The State of the Empire in Tabletop Technology

Master Thesis

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Abstract:

In this master thesis we have examined the state-of-the-art of the tabletop research field. The study is two fold: A literature review and a comparative study of single- and multi-factor authentication on a tabletop technology. In the first study we review the literature using a grounded theory approach. The data originates from leading conferences within the research field of tabletop, CHI, Tabletops and ITS. From the data a total of 8 distinct categories emerged, that characterize the research field. In the second study we used the foundation of the literature review and contribute with a comparative study on single- and multi-factor authentication mechanisms on a tabletop. The study compares 6 conditions;3 single-factor authentication and 3 multi-factor authentication. The results revealed that the users prefer to use a combination of possession and knowledge factors. The results also indicate that the combination of a TUI and a PIN was significantly better compared to the other conditions. Finally we discuss the research methods used throughout the studies and presents limitations based on the methods used.

PREFACE

This master thesis is written by two software students during spring 2013at the institute of computer science, Cassiopeia, at Aalborg University.

We want to thank all of the participants who took the time and helped us with the usability tests and fulfilling the questionnaire. A special thanks to our Supervisor Anders Bruun for providing constructive feedback during the project.

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This master thesis consists of this report concerning our motivation, our research methods and the results. The appendices consists of two research papers of our main research (Appendix A and B), a list of references used throughout the research of appendix A (Appendix C) and a summary of the master thesis can be seen in Appendix D.

CONTENTS

CHAPTER 1
INTRODUCTION

Surface computing is a popular topic within human-computer interaction. With the thought of having every surface as a possible computer, creates numerous opportunities for research. An example of research on this topic is the paper by Mistry et al. [1] who creates a wearable gestural interface. The idea is to use a small projector and attachments on the fingers to create gestures in mid-air and use all kinds of surfaces as interactive displays. Another example of surface computing is the paper by Weiss et al. [2] that research the interaction impact when dragging over curved surfaces. Another popular topic in surface computing is the interaction with surface though *Tangible User Interface (TUI)*. In the paper by Pedersen and Hornbæk [3] they use motorized robots as TUI for manipulate music and give haptic feedback to the user. Another example is a paper by [4] that makes everyday objects into TUI by combining the everyday objects with pattern stickers which is like a bar-code and QR codes, that can be recognized by surface technologies. Another topic in surface computer is *collaboration*. One of the advantages of surface computing has over desktop and laptop, is that the large surface makes it possible to collaborate around the digital information as people normally would do, when collaborating around a table or whiteboard. An example of research into collaboration is the paper by Perron and Laborie [5] that research in the social impact of using a tabletop during virtual meetings and informal design reviews. As can be seen the surface computing is a divers research field and have many opportunities. We chose to focus on the tabletop technologies as computer surfaces, as it support natural collaboration and use of TUI.

One of the challenges when collaborating around interactive surfaces is to protect the privacy of the user e.g. personal information. One of the methods is to use authentication to validate if the user is who he says he is, and only after being authenticated can the personal information be accessed. There exits three authentication factors: *knowledge factor* (information you know), *possession factor* (physical object you possess) and the *inheritance factor* (biometric properties you possess) [6][7]. Examples of the three factors; username/password is knowledge factor authentication, voice recognition is inheritance factor and a key is possession factor authentication. As here can be seen, there exist different authentication mechanisms, but there also exists different ways to comprise them e.g. knowledge factor suffer from shoulder surfing[8], possession factor can be stolen [9]. Shoulder surfing is when the user is being observed when inputting authentication credential. A way to make authentication mechanisms stronger is to use multi-factor authentication, which is to combine two ore more single factor authentication[6][9].

1.1 Research Question 1

In our search for an overview of the research field of tabletops, we lacked a review. Reviews are an essential part of any academic project [10]. Reviews are an effective way to create a foundation for future knowledge as these highlight promising research papers from the past and uncovers areas of future research. As a foundation, we created a study, with focus on the state-of-the-art research within the tabletop research field. Thus the first research question is as follows:

What is the current trends within tabletop technologies and where are the research opportunity?

1.2 Research Question 2

Our review showed that there was research opportunity in exploring authentication in tabletop technologies, as very little research was the subject, where none of them had explore the use of possession factor authentication for multi-factor authentication.

The tabletop technologies also introduces new forms of interactions such as gestures or tangibles. This brings up new possibilities within the seamless interaction spectrum as these interaction forms gain increased interest. One such possibility is the introduction of gesture based authentication utilizing the biometrics of a user [11]. Studies claim that the usability aspect of authentication mechanisms have been living in the shadow of the security aspect. This creates very secure systems, however users chose not to use the secure systems, instead they chose the systems based on usability [12]. With the identified opportunity of authentication on the tabletop and the lack of usability coverage within the literature, we follow the second research question:

What is the usability for single and multi-factor authentication for tabletop technologies?

CHAPTER 2
RESEARCH PAPERS

This chapter presents the two research papers in this thesis. The first paper presents a literature review of the tabletop research field to identify the current trends and research opportunities, within that topic. The papers used throughout the study literature review can be seen in Appendix A. The paper can be seen in Appendix B. The second paper presents a comparitive study on single- and multi-factor authentication mechanisms using a Tangible User Interface (TUI) as the possession factor. The paper can be seen in Appendix C.

2.1 Research Paper 1

The State of the Empire in Tabletop Technology - A Literature Review

Computing surfaces have increased in popularity in recent years, and interesting is it to see how this field have matured through time. We have examined the state of the tabletop research field and found eight categories that define the current literature.

The literature review is based on 273 research papers identified from leading conferences, IEEE tabletops, Conference on human-computer interaction (CHI) and conference on interactive tabletops and surfaces (ITS) from 2006 to 2012. The results of the literature review was eight categories. Each of these are elaborated below:

Implementation The implementation category covers papers that create software or hardware for the tabletop technologies. This can be by describing the composition of a device or the specific implementation of an application. An example is the use of a real brush to draw on a tabletop as a canvas [13].

Interaction The interaction category covers papers that focus on the interaction with a tabletop technology. Such interaction can be feedback, navigation or inputs. An example is to use a tabletop technology with haptic feedback to enhance interaction possibilities [14].

Design The design category covers papers that focus on design guidelines, suggestions or recommendations aimed at the tabletop technologies. An example is a taxonomy aimed for the 3D aspects for tabletops [15].

User The user category covers papers that focus on the user's needs or a specific type of users. An example is a study focused on the children age three-four years [16].

Visualization The visualization category covers papers that have focus on the visualization aspect of applications for the tabletop technologies. This can be 3D graphics, data visualization or 3D objects. An example is a (co-)authorship network visualization [17].

Individuality The individuality category covers papers that emphasizes the individual around the tabletop technology. This include focus privacy and territory. An example of this is to hide information through different levels of visibility [18].

Collaboration The collaboration category covers papers that focus on the collaboration aspect of a paper and explore the possibility of the tabletop device to be used in a collaborative setting. An example is to create an environment that supports collaboration over distances [19]

Cross-Device The cross-device category covers papers that focus on the integration of additional devices within the setting of tabletops. An example is to use a personal device for visualization purposes [20].

We conclude the study by relating these categories with previous work of reviews of the research field of tabletops from [15] and [21]. Finally we propose research opportunities within the categories with the least amount of identified papers.

2.2 Research Paper 2

Cracking the Safe - Usability Evaluation of Multi-factor Authentication on Tabletops

Tabletops is a promising new technology that utilizes the aspect of a seamless design and is ideal for collaboration. This creates additional security issues, as the users around the tabletop are subject for shoulder surfing and smudge attacks. To reduce these attacks, the multi-factor authentication is explored as a viable solution. However the focus have mainly been on security rather than usability in authentication research. In this paper we compare the single- and multi-factor authentication mechanisms using a Tangible User Interface (TUI) as the possession factor and PIN and password for the knowledge factor.

In this paper we compare the use of a single factor authentication with multi-factor authentication, based on the usability on a tabletop technology. We conducted a traditional laboratory experiment with 16 participants. We borrowed a tabletop from another department and the experiment was conducted in their creativity lab.

In the experiment we had 16 participants. These was divided into six conditions, 3 multi-factor, 2 knowledge factor and 1 possession factor; 10 participants in experiment 1 and 6 participants in experiment 2.

Username/password (UsPa The user uses a standard username/password combination to authenticate him. The user uses the on-screen keyboard for the whole process.

Username/PIN (UsPi) The user uses a username/PIN for the purpose of authenticating him. The user enters his username using the on-screen keyboard and the PIN using a developed numpad.

Tag/PIN (TaPi) The user uses a TUI/PIN combination to authenticate him. He places the tag on the tabletop, which reveals a numpad. He then enters the PIN.

Tag The user uses a TUI to authenticate him. The user places the tag on the table and finishes.

Tag/PIN(Saf1) The user uses a TUI/PIN to authenticate him. The design is based upon a safe. The user places the tag on the table, which reveals a safe lock. He then turns either way to specify the first digit. Rotate in the reverse direction to both select the previous digit and navigate to the next digit. Continue this until four digits have been specified and lift the tag to confirm the attempt.

Tag/PIN (Saf2) This is the same as Saf1, with the difference that in Saf1 the arrow is turned to select a digit, while in this condition it is the disc that rotates.

The experiment conducted as a within-group [22] experiment was divided into two experiments. The first experiment consists of *UsPa, UsPi, TaPi, Tag* and *Saf1*. The second experiment consists of *UsPa, UsPi, TaPi, Tag* and *Saf2*. The two experiments was separated to minimize bias among other conditions.

The participants were asked to fulfill a SUS questionnaire after the end of each test totaling 80 answers. The experiment was also recorded on video and an interview was also done after each session to elaborate the thoughts of the participants.

Each evaluator analyzed each of the three datasets. To minimize evaluator bias, the analysis was done independently. Each evaluator created a list of identified problems, which were merged afterwards. The evaluators had an any-two agreement of 50%, stating a high agreement [23].

We capture the task completion time (TCT) for each of the users run-through along with a questionnaire for the system usability scale (SUS) to have a quantity measure for usability.

The result of the comparison for each of the conditions is as follows. The UsPi have an average sus score of 68.75 and an average TCT of 34.36 seconds. The UsPa have an average sus score of 84.06 and an average TCT of 29.22 seconds. The TaPi have an average sus score of 92.5 and an average TCT of 10.39 seconds. The tag have an average sus score of 89.85 and an average TCT of 3.62 seconds. The Saf1 have an average sus score of 46.25 and an average TCT of 76.38 seconds. Finally the Saf2 have an average sus score of 47.08 and an average TCT of 65.53 seconds.

The results was compared to the interviews and the observations through the videos to create data triangulation. In relation to Saf1 and Saf2 and the relatively low sus scores, the comparison revealed several usability problems, that supports the low score. This is further strengthened by the TCT, which revealed to be high compared to the others. The main usability problem was the interfering of the users hand, when he turned the tag. This caused a problem with hitting the right digit. This problems was fixed in Saf2, however did not affect the sus scores.

In regards to using a multi-factor authentication mechanism on a tabletop, most of the users preferred to use the TaPi system when the purpose was to authenticate to a security-critical application such as a net banking service. For an application that was not so security-critical, the users preferred the tag.

The specified systems of this study lessen the impact shoulder surfing and smudge attacks have on the users, as the possession factor accounts for the aspect of compromising ones knowledge factor.

We conclude the study, that the multi-factor authentication mechanisms are a very good way of limiting the attacks of smudge and shoulder surfing. The participants of this study did not like the safe metaphor as a form of authentication, as several issues related to the turning of a tag and the time to complete a single attempt is very long, compared to the others.

CHAPTER 3
RESEARCH METHOD

3.1 Description of the Research Methods

In this chapter we present the research method used to answer each of the research questions. The chapter is based on the descriptions from Wynekoop and Conger [24] and Lazar [22]. In Table 3.1 a summary of the research methods used is presented.

RQ#	Purpose of the Study	Research Method	Research Setting
1	Overview of the tabletop technology research field	Normative Writing Grounded Theory	Environment Independent
2	Compare knowledgeÂ´factor, possession factor and multi-factor authentication	Laboratory Experiment	Artificial

Table 3.1: Summarizes the applied research methods

Each research method have different advantages and disadvantages. These are described in the following sections.

3.1.1 Laboratory Experiment

The laboratory experiment is characterized by control of subjects such as variable manipulation and control of assignments. This enables the researcher to conduct precise measures of the experiment and change each variable according to the specific needs of the experiment and hence be used for observing a phenomenon of interest. The laboratory experiment is also characterized by the disadvantages. The method assumes that the real world is not important. The major advantages and disadvantages is highlighted below.

Advantages:

- High reliability
- Great variable control
- Replicable
- Precise measures

Disadvantages:

- Unknown generalization to real settings
- Artificial setting
- Assumes that real world is not important

3.1.2 Normative Writing

Wynekoop and Conger [24] specifies the category of normative writing, to contain concept development or "truth". The truth category specifies suggestions or presentations of ideas. The concept development attempts to organize ideas through frameworks or present new perspectives on existing research. The characteristics of normative writings are environment independent, as the context these is written in, does not effect the result of finished work. Webster and Watson [10] further elaborates on the literature review discipline in information systems. A literature review creates the foundation to future knowledge, based on the previous research and uncovers areas where future research is headed [10].

Grounded Theory

In the literature review we have used a grounded theory approach, that is characterized by having a potential theory emerge from the data. Grounded theory is often called "Reversed engineered"' hypothesis, because of the emerging of theories from the data. To successfully use grounded theory requires the researcher to be open-minded and creative, as opportunities can rise at all points in the study [22].

