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Watch Your Steps

Pedestrian Navigation via Smartwatch

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Pedestrian Navigation via Smartwatch

DIPLOMA THESIS

submitted in partial fulfillment of the requirements for the degree of

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in

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by

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Vienna, 23rd July, 2017

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Erklärung zur Verfassung der Arbeit

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Martin Perebner

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Kurzfassung

Fußgängernavigation ist Teil unseres täglichen Lebens. Die Technologie entwickelt sich jedoch sehr schnell weiter und eröffnet dadurch neue Möglichkeiten für Navigationssysteme. Heutzutage ist es üblich, elektronische Geräte, wie zum Beispiel Smartphones, für die Wegfindung zu verwenden, welche auf Basis unserer Position Informationen über die Umgebung als auch spezifische Routenanweisungen bereitstellen. Und während diese neuen Technologien eine bessere Navigation ermöglichen, weisen sie auch Restriktionen und neue Problemstellungen auf, welche berücksichtigt und evaluiert werden müssen. Eine der jüngsten dieser Technologien ist die Smartwatch. Während diese interessante Eigenschaften für Fußgängernavigation aufweist, ist ihre Brauchbarkeit in diesem Gebiet noch nicht ausreichend erforscht.

Daher ist die Zielsetzung dieser Masterarbeit, Designs für die Fußgängernavigation mittels einer Smartwatch auszuarbeiten und deren Brauchbarkeit zu evaluieren. Darüber hinaus werden Landmarks in das Navigationssystem integriert und es wird evaluiert, ob diese einen Vorteil für Fußgänger aufweisen. Um geeignete Konzepte zu entwickeln, wird eine nutzerorientierte Gestaltung als Vorgehensweise angewendet. Während einer Designstudie werden Konzepte entwickelt, die auf bisherigen Forschungsergebnissen basieren. Um Feedback über diese Konzepte zu erlangen, werden diese mittels eines „Wizard of Oz Experiments" getestet. Basierend auf diesen Ergebnissen werden zwei finale Entwürfe erstellt und als Applikationen für eine Android Smartwatch implementiert. Während beide Prototypen aus einer Karten-View und einer Richtungs-View bestehen, unterscheiden sie sich durch die Nutzung von Landmarks und die visuelle Unterscheidung von folgenden und nicht direkt folgenden Abbiegungen. Schließlich werden diese zwei Prototypen mittels eines Feldversuchs evaluiert. Die Resultate dieser Evaluierung lassen darauf schließen, dass Smartwatches sehr hilfreich im Kontext der Fußgängernavigation sind. Die Kombination einer Karten-View mit einer Richtungs-View erweist sich als eine äußerst gute Lösung, welche einerseits eine gute Übersicht bietet und dennoch Details über Entscheidungpunkte zur Verfügung stellt. Zudem kann taktiles Feedback in der Form von Vibrationen als eine gute Ergänzung betrachtet werden, welches den Fußgänger über die nächsten Entscheidungpunkte informiert. Die Einbindung von Landmarks reduziert die wahrgenommene Arbeitslast und erhöht die Zuversicht der User während der Navigation.

Abstract

Pedestrian navigation is part of our daily life. Yet technology advances rapidly, which opens new possibilities for navigation aids. Nowadays it is common to use technical devices like smartphones which assist in the wayfinding by presenting information about our environment as well as providing specific route instructions dependent on our location. And while these new technologies allow for a better navigation experience, they also bear some restrictions and new challenges which have to be considered and evaluated. One of the youngest of these new technologies is the smartwatch. While these devices exhibit interesting characteristics for pedestrian navigation, their viability in this field is not well examined.

