	◯	x
4. I think that the table will easily break.	◯	x	◯	◯	◯
5. The tool has all the functions and capabilities that I expected it to have.	◯	◯	x	◯	◯

C.3.6 Tester 6

Total score: 72.5

	Strongly Dis-agree	**Somewhat Dis-agree**	**Neutral**	**Somewhat Agree**	**Strongly Agree**
1. I think I would like to use this tool frequently.	◯	◯	◯	x	◯
2. I found the tool unnecessarily complex.	◯	x	◯	◯	◯
3. I thought the tool was easy to use.	◯	◯	◯	x	◯
4. I think that I would need the support of a technical person to be able to use this system.	x	◯	◯	◯	◯
5. I found the various functions in this tool were well integrated.	◯	◯	◯	x	◯
6. I thought there was too much inconsistency in this tool.	◯	◯	x	◯	◯

7. I would imagine that most people would learn to use this tool very quickly.	◯	◯	◯	x	◯
8. I found the tool very cumbersome to use.	◯	x	◯	◯	◯
9. I felt very confident using the tool.	◯	◯	x	◯	◯
10. I needed to learn a lot of things before I could get going with this tool.	◯	x	◯	◯	◯
1. I think the tool looks durable.	◯	◯	◯	x	◯
2. I was able to complete the tasks given quickly using the tool.	◯	◯	◯	x	◯
3. I thought the tool responded timely to my inputs.	◯	◯	◯	x	◯
4. I think that the table will easily break.	◯	◯	x	◯	◯
5. The tool has all the functions and capabilities that I expected it to have.	◯	◯	x	◯	◯

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