Advantages of grounded theory:

- Systematic approach to analyze qualitative, text-based, data
- Generate theories out of qualitative data with backup in through coding
- Novices can use grounded theory
- Early study of data and refine the theory through constant interplay

Disadvantages of grounded theory:

- Overwhelming while coding as the researcher can be buried in details and feel lost in the data
- Hard to evaluate the theory developed through this method
- Findings can be influenced by the researchers opinions

3.2 Use of the Research Methods

We in the following describe how the two research methods are applied and how the advantages and disadvantages impacted our studies.

Research Question 1: What is the current trends within tabletop technologies and where are the research opportunities?

This research question was the basis of paper 1 and covers a study covering the sate-of-the-art research papers within tabletop technology that answer this question. For this paper we used a grounded theory approach. Grounded theory is an inductive research method, that starts in the specific data and then elaborates and expands the knowledge to create a general theory. This is the opposite of deductive research, where you start generally and through the study are more specific. In our study this had the impact of having a firm ground in the data and document the emerging theory through synthesis of the data.

From the data collected eight categories emerged that covered the research on tabletop technologies. By categorizing past published research papers, the lack of research within areas were uncovered and suggested for future work.

The approach for conducting the literature review was, through emergent coding, first to analyze an initial set of categories and let the categories emerge from the data. The process was then to expand the set of literature iteratively to mature the list of categories, by adding or removing additional categories. This created the option to keep track of the large amounts of textural data but also gradually refine the categories. Following Lazar [22] grounded theory consists of four stages; *open coding*, *development of concepts*, *grouping concepts into categories* and finally the *formation of a theory*. The process in our study much follow this pattern, however missing a step for the formation of a theory. However to form a theory, a more intensive study is needed and as such the final step is not covered in our study. These steps is closely related as one is depended on the other. These step follow the structured coding process as defined in Appendix B. First we used several terms identifying a paper. Then we grouped some of the terms used to define a concept and finally we specified categories from the concepts developed to the final categories.

Validity and reliability is two common concerns when using grounded theory. To be clear, validity concerns the aspect of using well-documented and well-known procedures for specifying the accuracy of the theory. Reliability is concerns the consistency of the results. To increase the validity of our results, we used an iterative process of selecting data and analyze the content of each data item. Through the first iteration, the categories were changing rapidly and additional categories were also added. As the work, and hence the theory, matured, the degree of change of the categories decreased, showing a tendency of a more robust theory [22].

To accommodate the disadvantage of evaluating a theory, based on the grounded theory approach, we used outside reviewers that was not a part of the project and not influenced by the opinions of us. Through this, a number of categories were merged. Additionally we used the technique of an affinity diagram to find a coherence between the levels of abstract of each of the categories.

The nature of open coding is of the subjective nature. Each evaluator have a set of opinions that influence the codings in the first stage of grounded theory. These subjective opinions have also been discussed with the other evaluator and as such a common agreement have been confirmed between the two. Additionally the outside reviewers have evaluated the categories to further enhance the manifestation of the categories.

The disadvantage of overwhelming data have occurred in this study as well. We used a digital tool to keep track of the progress and to highlight codings in the data set. This created overview of the papers and each paper was given a unique name to identify it. From the tool it was able to generate a list of the papers with all the codings for each paper. This further enhanced the overview as searching through the generated file was possible to find statements of interest.

Research Question 2: What is the usability for single and multi-factor authentication for tabletop technology?

This research question covers the results of a study, focusing on a user-based laboratory experiment using interviews, observations and questionnaires. The results of the experiment were compared to similar systems on desktop computers from Braz et al. [9].

The setting of the experiment is created to some degree by the researchers, and is thereby highly replicable. We had a high control of the environment to monitor the experiment, however limitations exists. As the tabletop device was borrowed, it created the limitation of moving the device around. We were not permitted to move the tabletop technology to other locations. This created a barrier of using the usability laboratory at the department of computer science, which is more fit for usability testing, as cameras, screen capture and other facilities that support usability testing exists in that lab. Secondly the room used for the experiment, was a laboratory used for creativity and as such several objects and posters exists in the laboratory. To limit the influence this had on the participants, we created an isolated space, with the use of partitions and covered the posters and other objects that could lead to distractions. We had control over the demographics of the participants, where open ended questions were asked to know, what experience they had of using touch devices and the knowledge of security systems.

One of the major disadvantages of using a laboratory experiment is the artificial setting. The difference between a field experiment and a laboratory experiment is based on the degree of how much the researchers want to control the environment. This comes at a cost as the laboratory is focused on a small set of participants and is aimed to be generalized between these participants. However in a field experiment the participant is in the setting, where the device is used and as such creates a better generalization [25]. An example of the importance of the real world can be seen in the literature of mobile devices as these mobile devices can be used in environments that is hard to imitate within a laboratory condition, such as walking, street noise and the danger of moving cars [26] [27].

The artificial setting of the laboratory experiment influenced the participants in various ways. First, the participants were not influenced and threatened by other users as each of the participants were in the room only with us. If several users were participating in collaboration with each other, they might tend to focus more on a security aspect of the authentication mechanisms. Secondly, the users were not aware of the collaboration aspect of tabletop technologies. A single participant mentioned that it was possible to hide the information, by putting hands down in front of the numpad. Additionally several people were surprised, when asked to the collaborative aspect and which of the conditions they preferred. Thirdly, the setting affected the participants effort to complete the task, even if they were very frustrated. One user stated that he would not use one of the systems at all and if he should use it on a daily basis, he would avoid using that system at all. This also tells us that the generalization to a real world setting is limited.

CHAPTER 4
CONCLUSION

In this master thesis we have examined the state-of-the-art literature of tabletop technologies to identify, where the current trend is heading and identify research opportunities in this research field. We found several opportunities that is interesting within the field of tabletops. Among these, the usability in security on the tabletops was studied in depth. In the following we present the results of the two research questions followed by limitations to the study and interesting future work.

4.1 Research Question 1

What is the current trends within tabletop technologies and where are the research opportunities? Through a grounded theory designed study we have conducted a literature review, that specifies eight categories that cover the recent literature of tabletop technologies. The categories are: Implementation, Interaction, Design, User, Individuality, Visualization, Collaboration and Cross-Device. Using the categories we categorized 238 tabletop technology papers and found that the leading categories are implementation and interaction. We identify research opportunities in the field of collaboration, cross-device and individuality, as these have some of the least categorized papers within them. We were surprised with the little focus on collaboration in tabletop technology as this is a promising feature for the tabletop technology.

4.2 Research question 2

What is the usability for single and multi-factor authentication for tabletop technology?

Through a comparative study of single- and multi-factor authentication, we have evaluated six conditions that utilize two authentication factors; Possession through the use of a TUI and Knowledge through the use of username/passwords and username/PIN. We compared 3 multi-factor authentication conditions, 2 knowledge based conditions and 1 possession condition on TCT, sus scores and user preferences. We have shown that the overall best condition was the TaPi condition. This was superior in sus scores and by the participants preferences in both security and usability. In terms of TCT, the TaPi managed good, in relation to related work from braz et al. [9] and the most of the other conditions.

We also compare an authentication mechanism based on the design of a safe. In the comparison, the safe was the least liked, as the system was cumbersome to use due to several usability problems. One such problem was fixed and compared to identify, if this was a solution, however, it was not the case.

CHAPTER 5
FUTURE WORK

In this chapter, we present future work for both the papers specified in this recapitulation.

5.1 Research Question 1

For future work of our literature review, a natural step, would be to expand the dataset to cover the most recent literature within the research field. Our review only covers literature to 2011 and some of the papers of CHI 2012. We know that the annual ITS was running while we wrote our final remarks. By expanding the literature review, we increase the completeness of the study and further improving the categories' maturity.

A limitation of the literature review, is that there is no researchers that have verified the categories and the descriptions of each of the categories. As for future work, this could be used to further verify and clarify the descriptions to create a robust set of categories, that covers the research area completely.

5.2 Research Question 2

In research paper 2, we have identified two limitations. The first is in relation to the threat of having multiple participants in the same room, when conducting the usability evaluation. This could impact the way the users could rate the sus scores lower for each system and it would force the participants to think about security concerns, when evaluating the systems. Secondly the collaboration around the tabletop was missing. Most participants became aware of this doing the third question of the interview. In order to clarify these hypothesis, a future work could be to replicate this study and add additional participants in the same room and run the experiments again.

One proposal of for authentication on a tabletop, that covers the user of additional devices, is to use Google glasses [28] or draw inspiration from LG's Dual Play [29]. With these emerging technologies, many new innovations can be thought of. E.g. could it be possible to let users see the content they have authenticated for, by calibrating the glasses before hand and specify that the users are currently using the tabletop.

Another opportunity is to use Google glasses as a possession factor. An idea could be to use proximics via WiFi to identify the user or to use voice activation for the inheritance factor. As the google glasses is a promising technology and a new addition to the artifact ecology research area, this further increases the amount of research opportunities for such devices.

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APPENDIX A
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APPENDIX B
RESEARCH PAPER 1

The State of the Empire in Tabletop Technology – A Literature Review

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ABSTRACT
In this paper we are reviewing the literature of tabletop technologies. This paper contributes to the current body of literature within tabletop technology research by first positioning 238 papers, from leading conferences on tabletop technologies such as IEEE Tabletop, ACM Interactive Tabletops and Surfaces (ITS) and ACM Conference on Computer-human Interaction (CHI), in 8 different categories, based on the research purpose and focus on the paper. Secondly this paper identifies an overview of the current types of tabletop technologies that is used in research. The aim of the categories is for researchers to easily identify research opportunities and identify the current trends of tabletop technologies. We discuss areas within tabletop technologies that are research opportunities e.g. the use of tabletop for collaborative purposes and group interaction.

Categories and Subject Descriptors
A.1 [General Literature]: introductory and survey

General Terms
Design, Human Factors

Keywords
Tabletop, horizontal interactive display, literature survey, categorization

1. INTRODUCTION
In the late '90 the focus within computer science was "The Disappearing Computer". This guiding principle have many products lived up to, and tabletop technologies is no different. Tabletops span from the illustration of having a table that has seamless interaction possibilities without the immediate presence of a physical computer. With the integration of a tabletop in modern homes, it is possible to access various information during family traditions such as eating, having a conversation etc. around the table.

Research in surface computing is a popular topic within HCI and ubiquitous computing (ubicomp). An example of recent surface computing is the paper by Antti Virolainen et al. from 2010 [1]. In the paper they build a multi-touch surface from ice to stretch the boundary of current ubicomp and incite people into exploring alternative materials. In the paper by Malte Weiss et al. from 2010 [2], they build a curved surface that combines horizontal and vertical surfaces to create a curved surface with the purpose of investigating the effect of dragging over a curved surface. Another context of surface computing is by using a projector to make an everywhere computing surface. The paper by Manuela Waldner et al. from 2011 [3] describes such system, as they develop an adaptive window management technique for using projector as a display and projecting onto diverse surfaces e.g. tables and walls.

Another popular topic within surface computing is interaction with Tangible User Interfaces (TUI) on the surface. In the paper by Esben W. Pedersen et al. from 2011 [4], they use active motorized tangibles to reflect the changes in the digital model thereby providing haptic feedback to the user. Another example is the paper by Kai-Yin Cheng et al. from 2010 [5], where they take everyday objects and transform these into TUIs with the use of pattern stickers, which can be recognized using a webcam. Another aspect of surface computing is collaboration. By using larger surfaces, compared to a computer display, it creates the possibility for people to collaborate around it. The paper by Romain Perron et al. from 2006 [6] research the effects of using a tabletop instead of a table for design meetings for distributed teams, which have collaborative challenges. From the examples it can be seen that, the field of tabletop technology research is diverse.

In this paper, we focus on tabletop as computing surfaces, because it supports collaboration and intuitive use of TUI and increasing interests in recent years have made tabletop a popular topic in the HCI field which can be seen in the increased publications of papers on the topic. In year 2006, 28 papers were published in Conference Tabletop and in year 2011, 52 papers was publish in ITS and several tabletops has since been commercialized. Examples of commercialized products are Diamond Touch[1] and Microsoft Surface[2]. With the increased interest in tabletops, an overview of this diverse field is needed which motivated us to create an overview of the research done in the area of tabletop technologies.

In this paper we contribute with: (i) an overview of the tabletop technology field showing the current trend. (ii) The design of categories to categorize tabletop technology papers, based on their research purpose and focus. (iii) We highlight research opportunities in the research field of tabletop technologies, based on the literature review. (iv) An overview of tabletop devices used in tabletop technology research. (v) We present naming conventions of tabletop technologies used in tabletop technology research.

[1] http://www.merl.com/areas/DiamondTouch/

[2] http://www.pixelsense.com

2. RELATED WORK

In the following we present various ways that the tabletop technologies are referred to and present an existing definition on the tabletop technologies. We use this definition and interpret this definition to cover modern technologies, such as tablets, as these devices have increased in popularity in recent years. Secondly we present current work that defines an overview of the research field, Müller [7] and Grossman and Wigdor. [8].

2.1 Definition of a Tabletop

The tabletop technology is referred to in different ways in the literature. We present four different examples of this diversity: 1) Large horizontal collaborative surfaces [9], 2) Direct-touch digital tabletop display [10], 3) Direct multi-touch, multi-user tabletop [11] and 4) Interactive tabletop [12]. From these examples it can be seen, that a tabletop technology is referred to with different properties. A tabletop is refereed to, based on the property of its *Size*, but is mostly used when the tabletop support more than four people. *Touch* is frequently used when referring to a tabletop and three types have been identified: *multi-touch* and *direct touch* and a hybrid of the two other: *direct multi-touch*. Multi-touch means that several fingers can be used to interact with the tabletop. Direct touch means that fingers can be used directly on the screen to interact with the digital content. The *Surface Alignment* is also used when referring to a tabletop as *horizontal, tilted* or *curved*. When several *users* are supported by the tabletop it is referred to as *multi-user* or *Collaboration*. The word used for the device itself has multiple variations*: tabletop*, *surface, interface*, *system*, *display*, *table* and *screen.* These can be used in combination as in example 2 above. It is important to note that the adjective properties do not indicate what a tabletop is not. E.g. if referred to as an *interactive horizontal tabletop*, it can support direct touch, multi-user and be large even if not stated in the referred words. Because of this diversity in referring to a tabletop we need to define what a tabletop is.