Therefore, the purpose of this thesis is to explore designs for pedestrian navigation systems via a smartwatch and evaluate their viability. Furthermore, landmarks are incorporated into the navigation system and it is evaluated if they provide a benefit for pedestrians. In order to develop suitable concepts a user-centered design approach is applied. During a design study concepts are developed which are based on findings in the literature. These concepts are tested by the means of a "Wizard of Oz experiment" in order to gather feedback. Based on the outcome of the design study two final designs are proposed and implemented as prototypes for an Android smartwatch. While both prototypes consist of a map view combined with a direction view, they differ in the use of landmarks and the visual distinction of subsequent and non-subsequent turns. Finally these two prototypes are evaluated by conducting a field trial. The results of the evaluation suggest that smartwatches can be very viable in the context of pedestrian navigation. The combination of a map view and a direction view proves to be a suitable solution which offers a good overview while still maintaining details about decision points. Furthermore, tactile feedback via vibrations can be concluded to be a good addition in order to notify pedestrians about upcoming decision points. The inclusion of landmarks reduces the perceived workload and increases the confidence of users during the navigation.

Contents

CHAPTER 1

Introduction

1.1 Motivation

Navigation is one of the oldest tasks in the history of mankind. When looked at it from a very abstract point of view, it can be described as moving from a point A to a point B. While most of the time the process of navigation is subconscious, sometimes we are not aware of the path to take and have to rely on features in our environment to find the way. Tools for aiding navigation exist for a very long time, but in the last decades the possibilities of how to guide people have been increased drastically. One of the most prominent advances in technology is the smartphone, which is able to aid users in navigation while still being small enough to be carried around in a pocket. They are capable of locating users, providing information about their environment for example in the form of maps as well as inform users about the path they should take.

For electronic devices the approaches for navigation aid can be classified as: map-based, text-based, voice-based, tactile, augmented reality as well as a combination of those [51]. Depending on the environment, means of transportation and the used form of aid, a different approach may be more suitable. Nowadays it is also very common to mix different approaches, as for example by using a map with additional tactile feedback in form of vibrations in order to notify the user about decision points. A *decision point* represents the location where two different path segments meet each other [53]. They play an important role for navigation in general and many systems try to ease the decision-making process at these intersections [27]. One approach for assisting users at decision points is to utilize landmarks which represent recognizable significant objects in the environment that can be used as reference points [15, 61]. While not limited to decision points, the concept of landmarks can be found in many different navigation systems, especially in regard to smartphone-based navigation. Many studies have shown that landmarks are capable of improving the performance during the wayfinding as well as increasing the confidence of users [37, 54].

In recent years a new technology has risen in the public's attention - wearables, smart electronic devices which can be worn on the body, often equipped with sensors as well as input and output functionality. One of the most notable of this category are smartwatches which are usually connected to a smartphone and are capable of providing internet and GPS. While smartwatches are not exclusively built for navigation, they exhibit some very interesting characteristics in the context of wayfinding. Similar to smartphones they are capable of providing map information as well as the location of the user. Smartwatches are wrist-worn devices even smaller than smartphones which provide more freedom in the everyday life. The size induces one of the biggest challenges for many kinds of applications though, as it reduces the amount of information that can be presented and constrains the input capabilities by limiting the number of elements that can be interacted with or hindering the interaction itself due to the "fat-finger problem" [50]. These challenges are also relevant in the context of navigation, as for example in a map-based navigation where interactions like scrolling and zooming are often desired, and thus play an important role in the design of a navigation aid for smartwatches.

While the topic of navigation has been discussed over decades, the research of smartwatch-based navigation has, due to its novelty, only started in recent years. Some studies show promise for smartwatches in the context of wayfinding, but much about it is still unknown and there seem to exist no guidelines on how to design navigation aids for this new technology [26, 68, 64, 7].

In this work, designs for a smartwatch-based navigation system are proposed and implemented which are based on the findings of the literature review coupled with a user-centered design approach. It should be noted that while the smartwatch is often only considered as a companion to the smartphone, the focus of this thesis evolves around the smartwatch as the center point of aid. The implemented navigation systems shall be evaluated in order to discuss (a) if pedestrian navigation via a smartwatch can represent a viable solution and (b) if the addition of landmarks provides a benefit to users. For the first question it is assumed that a smartwatch can be a suitable navigation aid, though viable designs for such an aid have to be explored and developed. Furthermore, for the second question it is assumed that landmarks are perceived as a beneficial addition by users. In order to evaluate these questions the proposed designs shall be implemented as prototypes for a smartwatch and evaluated during a field trial.