For comparison, we present the definition presented by Müller [7], defines a tabletop technology as:

"The term tabletop stands in the tradition of earlier terms, such as desktop and laptop, highlighting the location of the computer or display. Tabletops distinguish themselves by being suitable as group interfaces and by the fact that their horizontal display is the interface where the user directly interacts with digital information rather than using the keyboard and mouse."[7].

Based on this citation, it is possible to see similarities with the referred tabletop technologies and the definition. Both cover collaboration or group activities as well as, at least to some degree, surface alignment. Both refer a tabletop in relation to the interactive property, being direct. Where these differ is mainly on the size. A question one might ask is "how big should a tabletop technology be, in order to be covered with both the definitions and the adjective words?" This question is unclear both in the literature, stating "large" or "very large" and Müller et al. not stating a specific size. As the popularity of tablets has increased in recent years, we questioned whether such technology should be covered in a definition of tabletop technologies, as tablets can be used for group activities and that they can be placed on a table to create a suitable screen for these group activities. We conclude that the definition by Müller et al. also covers tablets as the definition highlights the aspect of group activities. Further increasing the conclusion of the definition to include tablets is also the fact that tablets is used with direct interaction.

Following the discussion of tablets is also the possibility of using a mobile phone. Through the review, we have not identified research specific to mobile phone applications. The definition states that the tabletop technologies can be used for group activities and following the smaller size of a mobile phone, we conclude that mobile phones is not able to uphold this requirement for use as a tabletop technology.

2.2 Current Overviews of Tabletop

The paper by Grossman and Wigdor from 2007 [8] is one of the first to present an overview of the tabletop research field. They determine categories emphasizing 3D for tabletop technologies and generating a taxonomy for the subject. The taxonomy is divided into 3 main areas; Display properties, Input properties and physical properties. The *display properties* are how the display works. Does it use stereoscopic 3D or is it using 3D graphics as visualization for the user. *Input properties* are how the user interacts with the tabletop. This can be in the interaction *space*, where the z-axe is considered and as such creates the opportunity to use interaction gestures in mid-air. Finally the *physical properties* are the form-factor and the size of the table. Grossman and Wigdor's work emphasizes a niche area within tabletops and does not focus on a general overview of the research area. Inspiration can be drawn from Grossman and Wigdor on how to categorize the research field into more specific terms by creating sub-terms within an identified field, as 3D for tabletop. Contrary to Müller who focus on providing an overview on a high level of abstraction, categorizes the tabletop research area with recent research on the topic. Müller presents three overall categories; "*Under", "On and Above"* and "*Around and Beyond"*. These categories represent three different aspects of research in tabletop and physical places the user can use a tabletop device. *Under* represents hardware specification and considerations that is needed in order to create a successful tabletop technology. This includes specifications on height of the table to specific dimensions on the size of the tabletop. The second category, "*on and above"*, concerns with the aspect of interaction. Specifically discussing tangibility and different interaction styles and ends with a taxonomy of the 3D tabletop systems, and presents the findings from [8]. The final part of [7] is *around and beyond* the tabletop. This part discusses aspects such as collaboration and social interaction around the tabletop device.

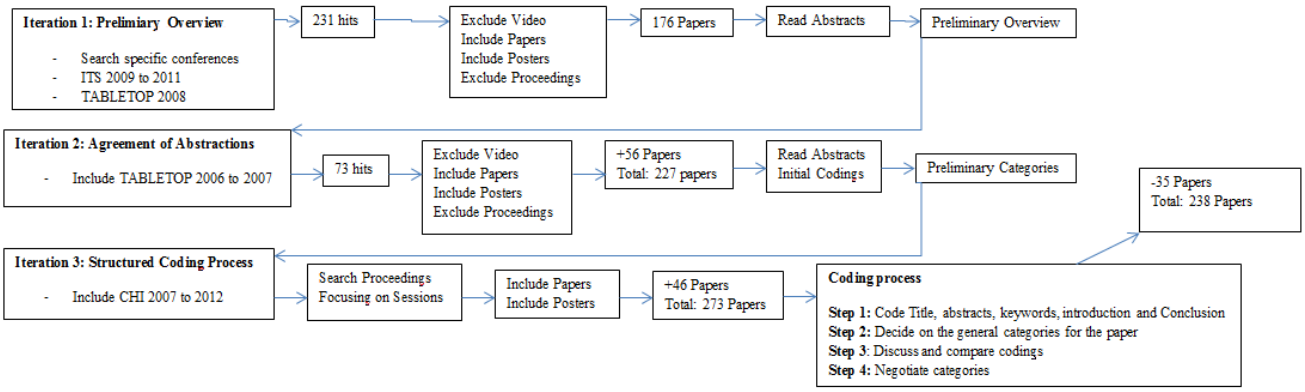

Figure 1 shows the stepwise method used for identifying papers and the selection process of them. Also presented is the coding process used for identifying the category for each paper.

In this paper, we aim for a compromise between Müller in terms of their *Under*, *On and Above* and *Around and Beyond* and Grossman and Wigdor, which identifies papers specific to 3D of tabletops. We want to broaden the categories from Müller by specifying additional categories that features the characteristics of Müllers categories. By broadening the categories we expect the research field of tabletop to enable researchers to identify the current trends and be able to categorize and identify where research is headed and current gaps in the research.

3. RESEARCH METHOD

Figure 1 presents the process of selecting papers and the process of coding the papers in our research. The processes are divided into 3 main iterations. The first iterations purpose was to create a preliminary overview of the research area of tabletop technologies, by searching for recent publications. In the second iteration the opportunity to create a literature review emerged as none were identified in the first iteration. Because of this, we broaden the search for literature and coded the papers with initial categorize. At the end of the second iteration we agree upon a level of abstraction of the initial categories were needed in order to create an overview that enables new and experienced people to locate and identify research opportunities within the tabletop research field. In order to create an even level of abstraction throughout the initial categories, we created an affinity diagram and merged categories based on the findings from the affinity diagram. To validate the categories, a structured process was needed to create system in the coding process used for each paper. This was the basis for the third iteration.

3.1 Preliminary Overview

The first iteration focused on creating a preliminary overview of the research area of tabletop technologies. The main conferences studied in the first iteration were ACM Interactive Tabletops and Surfaces (ITS) '09-'11 and IEEE Tabletop '08. To identify the most recent research within this field, we focused on this subset of conferences. ITS, as it name specifies, focus specifically on tabletop technologies and surface computing and the IEEE Tabletop conference is the previous name for the ITS conference. IEEE Tabletop was included to broaden the research and for completeness of this study.

Throughout the iterations we excluded videos and focused on text documents as the primary source of information. During the first iteration a total of 171 papers were identified. To possibly identify the research goal and contribution of each of the 171 papers, the abstract of each paper was read by each reviewer. This was firstly done individually followed by a collective discussion and negotiation. From the abstracts 4 observations were identified: 1) The research goals were not always present in the abstract alone 2) The research area of tabletop technologies was diverse, in that it covers many topics. 3) An overview of the research area of tabletop technologies could possibly enlighten the research field and help future researchers in identifying research possibilities. 4) The initial findings had a bias towards inconsistency, as the abstraction of each category, could be more specific in terms of coverage of the goals and purposes of the identified papers. This created a foundation for the second iteration, as further research in this manner would be needed to create the overview.

3.2 Agreement of Abstraction

In the second iteration, the focus was to extend the search of papers to include the IEEE TABLETOP '06-'07 conferences and create an agreement of the abstraction level.

We further discussed the papers to be included in the dataset. The question was, if to include posters (two pages). To ensure completeness and present the past and current trends of the research area, we decided to include them. A total of 56 papers were added to the existing 171 from the first iteration, summarizing a total of 227 papers. Each abstract and introduction was read again individually, the reason for including introduction also was research contribution and research focus could be hard to infer from the abstract. The abstracts and introduction were coded with terms that identified a marked area of text. The codes were individually decided at this point. From the individually coded segments of text, we compared each segment and compared it to each other's to form a set of initial categories. . Examples of categories that were identified *Build*, *Feedback* and *Process.* In the second iteration these were revised into more general categories. To ensure validity of the categories, a structured coding process was specified; see Figure 1 and the third iteration for details of the coding process.

Based on Müller and Grossman and Wigdor two different approaches were identified. Müller presents the abstracted categories while Grossman presents the specific categories, namely 3D on the tabletop. Based on these, we needed to agree on the abstraction for the review. By taking a grounded theory approach and let the categories emerge from the dataset, we agreed upon the abstraction level to be between Müller and Grossman.

Through the first read through of the first subset of papers, it was identified that the categories could belong to several of the categories. As many researchers typically have more than one contribution with each submitted paper, it was conflicting to solely code the paper into a single category and thereby force it into it. Based on this observation, we extended the notion of papers to the possibility of being coded as multiple categories. This expansion concluded the second iteration and followed by another read through in the third iteration.

3.3 Structured Coding Process

For completeness, we included the Conference on Computer-Human Interaction (CHI) '07-'12. We selected papers from sessions related to the topic of tabletop technology and large surface computing. An additional of 46 papers was added to the existing 227 summarizing a total of 273 papers from CHI. A comprehensive list of all the 273 reviewed papers is located in [13]. In the review 35 papers were categorized as not tabletop, based on definition in related work, e.g. lack of relevance, focus were on vertical displays, proxemics or other closely related topic. These 35 papers did not uphold the definition as specified earlier.

In the third iteration we specified a structured coding process to ensure the validity of each of the categories. The coding process was divided into 4 steps: 1) to ensure that categories were not influenced by each other, we individually code title, abstract, keywords, introduction and conclusion to identify what the research purpose of the paper was and identify research questions of each paper. As specified in the first iteration, the research purpose was not always present in the abstract alone. That is why the introduction and conclusion have been included. The conclusion is also included to identify coherence between the research questions and the results of a paper. 2) Decide, individually, on the categories of the paper. 3) Discuss the categories. 4) Negotiate the resulting categories[3] of each paper. The negotiation was based on the discussion from step 3. To decide the categories of each paper, the individual coded segments of text and arguments were presented to each other and continued until an agreement or disagreement was decided. In total we had agreements in 176 of the 238 papers. Disagreements was handled by returning to paper in question at a later point in time and discuss it again to see if an agreement could be made. The purpose was to wait for the categories to mature before the disagreements was discussed again in order to find the correct category of the paper in question. Often this solved the disagreement because either the categories had matured through additional papers being contained within it. In cases where it did not solve the disagreement, a thorough read of the complete paper was done and discussed again.

4. RESULTS

We got 3 types of result from the literature review of the tabletop technology research field: categories derived from the literature, gaps in research based on categories and the tabletop devices used in the research.

4.1 Categories

In this section we describe each category that emerged through the study of the 273 papers that have been reviewed. The categories are described with focus on identifying, how a paper is categorized. As the study enables multiple categories for a paper, a paper is not limited to be contained in a single category. This creates benefits and disadvantages. The benefits are that it resembles the nature of a paper, to covering multiple topics. The disadvantage, in this study, is possibility of ambiguous categories.

4.1.1 Collaboration

Papers categorized as Collaboration, focus on the collaboration aspect of a paper and explore the possibility of the tabletop device to be used in a collaborative setting. A collaborative setting can e.g. be as Yamashita et al. [15] presents. They create a location that supports remote collaboration by having screen picturing the upper body of a remote located team. Following our study, a collaborative setting consists of two different themes: Co-located and Remote Located collaboration. Co-located collaboration concerns the aspect of having people located at the same spatial location while remote located have people at different spatial locations.

For a paper to be contained within the collaboration category at least 2 of the 3 conditions must be met; 1) the paper states that focus is on a collaborative aspect. 2) The experiment of a paper has two or more persons that work together or at the same time around the tabletop device. 3) The paper enlightens the aspect of collaboration for a tabletop technology.

> *"This paper describes menu techniques for adding a new user's interface object on a shared device while preserving mutual awareness of the participants without disturbing them in their interaction."* Coded as Collaboration and Interaction [14]

> *"In this study, we examine how remote collaborators' upper body view affects collaboration when people engage in multiparty fluid tabletop activities across distances."* Coded as Collaboration [15]

4.1.2 Cross-Device

Papers categorized as Cross-Device have focus on a variety of devices that is used within the setting of the tabletop device. Example of devices that is used in this manner is not limited to, but includes mobile phones, tablets and laptops. The devices used in this category are independent from the tabletop, but communicate or interact with the tabletop. This leads to two identified themes within the category: 1) The devices used for communication purposes or 2) the use of a device as an additional screen.

For a paper to be contained within the Cross-Device category, 3 conditions must be met: 1) at least one tabletop device is present. 2) At least one other device is present within the study and 3) the focus is on the device having a participating role for interacting with the tabletop device.

> *"We Space provides seamless integration of personal devices to a table-centered, multi-user, multi-surface environment, as well as customized visualization facilities for visual exploration."* Coded as Cross-Device [16]

> *"We establish an entirely visual, secure and bidirectional communication channel at a speed superior to previous vision-based approaches, enabling users to establish connections and transfer data to and from interactive surfaces using ordinary out-of-the-box hardware."* Coded as Cross-Device [17]

[3] Resulting categories refers to the set of final categories that is presented in the result section.