1.2 Structure of the Thesis

In the next chapter 2 the state-of-the-art will be examined which is mostly concerned with research in the context of smartwatches and navigation. This research builds the basis for the ongoing thesis. Following, in chapter 3 the methodological approach for this master's thesis is described and an overview of the required tasks is given.

Chapter 4 contains the concept study which starts by proposing the first concepts. The concepts are tested during a field trial and the results are evaluated in order to adjust and define the final designs. The chapter finishes by describing these final designs and their behaviors.

Based on the final designs prototypes are implemented as presented in chapter 5 where the actual user-interface of the prototypes is illustrated and details about the implementation are given. Chapter 6 contains the final evaluation of the prototypes. Starting by discussing the experimental design the chapter finishes by presenting and examining the results of the feedback and collected data in order to evaluate the viability of the prototypes.

In the last chapter 7 the thesis is concluded and its results summarized. Furthermore, an outlook for future works is proposed.

CHAPTER 2

Related Work

While navigation in general has been a target of research for a very long time, navigation via a smartwatch is relatively new and thus less studied. That being said, navigation for smartphones has already been explored in various forms [52]. Since smartphones exhibit similar characteristics as smartwatches, the results of according researches should often be adaptive to smartwatches as well. In the following the state-of-the-art of smartwatches as well as navigation systems will be presented.

2.1 Smartwatches

Smartwatches are electronic devices which are worn on the wrist and are nowadays often paired with a smartphone. Smartwatches can be traced back to the 80's, though they started to gain most of the public interest in 2013 with the introduction of smartwatches by Samsung, Sony and Pebble as well as Motorala and Apple in the subsequent years [48]. While smartwatches can be seen as low interaction devices, many support interactions as for example clicks, gestures and voice input [36]. Most of the time smartwatches are used in conjunction with a smartphone and represent an additional interface, for example by forwarding notifications from the smartphone to the smartwatch [55].

Smartwatches have two big disadvantages when compared to smartphones or computers [50]. The first one is the reduced processing power. While this may be improved in the future in a similar fashion to smartphones, it is currently a restriction that has to be taken into account. For example, an operation which would require a heavy CPU usage may be sent to the smartphone instead which in turn performs the operation and returns the result to the smartwatch.

The second and from a user's standpoint more crucial disadvantage consists of the limited screen size. Most commercial smartwatches have a display size of about 1.2" to 1.5"[1].

[1] https://material.io/devices/

The small screen of a smartwatch not only limits how much information can be presented, but also adds restrictions regarding the freedom of interaction. While scrolling on a smartphone or computer is considered viable, this task can be cumbersome on a small screen. The small screen size also increases the impact of the so called “fat-finger problem”. When a user interacts with the smartwatch, as for example by zooming further in on a map, the portion of the screen where the finger is positioned is blocked. Thus the user is not able to see the effects of his or her interaction during the process [35].

It should be noted though that there exist several researches which try to overcome the issue of the small screen size, for example by directly increasing the available space via a cylindrical display which is wrapped around the wrist, as Strohmeier et al. proposed [65]. In their study, which compared different display sizes, they found that the smallest display had a significant worse performance when scrolling through a list. Oakley et al. proposed a different solution called EdgeTouch [43], which solves the interaction restrictions on the small screen of a smartwatch by adding sensors to the perpendicular edges. These sensors are capable of capturing touch and thus enable interactions without occupying the screen. They conducted an experiment in which participants had to select targets on the screen via the use of these sensors. The results of the study showed that the participants were able to select these targets in a timely manner and accurately. So while this solution does not increase the amount of information that can be shown, it can improve the interaction with a smartwatch. This could be especially useful for interactions like scrolling or zooming which suffer greatly on a small screen.

While smartwatches bear some constrictions, there are also some notable advantages. On of the big benefits is that they are carried on the wrist, which provides users a better freedom in their interaction with other objects and their environment when compared to a smartphone, which has to be hold and thus occupies at least one hand. Since they are worn on the wrist they also don’t have to be taken out of a pocket for a quick interaction. Smartwatches also support some possibilities for hand-free interaction. Android Wear for example automatically turns the screen on when the wrist is raised. The embedded accelerometer could also be used for custom interactions with an application. Furthermore, since smartwatches are always in contact with the body tactile feedback can be used as a rather reliable source for notifications as well as for conveying information [44]. It comes to no surprise that while there are several use cases for smartwatches, as for example health-tracking, many users see them mainly as an extension to their smartphone and utilize the notifications which are forwarded from the smartphone [55, 6]. Since smartwatches rely more heavily on vibrations than sound for feedback, receiving notifications can also be considered less distracting in social environments [19]. Furthermore reacting to a notification on the wrist can be considered faster and easier than grabbing and unlocking a smartphone [48].

It should further be noted that while smartphones also support tactile feedback via vibrations, they are often worn in the pocket and thus the feedback is more prone to be missed.

2.2 Navigation in General

Navigation has been a focus of research for many decades. It comes to no surprise that the definitions of the term differ. Montello et al. for example define navigation as a combination of locomotion and wayfinding [41]. While locomotion is concerned with the movement itself, wayfinding is about making decisions, as they pointed out: "*When we wayfind, we solve behavioral problems involving explicit planning and decision-making—problems such as choosing routes to take, moving toward distal landmarks, creating shortcuts, and scheduling trips and trip sequences.*" [41, p. 259]. So while movement plays an important role on choosing the correct aid for wayfinding, this thesis is mostly concerned with the latter. Golledge defines: "*Wayfinding is the process of determining and following a path or route between an origin and a destination.*" [17, p. 6]. He further points out that wayfinding is a purposive activity on a route through an environment, where the route has been defined beforehand and consists of route segments and turn angles. Wiener et al. created a taxonomy of wayfinding tasks [71], which divides navigation into locomotion and wayfinding, and differentiates wayfinding further by unaided and aided wayfinding. They argued that the cognitive demands of aided and unaided wayfinding are fundamentally different and that aided wayfinding can be very simple in some cases. When wayfinding is for example aided by maps different cognitive processes are relevant, like identifying symbols or mapping the own perspective to the representation of a map.

Downs et al. [12] differentiate the process of wayfinding by four distinct sub-tasks [14, cf.]:

1. Orientation
2. Planning of the route
3. Staying on the correct path
4. Finding the destination

While the first task is concerned with identifying the location in respect to the environment, the second task includes selecting a route which ends in the destination. The last two tasks consist of the continuous confirmation of being on the correct route as well as recognizing the destination.

Furthermore, wayfinding can also be broken into the planning of the route and the actual navigation process itself [53]. In order to plan a route a starting and end point have to be defined and in some cases also the concrete route is determined. During the navigation process users follow the route in order to reach the destination. It seems natural that the requirements for planning and navigating a route strongly vary and thus different aspects have to be taken into account when designing aids for them. Since this thesis is concerned with the actual navigation of a route, the research is primarily focused on this topic.

Decision points can be considered one of the core elements of a route, as Richter et al. points out: "*Following a route comprises two basic processes: getting to a decision point and, there, determining the further direction to take (e.g. Daniel & Denis, 1998).*" [53, p. 60] [8]. While a route can be described as a list of decision points, the main purpose of navigation aids is thus to support users at these decision points to move forward in the right direction.

The importance of decision points can be found in many researches, though the specific formalism varies. Werner et al. [70] developed an abstract theory around route-based navigation via graphs. They define a route among other things as a collective of directed route segments, where route segments are joined by a place. Their proposed definition of a place has similarities to the aforementioned decision point, though in their theory the route segment itself contains the required information on how to start each route segment. A similar definition can be also found by Klippel [27] who partitions routes into route segments and decision points.

Since decision points seem to constitute such an important concept regarding wayfinding, the question arises how to best aid users at those. While concrete approaches on how to lead users in a certain direction will be examined later, the principles are quite similar for most systems. It should be noted though that some approaches, as for example "follow-me", use a more implicit way to convey the information regarding the direction.