4.1.3 Design

Papers categorized as Design, have focus on principles, recommendations and/or guidelines for development of an application for the tabletop device. The guidelines can be aimed at a specific area such as 3D applications, hand-gesture interaction or aim at contributing general guidelines such as size of objects etc.

For a paper to be contained within the design category 2 conditions must be met: 1) Guidelines, recommendations, framework, comparison, principles or considerations on, how to design a tabletop artifact (could be application or device itself), must be proposed in the paper. 2) The findings must be general enough to be useful in developing similar artifact.

> *"In this paper, we survey previous 3D tabletops systems, and classify this work within a newly defined taxonomy."* Coded as Design [8]

4.1.4 Implementation

Papers categorized as Implementation have focus on the implementation of a tabletop technology. This can be describing the composition of a physical tabletop device or the specific implementation of an application. This describes the two themes that are identified, namely Hardware and Software implementations. More specifically Software contains toolkits, programming, architecture and/or frameworks. Frameworks differ from guidelines in that it is specific tailored aspect and have a software package attached to the tabletop technology, while guidelines represent a more general approach that is applicable to several tabletop technologies. The hardware theme describes implementations of sensors, displays or setups and focus on the implication of these settings.

For a paper to be contained in the implementation category, 2 conditions must be met: 1) the paper describes the construction of a tabletop technology. 2) The paper's contribution is an implemented prototype or working product.

> *"This paper presents a novel digital paint canvas, which allows for accurate registration of the actual contact surface of a real brush with the paint canvas, as well as the shape and direction of the bristles in the brush tuft in this contact surface."* Coded as Implementation and Interaction [18]

> *"We present a new approach for rapidly prototyping multi-touch and object sensing surfaces. It works by liquid displacement inside a malleable projection surface. The system provides both touch and pressure information and a distinct organic quality when touched."* Coded as Implementation [19]

4.1.5 Individuality

Papers categorized as Individuality emphasizes the individual around a tabletop device. This type of study is relevant in a collaborative setting, although the focus is on protection of the individual data or having the individual in focus. This could a game of poker, where it should be possible to hide the cards, in order for the opponent not to cheat. Through the study, four themes have been identified: 1) Privacy 2) Personalization. 3) The personal space 4) View dependent. Privacy concerns the aspect of securing personal information. Personalization describes different settings that are customizable for each user, e.g. the color scheme of a window. Personal space concerns the aspect of dividing the work space into smaller chunks, such that e.g. documents cannot be taken by others. Finally View dependent concerns aspects such as translation to each user and that only can be seen e.g. from a specific angle.

For a paper to be contained within the individuality 2 conditions must be met: 1) the focus must be on an individual in a tabletop setting. If the focus is on the user then it belongs in the user category. 2) The paper gives an implementation solution on *known* problem, which arises when interacting with digital information in a tabletop setting.

> *"We first introduce the IdLenses concept as a novel way of dynamic interface personalization for surface computing by describing its interaction characteristics. We then discuss what kind of personalizations are enabled by IdLenses (like, how user input and output can be customized)."* Coded as Individuality and Interaction [20]

> *"In this paper, we introduce and evaluate a number of novel tabletop authentication schemes that exploit the features of multi-touch interaction in order to inhibit shoulder surfing."* Coded as Individuality [21]

> *"Motivated by the work practice of territoriality, we implement a novel, tabletop-integrated multi-user tracking system that provides data on a user's location and movement."* Coded as Individuality [22]

> *"In this paper, we propose a novel display technique that provides different levels of visibility of digital content to different users who share the same display, by controlling the brightness of the projected information."* Coded as Individuality [23]

4.1.6 Interaction

Papers categorized as Interaction focus on the interaction between the user and the system. We have identified three themes of interaction; 1) Input 2) Navigation and 3) Feedback. Input concerns with different ways to use the tabletop device and manipulate data e.g. digital pens, different gesture etc. Navigation concerns the navigation of an application. E.g. it is possible to specify different menu types with very different forms and shapes or have different shortcuts to ease interaction. Feedback is different types of feedback that the user can experience throughout the use of the application. Mainly focus on tactile feedback however it is possible to have audio and visual.

For a paper to be categorized as interaction 4 conditions must be met: 1) the focus in the paper is on the interaction with the tabletop device. 2) The paper research on gestures or input 3) the paper focus on feedback to the user 4) the paper research in navigation patterns.

> *"The main idea was (1) to use glass fiber bundles to move the visual focus of the table to the required location in the structure and (2) to use that same glass fiber bundle to rearrange marker images into a 2D configuration the table can read."* Coded as Interaction and Implementation [24]

> *Our system does not only convey global confirmative feedback on user input but allows the UI designer to enrich the entire interface with a tactile layer conveying local semantic information. This also allows users to explore the interface haptically*. Coded as Interaction [25]

"Our goal is to develop design principles that can enable designers to construct new freehand, multi-point and multi-shape gestural interaction techniques whose invocation and action are easily understood and performed by users." Coded as Interaction and Design [26]

4.1.7 User

Papers categorized as User have focus on the user and the user's needs or a group of users. Research papers categorized as user analyze the user or user's behavior around a tabletop device, which gives insight in the user's needs in a tabletop setting. There are two themes one where users are studied with no hypothesis/expectations of their behavior and the other where the research is to confirm a user behavior. Examples of papers categorized as user are: a paper that research on a specific group of user that suffer from ADHD. Another is a longitudinal study of how a user responds to situation change.

For a paper to be contained within user category 4 conditions must be met: 1) the paper specify a user type. 2) The paper uses a research method that studies the user. 3) The findings give insight in what a user does or needs in a tabletop setting. 4) The goal of the paper is to study the user.

"This paper presents selected results from an experimental study designed to compare fantasy play in a virtual and physical setting. Twenty-two children (aged 3 and 4) played in same-sex dyads with a real wooden tree house and its virtual implementation on a DiamondTouch tabletop." Coded as User [27]

4.1.8 Visualization

Papers categorized as Visualization have focus on the visual aspect of an application. Aspects highlighted in the literature are 3D graphics, data visualization and 3D objects.

For papers to be contained within the visualization category 3 conditions must be met: 1) the paper presents information about the visual aspect of the application. 2) The focus is to use the visualization aspect such that users of the application have benefits of the visualization. 3) Results of the paper enlighten the aspect of the visualization in question.

"This paper describes research on rich opportunities for novel interaction on large multitouch tables to assist researchers. We have designed, developed and evaluated ResearchTable which provides an interactive visualization of (co-)authorship networks." Visualization [28]

4.2 Gaps in the Research

This section describes the category distribution of the 273 papers that have been reviewed and the result is shown in Figure 2. Due to the option of a paper to be categorized into multiple categories the sum of papers is not equal to the amount of categorization results. A total of 338 results are presented in figure 2. A total of 119 of the 338 (34.9%) have been identified as implementation. 76 of the 338 (22.4%) as interaction. 28 of the 338 as design (8.2%). 23 of the 338 (6.8%) as user. 20 of the 338 (8.9%) as visualization. 17 of the 338 (5.0%) as individuality. 12 of the 338 (3.5%) as collaboration and 8 of the 338 (2.4%) on cross-device.

In table 1 each of the sources is presented. The numbers refer to the same number from [13] that presents the list of all papers used in this review. The "*" indicates that the paper appears in more than one category. The papers that have been categorized into more than one category appear in both categories. Table 1 and figure 2 both indicate a field of "not tabletop". These are papers that have focus elsewhere and have been discarded. An example of focus is proxemics interaction.

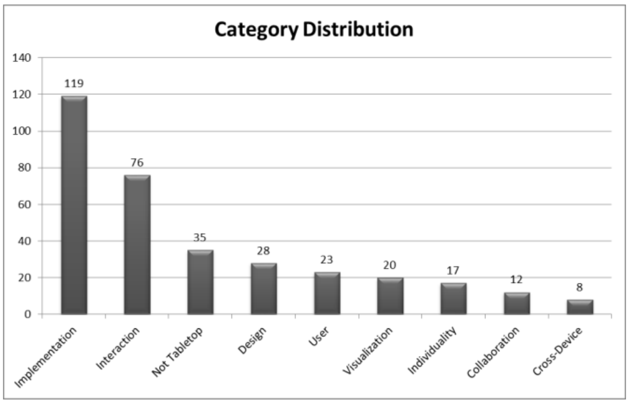

Figure 2 shows the distribution of the categories. The number above indicates the number of papers in the category. The total number is 338, as several of the papers is categorized into multiple categories

Table 1 shows the references and which category they have been categorized into. The numbers indicate the reference from [13]. "*" indicates that the reference occurs in more than one category and is hence presented both places.

Collaboration	268*, 57*,20*,79*,150*,256, 39*,153, 236*,184, 106, 148
Cross-Device	85, 26, 157, 155*,54*,181, 131, 105
Design	239*, 178, 90*,248, 74*,59*,57*,160*,223, 66, 83, 115*,262*,231*,111, 150*,77*,197, 266*,236*,203, 166*,89*,70, 170*,250, 167*,94*
Implementation	183*, 217*, 96, 128, 40*,19*,208, 76, 258*, 209, 268*,253, 104, 98, 17, 21*,82*,78, 238, 24, 102, 206, 80, 243*,110, 226*,45, 244, 7, 117, 255*,151, 246*,120, 4, 25, 43, 47*,67, 115*,133, 134, 158*,175, 201*,207, 262*,267*,231*,116, 261, 264, 130, 230, 2, 124*,41, 44, 229, 146, 225*,192, 241*,10*,161*,191, 12, 180, 119, 9, 173, 81, 50, 139*,152, 58, 36, 129*,39*,99, 168, 187, 213, 27*,135*,100, 237, 6*,154, 174, 87, 127, 234, 140, 109, 38, 121, 189*,3, 259, 214, 35*,88, 101, 242, 30*,170*,195, 200*,252*,198*,37*,55, 65, 251, 97, 108, 240
Individuality	118, 52*,226*,204, 158*,182, 201*,124*,172, 161*,164, 163*,77*,270, 107, 198*,37*
Interaction	46, 183*,217*,40*,19*,239*, 258*, 185, 232*,220, 235, 82*,48, 202, 260, 75, 5, 60, 84*,160*,243*,16*,1, 221, 73, 147, 22, 205, 103, 145, 20*,122, 222*,49*,255*,246*,47*,51, 144, 219, 267*,32*,224, 14, 15, 125, 162*,176, 247, 227*,61*,269, 86, 10*,199, 156, 155, 139*,159, 228, 54*,163, 233, 196, 27*,135*,71, 266*,89*,42, 137, 189*,35*,92, 30*,190, 200*,252*
User	90*, 149, 69, 272, 123, 18, 49*,33, 68, 32*,132, 179, 142, 141, 273, 6*,257, 166*,64, 143, 167*,94*

Visualization	232*,21*,74*,59*,84*,16*,52*,222*,8, 62, 79*,113, 162*,227*,61*,249, 225*,241*,129*,112, 72
Not Tabletop	271, 194, 136, 56, 29, 169, 186, 211, 171, 93, 28, 126, 218, 138, 215, 95, 53, 188, 13, 23, 193, 34, 31, 212, 216, 91, 114, 263, 63, 177, 11, 245, 265

4.3 Tabletop Devices in Research

In this section we present the tabletop technologies that current research use in their papers. Ten types of tabletop devices have been identified in this literature review; Smart Table, Diamond Touch, Microsoft Surface[4], Ideum, Lumisight Table, Interactive institute Umea, Self-built technologies and three technologies that can imitate a tabletop technology; Smart Board, Tablet and Touch Screen. Figure 3 summarizes the number of papers that uses each of the tabletop technologies. As three papers use 2 different technologies, the total number of technologies is 276, instead of the number of papers, 273.

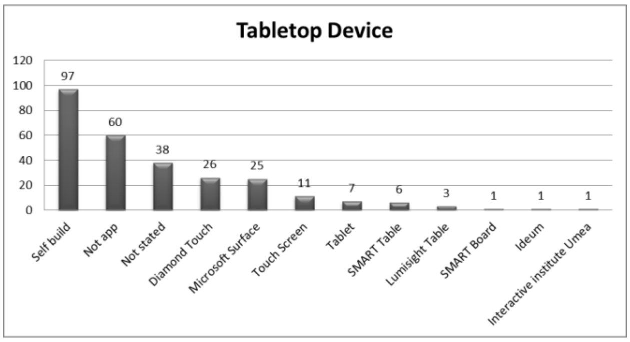

Figure 3 shows the distribution of the tabletop technologies used in the review set of papers. The total amount of devices identified is 276, due to three papers use more than 1 tabletop technology.

5. DISCUSSION

The interest in tabletop technology research has increased in recent years as can be seen from the number of papers published from 2006 to 2011 in our review set of papers. In 2006, 26 papers were published which belonged to the tabletop technology field. In 2007, where the papers from CHI were also included in our review, the number of publications is 27 and in 2011, 56 papers were published on the subject.

To answer the research question of creating an overview of the tabletop technology research field, we use the eight categories, as presented previously. When we compare the presented categories with the work from Müller, we see that our design and implementation belongs to the *"under"* concept. Additionally *cross-device, individuality, interaction* and *visualization* belongs to *"on and above"* concept. Finally *collaboration* and *user* belongs to the *"around and beyond"* concept. When comparing the properties concepts from Grossman and Wigdor the "display properties" belongs under *visualization*, "Input properties" belongs under *interaction* and "physical properties" belong under the *implementation* category.

First we present the current trend of the field based on those findings where after we discusses the research opportunity we see from this study which is our answer on "highlighting research opportunities in the research field of tabletop technologies" and lastly discuss our findings on the use of tabletop devices in the research.