One problem when it comes to communicating the direction is that humans are not able to interpret them very precisely. So while from a technical point of view it is possible to provide the angle of the direction with a high accuracy, this accuracy would be lost to the user. Montello et al. [42] for example found that while human's knowledge is metric, it is only so in a very imprecise way which can lead to errors. Klippel [27] for example proposes an 8-sector model for wayfinding which samples the circle around the user in eight equal parts. These directions can be represented by arrows or via text as for example: "*Turn left then half-right.*" By the use of sampled directions the precise accuracy is reduced to fixed intervals, which not only allows more optimized ways to convey this information, but also reduces errors on the part of the user.

2.2.1 Landmarks

Landmarks represent prominent objects in the environment of the user which can be used as reference points along the route [15, 61]. In order for an object to be considered a landmark it has to differentiate itself from its surroundings [49]. One example for landmarks are buildings with a special kind of description or function, such as a well known supermarket chain or a church [13]. The main purpose of landmarks in the context of navigation is to identify decision points as well as to provide cues for orientation and verification of the route [61, 17].

In recent years landmarks play an increased role in navigation systems, especially when designed for pedestrians [9]. While landmarks are rarely used in commercial products when it comes to the navigation itself, many tools present them in an overview and allow to search for them. For example in many navigation systems it is possible for a user to search for restaurants and banks. They are thus more perceived and used as a point of interest instead of a mean for navigation. Contrary to that people often make use of landmarks when describing routes to other people, as for example: "*Turn left after the church.*", instead of referring to street names or road types [37]. As studies have shown users prefer landmarks for navigation instructions as an additional aid and thus they are often recommended for navigation [51, 37, 10, 54, 59]. One of the benefits found when using landmarks is an increase in the confidence of the user during the navigation. Users can reference the landmark to the object in the real environment and thus can be reassured that they are on the correct path. Landmarks can also help to identify the exact locations of decision points at greater distances and more so than street names, since street names are most of the times only readable when the user is already in the proximity. However, landmarks are not only useful at decision points for orientation [40, 24]. They can also be used between decision points as route marks, where they confirm the correct path. Furthermore, distant landmarks, as for example mountains which can be seen from far away, can be used in order to improve the overall guidance.

An important aspect when using landmarks is to find and show the most suitable ones [30]. Thus the question arises: what constitutes a good landmark? In order to support the user during the navigation the landmark has to be recognizable by the user, since otherwise the user won't find the object in the real world and may lose confidence. Several researchers found that shop buildings are very suitable candidates for landmarks, especially when the shop has a recognizable trademark [37, 58]. Sefelin et al. [58] furthermore recommend the following five methods for identifying the optimal landmarks:

1. **Picture-based object recognition:** Participants take a short look at pictures and afterwards point to areas with the most recognizable objects and name them.

2. **Way descriptions:** Participants have to find a location and talk about the objects they encounter.

3. **Eye-Catcher detection:** Participants walk around an area and have to name the most noticeable objects afterwards.

4. **Picture-based object description and naming:** Participants are asked to name the object in a picture. Participants are asked how they would describe a way along a certain object.

5. **Wizard of Oz Prototyping:** Testing the landmarks for navigation in an application where an instructor simulates the system.

While the first three methods aim to identify viable landmarks, the fourth method tries to solve any inconsistence regarding the naming of certain landmarks. The last method evaluates the chosen landmarks during a navigation task. It should also be noted that there are efforts to automatize the selection of landmarks, for example by the use of image recognition as proposed by Hile et al.[25]. Not only does their prototype select suitable landmarks during the navigation, it also uses low-level spatial reasoning to choose an appropriate image for that landmark depending on the location.

While there currently do not seem to exist databases which contain landmarks for the explicit use in navigation, there has already been conducted some research in that direction. Helgath et al. [23] for example used a smartwatch with speech recognition to mine landmarks. A more automatic approach for collecting landmarks is proposed by Lander et al. [32], where they infer landmarks by the use of Google Street View and eye-tracking.