5.1 Trends

The eight categories presented represent the current trend in the research field of tabletop technologies, where it can be seen that most focus in the last five years have been on implementing tabletop devices and application for the tabletop, with 119 papers categorized as implementation. This could be explained by the fact that it is a relatively new field of research and many possibilities are still being explored e.g. different materials for the display, the possibility of curving the surface, hiding information and information display levels based on z-axis etc. The need for applications to be developed also emerges in this time period with Lumisight Table introduced in 2004 and the Diamond Touch became available in 2006 and shortly after in 2008 the SMART Table and Microsoft Surface were announced. This could have affected the amount of research in implementation, but from our data it cannot be inferred as in 2006, 31% of papers are categorized as implementation, here papers categorized as not tabletop has been excluded from total paper count that year. In 2007 it increased to 59% and in 2008 it increased to 61%. In 2009 it decreased to 40%, were we expected it to increase with the launch of 2 tabletop devices in the year before. In 2010 it increased to 54% and in 2011 it decreased to 48%. This show that implementation is still the category with most focus in the research of tabletop technology, and will not likely decrease in the coming years. The reason is that the tabletop technology field is still in the "trough of disillusionment" and start of "slope of enlightenment" from the hype cycle [29] and there is a paradigm shift from projection to direct display technologies, where they also predict that tabletop goes towards interactive tablecloth.

Another leading trend identified through this study is related to interaction, with 76 papers categorized as this. The new hardware and software opportunities in the tabletop setting, as mentioned above, create a need to research the interaction aspect and explore the interaction opportunities created from the implementations. Most prominent is the touch interaction and the TUI research, in the interaction research, as both of those input types are relatively new, combined with a new setting. In 2006 31% of the paper is categorized as interaction, but decreased to 17% in 2007 and then a small rise to 21% in 2008. In 2009 the number doubled with 50% categorized as interaction, but decreased the year after to 29% and increased to 41% in 2011. We believe that in the future interaction will overtake implementation, especially because of the growing interest of tablets and the focus on user-friendly and natural interaction.

The 8 categories represent the current trend for the overall tabletop technology field, but in the future new categories might emerge, one of them could be *processes*; the focus on the development method for tabletop. Some of the categories are matured like implementation, where much research has had its focus, and themes have been observed, however for the *cross-device*, the direction of that category is still not clear within the setting of tabletops, as such we expect new themes will emerge with more research in the future.

5.2 Research Opportunities

As mentioned above, implementation and interaction has had the focus in the last five years. For research opportunities within these

[4] Now known as Microsoft Pixelsense

categories, we suggest to use the previous research as a foundation to create research within other categories. An example is haptic feedback, how does it affect the long term use of the tabletop (user), can some general design guideline applied to haptic feedback tabletop(design) and what effect does haptic feedback do to the way the user interact with the tabletop (interaction) and can several people work with it together (collaboration).

Another research opportunity is research into **collaboration** in a tabletop setting, as only 12 papers have been categorized as collaboration. We had expected there would be more papers researching the collaboration aspect of the tabletop. One of tabletop strong points is that multi-users are supported, and the device has a size that enables the users to collaborate around it. Several of the papers that have been reviewed specify a collaboration setting. However the focus in said papers, have been elsewhere besides collaboration. The current research in collaboration spans from remote locate collaboration, where a room is built to be able to emulate remote users presence in the room, facilitate collaboration[15], to research the interaction in a collaborative setting [14], were some interaction can be disturbing for the other users of the tabletop system. So much collaboration research would be a contribution to the tabletop technology field. We suggest that more research being done in relation to interaction and collaboration, because in [14], some interaction was found to be harmful to the other user, which can have very negative effect on the usability and thereby many applications.

Another research opportunity is research in **cross-device**, as seen in Figure 2, 8 papers have touched the subject. With so many new digital devices being developed all the time, the research on the subject is needed. With this trend, research within artifact ecologies is proposed, as an emerging field of research [36] [37], the devices range from laptop, mobile phone to game console and digital watch etc. Current research on the subject, identified in this study, have been on communication, use of mobile phone as individual displays and the extensions of a walk-up-to larger device to exchange information. One paper researches the use of the mobile phone as a TUI [30] and [16] is the only research paper where a laptop is considered in a cross-device setting. Both research in the mobile device area and the laptop area is a promising opportunity for research. Research on cross-device will be a contribution to the tabletop technology field as little exists, and there for a lot of research opportunities exits in the category and always will because of the fast development of digital devices [37]. The problem is that the development is so fast that the research risk of being outdated; if not general for all devices of certain type e.g. mobile phone, digital watch or MP3 player.

The **individuality** is another opportunity for contributing research as only 17 papers belong to the category as can be seen in Figure 2. The category has currently 4 themes; privacy, personalization, personal space, view dependent, where privacy and personalization is the least covered in the current research. Most research has been on establishing the personal space and view dependent to protect the user's information e.g. hiding poker card in [31] and view dependent with use of Lumisight Table as in [32] or use a vector field to rotate information displayed to show correctly to the use it is closed to [33]. Few papers has researched authentication on the tabletop, where [21] is one of the few trying to find authentication mechanic that can be used in collaborative setting, and not suffering from shoulder-surfing. [34] uses a digital pen to acquire the users handwritten and use it for authentication of the user.

The papers categorized as **user** are often also categorized as design as that is the next natural step in the research of users that is to condensate the knowledge of user behavior to general design considerations. So research opportunities exist in researching the findings in papers categorized as user and make it into general design considerations.

5.3 Maturity of the Technologies

In our literature review the most used tabletop device are self-build. Reasons being unclear from the papers, but we speculate it is because they can be tailored to the specific need of the research, but also cheaper than the current commercialized tabletop devices. There are around four times as many using self-build than the most used commercialized tabletop devices Diamond Touch and Microsoft Surface which can be seen in Figure 3. The Microsoft Surface has only been on the market since 2008, but has caught up to the number of Diamond Touch used, in the tabletop technology field. We see a tendency that the papers categorized as implementation; those of the software theme often use a commercialized tabletop. Those that focus on the hardware aspect tend to focus on self-build solutions.

There exist other tabletop devices than those mentioned in this paper e.g. reacTable, however through this study; it has not been able to identify any papers using this technology which is another research opportunity. In our review we did not find any papers that compared different tabletop technologies, which is needed to make more generalized design papers, to guide in the choice of which tabletop technology to use for one's applications or research. A poster by Wimmer from 2010 [35] suggest a model for comparing different touch tabletop technologies, but currently no papers have followed that recommendation, which is another research opportunity.

CONCLUSION

In this paper we examine and review the current trend in the last 5 years in the tabletop technology field, by categorizing 238 tabletop technology research papers. The papers were chosen from the most prominent conference in the field: Tabletops, Interactive Tabletop and Surfaces and Computer- Human Interaction. We identify 8 categories, based on the research purpose and focus on the paper: collaboration, cross-device, design, implementation, individuality, interaction, user and visualization in the tabletop technology field. The 238 papers are categorized with the 8 categories, which gives an overview of the current trend in tabletop technology. The two leading trends are implementation and interaction, and the least are collaboration, cross-device and individuality.

A surprise is that the number of papers categorized as collaboration is only 12. We had expected a higher number of papers, because the possibility to collaborate around digital information is one of the unique traits of the tabletop technology.

In the research the most used tabletop devices are self-build, there are four times more self-build technologies than the most used commercialized tabletop technology which are Diamond Touch and Microsoft Surface.

A limitation to the study is the approach of having additional people read the descriptions of the categories and let them categorize a small set of papers we have categorized to see if they reach the same result. This creates more robust categories and hence the use of these categories in the future.

There is a need and opportunity for more research on collaboration, cross-device and individuality and to take the implementation and interaction papers and create cross-category research e.g. how does implementation do in a collaborative setting and is the individual's interest protected. We hope that in the future more design papers are published, which is an indication of the maturity of the field, because they can be used as a foundation for future research.

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APPENDIX C
RESEARCH PAPER 2

Cracking the Safe – Usability Evaluation of Multi-factor Authentication on Tabletops

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ABSTRACT
With the introduction and adoption of the tabletop technology a need for different user authentication mechanism has risen, as the tabletops support close collaboration between users, which makes tabletops more vulnerable to shoulder surfing compared to desktops. We explore the use of multi-factor authentication as a more secure authentication mechanism for tabletop technologies with the use of knowledge- and possession factor where we focus on password and PIN as knowledge factors and a TUI as possession factor. We compare single factor and multi-factor authentication mechanisms using usability evaluation. We found that the best authentication mechanism was a multi-factor authentication using TUI and PIN, which have a low completion time and high usability.

Categories and Subject Descriptors
H5.2 User Interfaces.

General Terms
Security, Human Factors, Design.

Keywords
User authentication, tabletop, interactive horizontal display, multi-factor authentication, TUI, fiduciary tag.

1. INTRODUCTION
Tabletop is a technology for use in both the public and private space where users can collaborate and interact with digital information, where the computer seamlessly disappear [1]. The use of Tangible user interface (TUI) and direct touch gives a feeling of interacting with content on a table [13][14]. As the computer seamlessly disappear the focus on security and protecting personal data is overlooked by the user, but it is still as important as with laptops and other digital devices that displays personal information.

To prevent compromising personal data, several authentication methods have been proposed to validate and the user's permission to access the personal data. A common authentication approach is the username/password combination that identifies a single user through the knowledge of the user. There are 3 authentication factors: *knowledge factor* (information you know), *possession factor* (physical object you possess) and the *inheritance factor* (biometric properties you possess) [2][10].

With the growing risk of compromising these passwords and usernames, alternative methods have been introduced to reduce the problem. One such method is multi-factor authentication which is considered stronger than single factor authentication [2][7]. Multi-factor authentication is authentication that combines 2 or more of the above authentication factors e.g. a password (knowledge factor) and iris-scanning (inheritance factor) for authentication. The multi-factor authentication has gained increased interest within recent years to change direction from only using the knowledge factor to broadening the perspective to cover the possession and inheritance factors [2][9][10].

The focus in authentication research has primarily been on security and lesser on the usability aspect. Studies tend to focus on the security aspect of such systems; [1][2][14]. Design of security systems often conflicts with usability concerns, although the two aspects are equally important to address [7][11]. [11] States that people ignore secure systems and chose those that are more usable, and therefore propose that usability is prioritized first and security second when making the trade-off between the two design qualities.

As for security systems and the individual aspect of such systems, not much research has been considered within the research field of tabletops [1]. New shortcomings are introduced within a tabletop setting, as the nature of these devices is for co-located collaboration. This creates design considerations between the individual users and the security considerations of such settings. One such shortcoming within a collaborative setting is shoulder surfing, which is when a person observes to get information, in this case the authentication information as everyone around the tabletop can see what everyone else does [1]. Another security threat is smudge attack which is when fingerprint oil is left on display when using direct touch to interact, which can be used to deduce authentication credential [15].

We contribute with a comparative study on usability of single and multi-factor authentication in tabletop technologies by introducing TUI as possession factor in authentication mechanism for a tabletop technology. We also introduce a safe combination authentication method as one of the authentication mechanisms and we explore the use of multi-factor authentication to diminish the threat of shoulder surfing.

2. RELATED WORK
In this section, we present work of current research within authentication and multi-factor authentication on both desktop and tabletop technology. Recent research has been on multi-factor authentication methods [1], [2], [5] on various systems.

In terms of comparing the conditions with traditional systems on a desktop computer, Braz et al. [7] presents a comparative study of authentication mechanisms, where they compare existing systems such as password, proximity card, multifunction card, public key and fingerprint among others. They compare the systems on parameter advantages, disadvantages, security, usability, input time and others. The find that the three systems with best security are: voice, password and PIN. The three systems with best usability are: password, PIN and retina/iris. They conclude that there is a need for more focus on usability to make reliable, effective and usable authentication systems.

Sabzevar and Stravrou [2] presents multi-factor authentication for graphical password. Graphical password is where the user is prompted with an image for authentication. The user then has to click different areas of the image to input the password. In [2] the knowledge factor is a password and possession factor is a one-time generated key image that show click points and the corresponding digits. The authentication mechanism addresses security issues such as guessing and shoulder surfing. They also specify usability challenges in relation to multi-factor authentication. At that point in time (2008) the multi-factor authentication mechanism is not a standard and there exist a number of implementations of this mechanism. However in modern society, the multi-factor authentication mechanisms have gained popularity. In Denmark the government have introduced NemID [8], a java based multi-factor authentication scheme. NemID is multi-factor authentication due to having a physical card with a series of numbers and a username/password.

Kim et al. [1] specifies systems on a one-factor authentication using multi-touch on a tabletop technology. Each system utilizes the knowledge factor relying on the user to know and remember a certain phrase, such as a password or personal identification number (PIN). Concretely they specify pressure-grid, a system using colors and a series of pictures as an authentication mechanism, where the user chose picture by chance the pressure of two fingers touch the pressure-grid, which limits shoulder surfing. They user study was based on one login with the system and two observer that afterwards tried to login as that user. They measure the completion time and successful replicated logins. PressureFaces was the system that took longest (8-14seconds) and the only one that was not compromised was the PIN which had the shortest completion time (ca. 1.5 seconds) were replicated 70%. Furthermore Kim et al. specifies research opportunities in how to distinguish between several users on shared interfaces such as tabletops.

Sae-Bae et al. [13] presents an authentication mechanism utilizing behavior-biometric in multi-touch gestures on multi-touch device (iPad). Behavior-biometric is the inherence factor authentication. They analyzed the system based on accuracy and user experience (ease of use, pleasure and excitement). The system does not suffer from shoulder surfing or finger oil attack. They find that the users' preferences correspond to the systems performance and users were open to adopt the system for everyday use.

Marquardt et al. [6] specifies a system using a fiduciary-tagged glove. Fiduciary-tag is like barcodes and QR codes. By placing 15 tags strategically on the glove to identify which part of the hand is actually touching the surface. This enables their system to enhance gesture recognition and thereby expand the interaction possibilities. The glove also makes it possible to identify the user, as the glove is meant to be a unique possession for each user. As such the fiduciary-tagged glove can be considered as a possession authentication mechanism.

Qin et al. [14] present pPen, a pressure sensitive digital pen for tabletops. They present an authentication mechanism where users perform their signature with pPen for authentication, based on biometrics and pressure dynamics. The system can be seen as multi-factor authentication as the user has to remember their signature (knowledge factor) and write the signature (inherence) as the focus of authentication is matching the handwriting. They measure their system performance based on successful logins and possibilities of identification attacks. They have one user that login and 7 attacks that observe the login and attempt to replicate it. They conclude that 91.6% login success and 9.4% rejection rate, and system does not suffer shoulder surfing attack.

Braz et al. [7] conclude that there is a need for more focus on usability, to be able to implement reliable, effective and usable authentication system. They find that password and PIN authentication is the most security and usability mechanism on desktop system. Sabzevar and Stravrou [2] use multi-factor authentication to remove the shoulder surfing threat for graphical password authentication desktop system. They use a picture on a mobile phone as possession factor and the password is knowledge factor. Kim et al. [1] highlight the need for authentication system that takes into consideration the collaboration nature of the tabletop and explore a pressure input system to limit shoulder surfing, which is a knowledge factor. Sae-Bae et al. [13] use a behavior-biometric authentication mechanism that limit the threat of finger oil attack and shoulder surfing on multi-touch device, which use inherence and knowledge factor. Marquardt et al. [6] use fiduciary tag to create a glove to expand the interaction possibilities on a tabletop, which also can be used for possession factor authentication. Qin et al. [14] use a pressure sensitive digital pen for user authentication on a tabletop. As can be seen from the related work no research into multi-factor authentication with possession factor on tabletop exist and as such no comparison between single factor and multi-factor authentication. The related work inspire to further research into, how to leverage multi-factor authentication on a tabletop technology extending research into the possession factor of multi-factor authentication.

3. METHODOLOGY

In this section, the method used for the study is described. We focus on usability of single- and multi-factor authentication for tabletop device where the knowledge factor is PIN and Password as in Braz et al. [7] found these to be the most secure and usable. For the possession factor we chose to implement a TUI using fiduciary tag as it shows promise in Marquardt et al's [6] paper as a mean of authentication.

Our study is to compare the knowledge factor, the possession factor and a combination of the two. The study included six authentication conditions, where 3 are multi-factor authentication, 2 knowledge factor and 1 possession factor. We use a TUI as the possession factor using fiduciary tag to create personalized objects that can be attached to e.g. credit card, another personal object and in our case small rubber square. Personal objects have been in the market for several years in terms of dongles and key generators to create a multi-factor authentication mechanism.

We chose to evaluate the 6 conditions using usability evaluation to compare the authentication mechanism. Braz et al. [7] state that there is a need to focus on usability to make reliable, effective and usable authentication mechanisms. To compare the 6 conditions we measure the task completion time and use a SUS survey and to elaborate on user preferences, we use interviews.

Out study is separated in 2 experiments, both comparing single and multi-factor authentication. Each study examines 5 conditions; 2 knowledge factor, 2 multi-factors and 1 possession factor authentication. The difference between the two experiments is one of the multi factor authentication has been replaced in experiment 2. The reason for this was a major usability issue was found in the multi factor authentication which affected the study. Elaboration on the problem is described in the discussion. The purpose of Experiment 2 was to find a relation between the usability issue and the SUS score.

Throughout the study, a Microsoft Surface 2.0 is used for the purpose of a Tabletop technology.

3.1 One-Factor Authentication

In this study two main variables are considered; one-factor authentication methods and two-factor authentication methods. These two variables have been chosen based on the popularity in modern systems. Previously mentioned, these factors consist of knowledge-, possession- and inherence factors. In this experiment we convert the types of factors to a context only briefly explored in the literature of the tabletop research field [1][2]. Due to fiduciary tag identification, it is possible to create a physical personal identity object to authorize the user of a system on a tabletop device, such as Microsoft Pixelsense and ReacTable.

For the one-factor authentication viable, three conditions are focused on. Two of these focus on the knowledge factor, with the use of a username/password combination and a username/PIN combination. The third condition focuses on the possession factor by using the TUI.

3.1.1 Username and PIN Condition (UsPi)

In the UsPi condition the user uses a combination of a username and a PIN for authentication. To input the username, a standard tabletop keyboard is provided. To enter the PIN a numpad is provided. When the user input a Pin digit a * character is added to the progress bar which is located below username input. This is to give the users feedback, that a digit has been entered and to give an overview of input status. The progress bar is repeated in 4 of the 6 authentication conditions, which all use PIN for verification. A space between progress bar and numpad has been added so user can cover the numpad with one hand. To authenticate, the user enters a username and a PIN. The user confirms the authentication attempt by clicking OK. The application closes, if the user has entered the correct credentials or an error showing that either the PIN of username is wrong. In Figure 1 an image of the UsPi condition, showing the Keyboard, numpad, username input box and the progress bar.

3.1.2 Username and Password Condition (UsPa)

In the UsPa condition the user uses a combination of a username and password. The purpose is to use this condition as a benchmark for the 5 other conditions, as this is the traditional way of an authentication mechanism on a traditional desktop computer. The condition has two input boxes; one for username and one for password. To input the username and password, a standard tabletop keyboard is provided. The user enters the credentials and presses login or enter. The application closes, if the user has entered the correct credentials or an error showing that either the password of username is wrong.

3.1.3 Tag

In the tag condition the users uses a TUI. The TUI is implemented using fiduciary tag which is a paper based 8 bit picture code that Microsoft Pixelsense recognizes. Through the Surface API various information is available: its 8bit identification number, the coordinates on the table, the orientation to the surface normal.

With the Tag condition the user places the TUI on the tabletop. Due to the possession factor, the TUI is the only identification that is needed to authenticate. An image of a fiduciary tag can be seen in Figure 2, which is the side faced down on the tabletop.

Figure 1: UsPi prototype, knowledge factor authentication

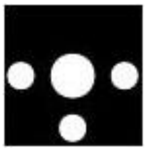

Figure 2: Fiduciary tag

3.2 Two-Factor Authentication

The second variable is two-factor authentication, where three conditions are proposed to evaluate the effect of implementing a two-factor authentication method. The first condition focuses on the use of a TUI for a safe metaphor. The second condition focuses on a modified version of the safe metaphor. Lastly the third condition focuses on a combination of using a TUI and a PIN.

3.2.1 Safe Version One Condition (Saf1)

This condition uses a mental model of a safe, as inspiration for a multi-factor authentication mechanism. The Saf1 condition uses a TUI that the user places on the tabletop and a PIN. The tabletop registers the tag and shows a graphical user interface element of a circle. The circle has digits 0 to 9 divided evenly around the circle along with an arrow to indicate the number to select. The user turns the TUI as a tangible object which rotates the arrow relative to tag. To select a digit the user turns the arrow to the digit’s interval and then turns the opposite direction to confirm the selection of digit. The digit the arrow point to from start depends on the orientation of the TUI when placed on the tabletop. For example user1 places the TUI on the tabletop, which starts at four. He then turns it left to select the digit 7. To confirm the digit 7 he begins to turn right to the next digit. When the second digit is reached, he turns left to confirm and turn to the third and continues this pattern to select a total of 4 digits as the PIN. To confirm the authorization attempt, the user lifts the TUI and waits for a period of time until the application closes. To cancel an authentication attempt the user removes the TUI from the tabletop device. Figure 3 shows the disc, the arrow, progress bar and TUI of Saf1.

Figure 3: Saf1 prototype, two-factor authentication

3.2.2 Safe Version Two Condition (Saf2)

This condition resembles the description from 3.2.1. The purpose is to differentiate the interaction of Saf1 and Saf2. In Saf1 the user turns the arrow relative to the TUI, if the TUI is turned right the arrow turns right. In Saf2 the user turns the circle relative to the TUI. The reason for the change is to remove the usability issue that the hand can cover the arrow or digit and the user cannot orientate how far he has rotated the arrow. This should limit the wrist twisting, when selecting a digit. Otherwise the interaction scheme is the same as Saf1. Image of Saf2 prototype can be seen in Figure 4.

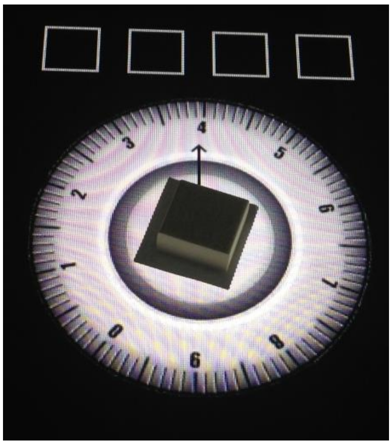

Figure 4: Saf2 prototype, two-factor authentication

3.2.3 Tag and PIN condition (TaPi)

The TaPi condition uses a TUI with a PIN input. The difference from Saf1, Saf2 and TaPi is that in TaPi the PIN is entered with a standard Numpad. The process to authenticate is first to place the TUI. When the TUI is registered by the tabletop a numpad and progress bar appears relative to the TUI, where the TUI is in the upper left corner. The user then enters a four digit PIN and presses OK. After a small time period, the application closes if the correct tag/PIN combination is entered otherwise a notification of wrong PIN is shown to the user. In Figure 5 shows TaPi with the TUI in upper left corner, progress bar and the numpad. The difference between TaPi and UsPi is the identification of the user, where the user in TaPi has a physical possession as an identity and in UsPi a username.

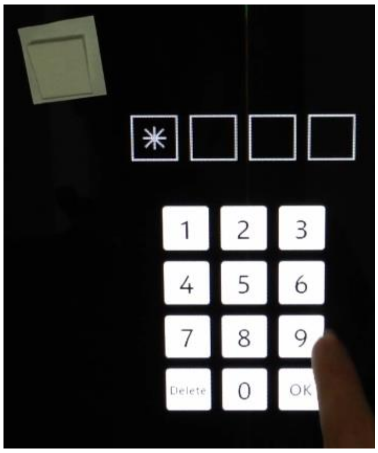

Figure 5: TaPi prototype, two-factor authentication

3.3 Participants

Each system is evaluated by users. The experiment had 16 participants, where 2 of these were females. Each participant was asked to fulfill a questionnaire asking about age and experience with both computers and touch devices and which devices they were familiar with. The participant's age was 24 (3.66) in average and was all students at Aalborg University. The participants have between 1 to 8 years of experience using touch devices, such as tablets and smartphones. We also asked the participants whether they knew tabletop devices, where 2 of the 16 said that they have seen and used one before. We also asked for their experience with authentication and which types of authentication types they knew. Experience with authentication mechanisms range from 5 to 16 years and not surprisingly the most frequent used is the username/password, while others also was mentioned, such as the Android Pattern Lock [12], voice recognition, NemID and key generators. The users are familiar with multi-factor authentication on a traditional PC. As thanks for their participation, we randomly chose a participant that received a gift certificate.

The distribution of user on the different condition can be seen in Table 1. The study was conducted as a within-subject study and the total number of participants was 16. All participants went through each of the prototypes with exception of Saf1 and Saf2, where only one was used. The number of participants for Saf1 was ten (n=10) and the number of participants for Saf2 was six (n=6). The order, in which each participant tested each of the prototypes, was randomized to limit ordering bias.

Table 1: presents an overview of the conditions within this study. Two conditions focus on the knowledge factor. One focuses on the Possession factor and 3 for two-factor authentication. n = number of participants.

Knowledge	Possession	Knowledge + Possession
UsPi (n=16)	Tag (n=16)	Saf1 (n=10)
UsPa (n=16)		Saf2 (n=6)
		TaPi (n=16)

3.4 Procedure

The study was conducted within a lab that was suitable for a tabletop technology. The room was darkened, to limit sunlight to interfere with the tabletop. Each condition was recorded using an iPhone 5 and focus was on the interaction on tabletop display. Each participant's video was recorded into separate files for each of the 5 conditions. The interview was recoded using the ITalk application and placing the iPhone on a table to ensure consistent audio feedback. Each participant's interview was recorded into separate files.

The procedure of the experiment was conducted as follows:

1. The participant filled the initial questionnaire, with demographic questions.
2. The participants were informed of the experiment, what the intention was and how the following procedure was planned.
3. To reduce ordering bias, we generated a random sequence for the order of systems that the participant should complete.
4. Information about the credentials for authorization was informed to the participant by handing out a note with the credentials written on and giving the TUI and carefully explaining them to the participant to ensure that the information was understood.
5. The participant was informed of the system in question and how he should use the system to complete the task.
6. The participant tried to authorize himself with the credentials from step 4.
7. Either after 3 minutes of authorization attempts or a successful attempt, the participant was asked to fulfill a system usability scale questionnaire, as specified by John Brooke [3].
8. Repeat steps 5 through 7 until the participant have completed the 5 conditions. Only one version of the safe was tested in any given iteration.
9. The participant was briefly interviewed to elaborate on their opinion on the different systems and to see if they understood the collaborative nature of a tabletop. The questions here were of the nature "what system would you chose? And why?", "what system would you chose based on security?" and "the tabletop is ideally used for collaboration tasks, with this knowledge in mind, which system would you chose?" and "Is the type of login system based on the purpose of the authorization? E.g Net banking or social media sites".
10. After the experiment the participant was able to explore the tabletop device freely with standard applications, showing the potential of such technologies.

3.5 Data Analysis

The data analysis was conducted by the two authors in. Each author analyzed all the data from the 16 tests. For each usability evaluation, five videos, 5 SUS questionnaires and an interview of five to 15 minutes were collected. In total 80 videos, 80 SUS questionnaires and 16 interviews were recorded.

We used Nvivo10 for the purpose of analyzing the videos and noting completion times. Completion times was recorded either from when the user was touching the surface of the tabletop or placing the TUI on the tabletop to when the first frame was recorded of the main menu. Each video was analyzed and usability problems were noted. Afterwards the authors made a comparison of the identified problems. Hertzum and Jacobsen [4] state that each evaluator never finds the exact same problems on the same data set. To verify the agreement between the two authors, the evaluator effect can be calculated as any-two agreement describing to what extent the evaluators agree on the same problems [4]. In this study the authors had an agreement in 22 of the 44 identified problems with an any-two agreement of 50%. According to Hertzum and Jacobsen, the any-two agreement for this study is high, as other studies have an agreement of 6% to 45% [4].

For each of the SUS questionnaires the SUS score was calculated. This is a standard procedure, as specified by Brooke [3]. The SUS score shows a numerical value and thereby a comparable score for usability.

Each interview was transcribed into a document and read through by both authors. The purpose was to find a correlation between the observed usability problems in the videos, the SUS scores and opinions of the participants stating positive or negative critique for the six conditions.

4. RESULTS

In this section, we present our findings for multi-factor authentication on a tabletop technology using knowledge- and possession based factors for authentication purposes. First, the system usability scale results are presented. Secondly Completion time results are presented. Thirdly the elaborated results from the interviews are presented.

4.1 System Usability Scale

In Table 2, a summary of the user's evaluation using SUS of each of the six prototypes is provided. Users 1 through 10 participated in experiment 1 where Saf1 condition was included. Users 11 through 16 have participated in experiment 2 where Saf2 was included.

4.1.1 Experiment 1

A one-way ANOVA test for experiment 1 show significant differences between one and more of the conditions (df-resid=45, $F=14.94$, $p<0.001$). A Tukey's pair-wise comparison test, as can be seen in Table 3, reveals significant differences between Saf1 and all the other prototypes ($0.001<p<0.04$), where difference is highly significant between Saf1 and the 3 conditions: UsPa, TaPi and Tag ($p<0.001$). It also reveals significant differences between UsPi and the 2 conditions: TaPi and Tag ($0.01<p<0.05$). Tag condition shows no significant different to the 2 conditions UsPa and TaPi. No significant between condition TaPi and UsPa and same goes for UsPi and UsPa.

4.1.2 Experiment 2

The one-way ANOVA test for experiment 2 also reveals significant differences in one and more of the conditions (df-resid=25, $F=19.84$, $p<0.001$). The Tukey pair-wise comparison, as can be seen in Table 4, reveals a significant difference between Saf2 and all the other conditions ($0.001<p<0.02$), where difference is highly significant between Saf2 and the 3 conditions: UsPa, TaPi and Tag ($p<0.001$). There is very significant between TaPi and UsPi ($0.001<p <0.01$) and significant between UsPi and TaPi ($0.01<p<0.05$). There is almost significant differences between UsPi and UsPa ($0.05<p<0.1$). Tag condition shows no significant difference to the 2 conditions UsPa and TaPi. No significant difference between TaPi and UsPa.

Table 2: SUS scores for each of the prototype and user.

	Saf1	UsPi	UsPa	TaPi	Tag	Saf2
Exp1						
U1	80	37,5	77,5	100	92,5	-
U2	25	55	67,5	95	75	-
U3	60	95	92,5	97,5	85	-
U4	50	52,5	97,5	100	100	-
U5	50	92,5	87,5	100	95	-
U6	35	67,5	75	70	72,5	-
U7	57,5	80	95	95	97,5	-
U8	35	97,5	95	97,5	100	-
U9	40	77,5	77,5	87,5	87,6	-
U10	30	35	67,5	72,5	87,5	-
Avg	**46,25**	**69**	**83,25**	**91,5**	**89,26**	-
Exp2						
U11	-	75	95	80	85	35
U12	-	52,5	97,5	92,5	87,5	40
U13	-	75	77,5	97,5	85	60
U14	-	70	57,5	100	97,5	55
U15	-	82,5	85	100	95	47,5
U16	-	55	100	95	95	45
Avg	**-**	**68,33**	**85,42**	**94,17**	**90,83**	**47,08**
Total avg (stdev)	***46,25 (15,8)***	***68,75 (18,7)***	***84,06 (12,6)***	***92,5 (9,6)***	***89,85 (8,0)***	***47,08 (8,5)***

Table 3 and 4 summarizes the results from the Tukey pair-wise test. In experiment 1 the Saf1 was rated significant worse than all the other conditions and UsPi was also rated significant worse than TaPi and Tag. TaPi and Tag was rated highly significant better than Saf1 and significant better than UsPi. There is difference in significant between experiment 1 and 2, in conditions UsPi and UsPa, where there is no significant in experiment 1 but almost significant in experiment 2. The other difference is in compare of condition TaPi and UsPa where in experiment it is significant and in experiment 2 very significant difference.

Table 3: Tukey's pair-wise comparison test results for experiement 1 of the SUS score, showing the significance in the 5 conditions.[2]

	Saf1	UsPi	UsPa	TaPi	Tag
Saf1		P<0.01 *	P<0.001 ***	P<0.001 ***	P<0.001 ***
UsPi	P<0.01 *		P>0.1	P<0.01 *	P<0.01 *
UsPa	P<0.001 ***	P>0.1		P>0.1	P>0.1
TaPi	P<0.001 ***	P<0.01 *	P>0.1		P>0.1
Tag	P<0.001 ***	P<0.01 *	P>0.1	P>0.1	

Table 4: Tukey's pair-wise comparison test results for experiment 2 of the SUS score showing the significance in the 5 conditions.[1]

	Saf2	UsPi	UsPa	TaPi	Tag
Saf2		P<0.05 *	P<0.001 ***	P<0.001 ***	P<0.001 ***
UsPi	P<0.05 *		P<0.1 .	P<0.01 **	P<0.05 *
UsPa	P<0.001 ***	P<0.1 .		P>0.1	P>0.1
TaPi	P<0.001 ***	P<0.01 **	P>0.1		P>0.1
Tag	P<0.001 ***	P<0.05 *	P>0.1	P>0.1	

4.2 Completion Time

In Table 5, a summary of the completion times for each of the six prototypes are provided. In experiment 1 three users didn't manage to login using the Saf1 prototype and is marked with x. Users 1 through 10 participate in experiment 1 where Saf1 condition was included. Users 11 through 16 have participate in experiment 2 where Saf2 was included.

4.2.1 Experiment 1

Using a one-way ANOVA test on the results for Exp1 show significant differences between one and more of the conditions in experiment 1 (df-resid=42, F=13.18, p<0.001). Using a Tukey Pair-wise comparison on each of the experiments, as can be seen in Table 6, reveals significant differences between Saf1 and each of the other conditions in relation to UsPi, UsPa, TaPi and Tag (0.001<P<0.01), where very significant between UsPa and Saf1 (0.001<p<0.01), and highly significant between Saf1 and the 3 conditions UsPi, TaPi and Tag (p<0.001). There is very significant between UsPa and Tag (0.001<p<0.01) and almost significant between Tag condition and UsPi (0.05<p<0.1). There was no significant difference between the rest of the conditions.

4.2.2 Experiment 2

Using a one-way ANOVA test on the results for Exp2 mean show significant differences between one and more of the conditions in experiment 2 (df-resid=25, F=10.98, p<0.001). Using a Tukey Pair-wise comparison on each of the experiments, as can be seen in Table 7, reveals significant differences between Saf2 in relation to UsPa, TaPi and Tag (0.001<p<0.01), where very significant difference between Saf2 and UsPa (0.001<p<0.01) and is highly significant difference between Saf2 and the 2 conditions TaPi and Tag (p<0.001). There is significant difference between Tag and UsPi (0.01<p<0.05) and almost significant between UsPi and TaPi (0.05<p<0.1). There was no significant difference between the other conditions.

Table 6 and 7 summarizes the result of the Tukey pair-wise comparison of experiment 1 and 2 for completion time. In experiment 1, Saf1 performs significant worse than all the other conditions and Tag condition performed significant better than all the other condition with the exception of TaPi condition. In experiment 2, Saf2 performs significant worse than all other

[1] * = significant, ** = very significant, *** = highly significant, . almost significant

condition with the exception of UsPi. Tag was rated significant better than Saf2 and UsPi.

Table 5: The Completion time in seconds for each prototype and user.

	Saf1	Saf2	UsPi	UsPa	TaPi	Tag
Exp1						
U1	83,2	-	107,1	23,5	14,6	3,5
U2	120	-	33,8	27,3	15,5	3,1
U3	105,5	-	25,3	39,9	7,3	3,3
U4	25,5	-	24,2	19	7,9	3,1
U5	x	-	19,5	27,5	7,8	3,2
U6	x	-	17,7	45,9	9,4	3
U7	69,8	-	24,9	19,6	9,2	4,8
U8	19,4	-	14,4	23,2	10,9	6,1
U9	x	-	16,2	86,1	6,5	3,1
U10	112,7	-	23,5	22,3	14,6	3,3
Avg	**76,58**	**-**	**30,66**	**33,43**	**10,37**	**3,65**
Exp2						
U11	-	101,8	32,3	23,9	10,2	3,5
U12	-	52,8	46,6	27,5	8,3	3,3
U13	-	61,8	24,9	20	10,2	4,6
U14	-	27,2	20,1	18,8	15,6	3,3
U15	-	77	15,9	23	8,8	3,4
U16	-	72,6	103,3	20	9,5	3,4
Avg	**-**	**65,53**	**40,52**	**22,2**	**10,43**	**3,58**
Total avg (stdev)	**76,58 (31,1)**	**65.53 (22,9)**	**34.36 (27,1)**	**29.22 (15,9)**	**10.39 (2,8)**	**3.62 (0,8)**

Table 6: Tukey's pair-wise comparison test results for experiement 1 of the completion time, showing the significance in the 5 conditions.[2]

	Saf1	UsPi	UsPa	TaPi	Tag
Saf1		P<0.001 ***	P<0.01 **	P<0.001 ***	P<0.001 ***
UsPi	P<0.001 ***		P>0.1	P>0.1	P<0.1 .
UsPa	P<0.01 **	P>0.1		P>0.1	P<0.01 **
TaPi	P<0.001 ***	P>0.1	P>0.1		P>0.1
Tag	P<0.001 ***	P<0.1 .	P<0.01 **	P>0.1	

Table 7: Tukey's pair-wise comparison test results for experiement 2 of the completion time, showing the significance in the 5 conditions.[2]

	Saf2	UsPi	UsPa	TaPi	Tag
Saf2		P>0.1	P<0.01 **	P<0.001 ***	P<0.001 ***
UsPi	P>0.1		P>0.1	P<0.1 .	P<0.05 *
UsPa	P<0.01 **	P>0.1		P>0.1	P>0.1
TaPi	P<0.001 ***	P<0.1 .	P>0.1		P>0.1
Tag	P<0.001 ***	P<0.05 *	P>0.1	P>0.1	

4.3 Qualitative Data

We have two types of qualitative data from our study first the results of the preference questions asked in the interview, the second is usability issues extracted from videos and compared with the interviews. The most severe of the usability problems identified is presented.

4.3.1 User Preference

The users preferred TaPi and Tag, when asked after the completion of all of the prototypes, and none mentioned Saf1 or Saf2. When asked which they preferred, with security in mind; UsPi and TaPi were most preferred and none mentioned the Tag. When asked which they preferred in a collaborative setting TaPi was most preferred but Tag was also preferred, while only one user still preferred UsPa.

4.3.2 Tag Flickering

We identified a problem within the conditions using a TUI (Tag, TaPi, Saf1 and Saf2). The TUI began to sporadically flick meaning the tabletop device lost track of the TUI, which has the same effect at lifting the TUI. The observed problem is very severe as the users were prevented in continue before the TUI had reconnected to the surface or some cases start over. This problem also lead to other usability problems for Saf1 and Saf2 e.g. the user rotated the TUI to far because the arrow did not follow the TUI as the surface had lost track of it. One participant stated that *"as you can see, I have had very severe problems with the TUI, and might be the cause of not liking this prototype"* (user 6) while speaking of the Saf1 condition.

4.3.3 Unnatural Interaction

Using the Saf1 system cause interaction problems, as the turning of a participants hand caused a twist in the wrist. This caused unnatural interactions as this was uncomfortable. A participant states *"It is so unnatural that I have to turn and twist my wrist, almost break my wrist, every time I have to turn the TUI all the way around. If I am unlucky with a random generated PIN of 9 and 1 and I start from 9 and have to turn it all the way to 1"* and follows *"this is irritating"* (user 8).

The participants also mentioned that the movement of the digital content and its relation to the TUI was a problem. A user states *"I would like the digital content to be static. When the content follows the TUI, it was confusing"* (user 8) and suggests a solution *"Where ever I place the TUI, the content should be stationary"*.

4.3.4 Selection of PIN digits issues

Another usability issues was related to input of PIN of the Saf1 and Saf2 conditions, where user didn't know they had to hit in the interval and not the precise number. A participant mentioned *"I [first] thought that I had to hit the number directly and afterwards I thought that this cannot be true, because that is simply too imprecise. After the first try I figured that it registers the number in intervals"(User 13).* The same participant also commented on the imprecise PIN selection *"… It was a really smart function; however it was hard to hit the number precisely, however I figured that this was not needed"(User 7).*

Observed was a participant not letting go of the TUI, when turning. When questioned further for this, she replied *"I thought that the PIN digits were selected by letting go of the TUI"(User 16).*

Participants mentioned confusion in the interpretation of how to use the progress bar in three of the conditions, Saf1, Saf2 and UsPi. A participant mentions, when trying to continue *"I was confused on how to continue and tried to press the keyboard and the progress bar"(User 16)* pointing at the four spaces in the UsPi condition.

4.3.5 Platform and Implementation Issues

Several of the participants stated issues related to the rotation speed in Saf1 and Saf2. A participant elaborates *"It feels like I have to rotate it for an unbelievably amount of time, to get to the digit to select" (User 6).*

A participant experienced problems with the keyboard in UsPi condition. Observed was that he was searching for a specific button on the onscreen keyboard, however the button was missing from it. When asked specifically to it, he answered *"I searched for the Tab button but could not find it at all, and then I was in trouble of how I should continue from here"*.(user 16) The problem occurs as the tabletop touch keyboard has no Tab button.

5. DISCUSSION

Very few have researched into the use of multi-factor authentication on tabletop, especially the use of possession factor authentication. We compare single and multi-factor authentication, discuss multi-factor authentication and then possession authentication. Lastly we discuss the conditions separately.

5.1 Authentication Comparison

In experiment 1 we found that Saf1 performed significant worse than the other conditions, both in relation to SUS scores and completion time. UsPi was also found to be worse than TaPi and Tag conditions. We found a serious usability problem with Saf1, which we thought might be the reason for performing significant worse. The problem was the users covered part of the graphical authentication scheme with their hand e.g. the arrow, the PIN digit or both, which caused other usability problems. The solution to the problem was instead of the arrow rotating with the TUI, the disc with PIN digits rotates with the PIN, which became condition 6 called Saf2. This lead to experiment 2 to check if this removed the significant difference between Saf2 and the other conditions. The result was that there were still significant differences between Saf2 and the other conditions in regards to the SUS scores, so the change from Saf1 to Saf2 didn't not even out the problems and it still performed worst, what did change was the completion time of UsPi and Saf2. UsPi did worse in experiment 2, than in experiment 1 as it average completion time increased with 10 seconds. Saf2 had a decrease in the average completion time with 11 seconds but did not increase in SUS score. Our result from SUS score and completion time corresponds to usability issues found for the different prototypes, where most occurred in Saf1 and Saf2 and second most in UsPi. UsPi's worst usability problem was the way to input a PIN digit. This did not fit with the user mental model. The problem likely occurred because of users identifying, where the users needed the keyboard to identify them and then also wanted to use it for inputting the PIN, but the PIN logic was implemented as in TaPi, but users approach it as UsPa e.g. touch the progress bar to "change focus" for keyboard, but progress bar was not implemented as such. So the conclusion is that Saf1, Saf2 and UsPi are not suitable for authentication in tabletop setting with the current technology and user behavior around a tabletop device, while TaPi and Tag are the best choice of the 6 conditions.

5.2 Multi-factor authentication

We wanted to compare single factor authentication with multi-factor authentication. In relation to completion time Tag condition was fastest with an average completion time 3.62 seconds and second best was TaPi with average 10.39 seconds. In relation to SUS score TaPi is best with a score of 92.5 and Tag is second best with score 89.85. When we asked the user which of the prototype they preferred the TaPi was chosen most often and second was Tag. When we then was asked which they preferred if they had to choose based on security concerns, the UsPa and TaPi was most often chosen and Tag was not chosen. We point out the tabletop could be used in a collaborative setting and asked, which they would prefer under this condition. TaPi was most chosen and second was Tag. There was only one that wanted to use UsPa in a collaborative setting. The last question was if the personal information accessed through authentication affected their choice of authentication mechanism, with the example of login to a net banking service. Many mentioned that they wanted to use TaPi for authentication to personal information. Some mentioned that to access not so security-critical information TUI was a good choice. Based on our study we can say that user are willing to use an authentication mechanism that takes more time to complete to be more secure in a collaborative setting and that they prefer possession and multi-factor authentication in a collaborative setting, but they feel less secure with only using possession factor. The average TaPi score of 92.5 also indicate that the usability of the system was very high, meaning it was easy to understand and use and little introduction was needed for the user to be able to login. TaPi also lessens the shoulder surfing problem with the use of the possession factor, which can also be derived from the user feeling more secure using possession-factor authentication in collaborative setting. Saf1 and Saf2 completely eliminate smudge attacks and TaPi lessen the problem with the use of possession factor.

5.3 TUI as Possesion-factor Authentication

Three of the systems proposed in this study use the TUI. One of the research goals was to identify if this TUI can be used as an authentication mechanism. The answer to this question depends on the purpose of the application. The users of this study state that the prototypes TaPi and Tag, which use the TUI, are easy to use. However some of them state a concern towards the portability of such TUI. However the TUIs size and the ease to replicate make it a viable artifact for the possession factor of multi-factor authentication. A consequence of the ease to replicate it is that malicious people can easily create another TUI and create a false identity, if the information of the TUI is discovered. So in general the tag alone is not secure enough for participants that have the purpose of authenticating to secure-critical applications such as internet banking. Another problem the user states was the need to bring it with them to be able to login, but to solve that issue would be to change to inherence factor or combine the possession-factor with an object they bring with them every day.

The participants of this study prefer solely to use the TUI alone (Tag condition), when using a system in collaboration with other people.

5.4 Conditions performance

In this section we look at each conditions performance in relation to completion time, SUS score and usability issues. We compare the measured completion times with the input time from Braz et al. [7] in cases where it is appropriate. The conditions we compare to from Braz et al. are Password, PIN and Proximity Card as this is closes to our Tag condition as it is a possession and lack from the same disadvantages (theft, fraud, counterfeit).

5.4.1 Username and PIN Condition

For the UsPi condition, we compare it with the PIN condition taken from Braz et al., which states their participants used between 5 and 10 seconds to input their information. The participants in this study use on average 34.36 seconds to complete the task. The reason for the longer completion time is that besides inputting the PIN they also have to input a username. Another factor of the longer completion time is due to participants trying to highlight the progress bar or trying to input the PIN by using the keyboard, but was not possible. This was also reflecting in SUS score, where average score is 68.75 seconds.

5.4.2 Username and Password Condition

For the UsPa condition, we compare it with the Password condition from Braz et al., which states that their participants used between 7 and 20 seconds to input their information. They do not include input of the username in completion time. The participants in our study range in completion time 18.8 to 86.1 seconds and the average completion time was 29.20 seconds. The reason for the higher completion time for some of the participants is because of wrong input of username or password and when in the input process they discover the error. The completion time of UsPa is not very higher in relation to Braz et al.'s as their completion time is on input of 8-12 digits, where in our condition the user has to input a user of 7 digits and then change input focus and input 6 digits. The UsPa do well in usability as the average SUS score is 84, but users would not choose it for authentication in a collaborative setting, because they felt it was too easy to observe the authentication credentials, but if they had to only consider security is was desirable as authentication.

5.4.3 Tag Condition

For the Tag condition we compare it with Proximity card as the fiduciary tag can be glued to a piece of plastic and used as a card. The comparison reveals identical input times with 2-5 second in Braz et al. and Tag condition 3-6 seconds with and average completion time 3.6 seconds. In our study however technicalities creates excess time for the completion time. The technicalities occur when closing an application. The Tag condition revealed to be accepted by the participants, based on the high SUS score of 89.85 and preferred in a collaborative setting. They acknowledge the simplicity of the condition; however question the security aspect of it, as it is solely a matter of possessing the correct tag to get access to one's personal account.

5.4.4 Tag and PIN condition

TaPi had an average completion time of 10.39 seconds which is better than password in Braz et al. but slower in both PIN and the use of Proximity card. In the interviews it was the most preferred authentication mechanism both usability, security and used in a collaborative setting, which is also reflected by it having the highest SUS score of 92.5. Not many usability problems were found in TaPi, which also reflected in the superior SUS score and acceptable completion time.

5.4.5 Saf1 and Saf2 conditions

For Saf1 and Saf2 there is no responding authentication method described in Braz et al. as it focus on single factor authentication and therefore cannot be compared. The average completion time for Saf1 is 76.58 seconds and Saf2 is 65.53 seconds. 3 of the participants in Saf1 condition did not successful login and have therefore been excluded from the completion time. The general opinion on Saf1 or Saf2 was the idea was interesting but they would not use it, both because of usability issues but also due to workload in order to authenticate, which is also supported by our data as user 8 had a completion time of 19.4 seconds but still rated Saf1 very low in SUS with a score of 35. Many of the usability issues for Saf1 and Saf2 was due to that many of the users had no experience with a physical safe authentication mechanism, but also because of tabletop technicality problems.

5.4.6 Summary

The worst authentication time in Braz et al. is 20 seconds where many of this paper's authentications take longer. Some of the reasons are that in Braz et al. [7] the users is not identified in the authentication process, where in 5 of our 6 conditions the user is identified either though a username or use of TUI. Only in Tag condition is the identified user also the authentication. The fastest of our authentication condition is Tag and second fastest is TaPi, both having and average completion time in same range as those from Braz et al. The condition which was best in relation to usability is TaPi and second best is Tag.

6. LIMITATION/FUTURE WORK

A limitation of the experiments setting with only having one user was that the user was not aware that the tabletop could be used in a collaboration setting. Only 3 users commented on the possibility and took it into consideration in the answers. The users first considered it after we asked question 3 in the interview. This could be solved with having multiple users interacting with the tabletop at the same time. Another limitation we found from our study was that the user did not feel threated from the evaluator and therefor did not consider protecting their authentication credentials. To overcome this problem the experiment would need onlookers that the user is not familiar with and make the user aware of the treat and give them a sense of need to protect the information. This might be solved by conducting the experiment as a field experiment. Another research opportunity is on user feeling of security using the tabletop device. We had a user that stated he would never login on his net bank service from a tabletop device (user1), because he did not feel it was secure, while others state they do not mind using the tabletop for net banking.

There were several users that suggested obscuring the authentication based on point of view. This means that only by viewing from a specific angle, was it able to see the authentication schema, to prevent shoulder surfing. There exist several papers researching on this possibility e.g. [16][17], but not much research on it in relation to authentication mechanisms. Another possibility is to use Google glasses to display the authentication schema on the tabletop, which is a future research opportunity.

7. CONCLUSION

In this paper we compared single and multifactor authentication as authentication mechanisms on a tabletop technology. We focus on using the two authentication factors: knowledge and possession, where we used PIN and password for knowledge factor and a TUI for possession. We compare 3 multi-factor-, 2 knowledge factor and 1 possession factor, on completion time, SUS score and user preferences. We find that the combination of PIN and TUI gives the user the best authentication mechanisms for tabletop in sense of usability, but users also feels secure using the mechanism especially in a collaborative settings. It is also fast to input the authentication credential information with an average of 10 seconds which is only beaten by the possession factor authentication which takes an average 3.5 seconds.

We also compared a multi-factor authentication mechanism inspired from a safe, where a TUI is used for a tangible rotation mechanism. The safe mechanisms performed worst. The reason for this was that the users were not familiar with the safe metaphor and therefore their mental model of how to complete the authentication did not correspond to the implementation. Another problem is the tabletop technology is not yet entirely mature for tracking TUI in movement and as such input lag was experienced.

A privacy problem that has yet to be solved is the connection between the authenticated user and access to private information is only given to that user when the tabletop is used in a collaborative with other people. Our authentication mechanism does not distinguish that it is only the authenticated user that has access to his person information, so this is still a challenge that have yet to be solved in tabletop technology research.

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APPENDIX D
SUMMARY

Our motivation behind this master thesis comes from the fact that literature reviews are often used to gain an initial knowledge base, when starting a new project. Literature reviews create an overview of the research field and presents several research opportunities, which can be pursued to contribute to the research field. In our case, it was not possible to find such literature review, which motivated us to create a study, focused on literature to gain an a firm knowledge base and to locate research opportunities for the master thesis.

In this master thesis we have examined the current base of literature within the tabletop research field to identify interesting opportunities. We found that a lack of usability assessment on a tabletop technology was lacking, and as such conducted a laboratory experiment for the purpose of a comparative study.

To answer our question we have made two empirical studies:

- In the first study, we examined the current literature of tabletops to create the foundation and overview through a literature review. The data was taken from leading conferences of HCI such as CHI and the specified aimed conference ITS We used a grounded theory approach to the data to create 8 distinct categories that characterizes the research field of tabletops. The eight categories was reviewed
- In the second study we conducted a comparative study of single- and multi-factor authentication on a tabletop technology. The purpuse was to compare 6 conditions, that use the possession and knowledge factors. We created a within-group study with 16 participants that evaluated the 6 conditions based on the usability of each. To measure usability we used the System Usability Scale (SUS), Time Completion Time (TCT), Videos and interviews. By using data triangulation the results were compared and analyzed revealing usability issues related to the tabletop setting.

The key findings from the first study, was the identification of the 8 categories that characterizes the research field of tabletops. The categories are: *Implementation, Interaction, Visualization, Design, Users, Individuality, Cross-Device and Collaboration*. We show the quantity of how many of the papers that is specified in each of the categories. The result was as follows: A total of 119 of the 338 (34.9%) have been identified as implementation. 76 of the 338 (22.4%) as interaction. 28 of the 338 as design (8.2%). 23 of the 338 (6.8%) as user. 20 of the 338 (8.9%) as visualization. 17 of the 338 (5.0%) as individuality. 12 of the 338 (3.5%) as collaboration and 8 of the 338 (2.4%) on cross-device. Furthermore we propose several research opportunities and one is authentication on the tabletop devices, leading to the second study.

The main findings from the second study, was that the multi-factor authentication mechanism using TUI and PIN was the best of the authentication mechanisms in usability, users feeling of security especially in a collaborative setting. The Tag was the second best of the authentication mechanism, and did well in relation to usability and users feeling of security in collaboration, however in general the user did not feel it was a secure authentication mechanism. We also found that safe metaphor as an authentication mechanism is not appropriate for tabletop technologies, as the user mental model of it was not matching the implementation and caused problems with tabletop device technicalities, where it had problem tracking TUI in movement.