While landmarks can be mixed with various of navigation concepts, how they are presented varies. The types of landmarks can vary so much that different representations in the same tool may be considered viable. When considering how landmarks should be visualized, the level of abstraction plays an important role. Elias et al. [13] for example proposed the following abstractions from lowest to highest:

1. Image
2. Drawing
3. Sketch
4. Iconic
5. Symbol
6. Words

Which visualization should be used depends highly on the particular landmark. For a well known food chain the logo may be the best representation, while for a church a symbol may be a better fit. If on the other hand the landmark cannot be described by any imagery accurately a simple text may be used. In the research of Elias et al. they found that 50% of the landmarks used in navigation instructions are buildings which they categorized into: shops that are well known as for example shop chains, shops which can be referenced by their type, buildings which have a specific function as well as buildings which can be described by their visual appearance. They furthermore developed guidelines for these categories and for example recommend for a well known shop chain an icon and for a shop with a specific type the corresponding symbol representation.

The differentiation between shop chains and shops for a specific type has also been found by Sefelin et al. [58], where participants referred to famous chains by their names and to the latter by their function. May et al. [37] furthermore recommended that if a shop has a recognizable trademark the exact name of the shop or the logo if applicable should be used instead of the functional icon or name.

Besides the actual representation of the landmark also the size should be considered. On the one hand the landmark should not occupy too much space as to not overlay other information but still has to be recognizable by the user. Depending on the visualization of a landmark a different size may be chosen, where for example a sketch requires a smaller size than a logo [13].

One aspect that should be taken into account as well is if landmarks should be displayed all the time or only in certain situations like close proximity. Generally landmarks are most useful when they are relevant to the wayfinding of the user at that moment, but furthermore landmarks which cannot be seen from the user's current location may be problematic since the user searches for it and may be confused if it cannot be found [58].

2.2.2 Classification of Pedestrians

One important aspect regarding designing tools for navigation is that users tend to navigate very differently. Dependent on how users are used to navigate they prefer a different aid and even use the same tool in varying ways. Thus it is very important to tailor the navigation system in a way that most users understand it and are able to use it to their benefit. In order to do so it is necessary to understand how users think when it comes to navigation. Wen et al. [67] tried to classify users for mobile pedestrian navigation by allowing users to use different types of applications and evaluating which applications were used. In their study they provided a north-up based map, a track-up based map, a compass as well as an augmented reality based map and a radar. In defined intervals along a route users had to choose between these systems. From their observations they identified four different types of users as illustrated in figure 2.1.

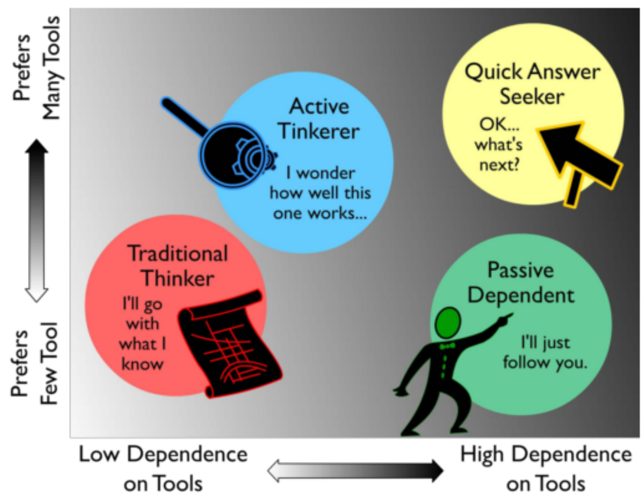


Figure 2.1: Classification of users regarding navigation (from [67, p. 15, figure 4])

Dependent on the classification different tools may be better suited for users. For example a "Traditional Thinker" may prefer a map in north-up orientation, while a "Quick Answer

Thinker" on the other hand would like to have simple arrows showing the next turn direction. Similar categorizations could be found by Webber et al. [66] who identified the "Constant support & Information", "Independent & Attentive" and "Least Effort & Inattentive" groups.

Since the goal when designing navigation systems generally should be to capture the behavior and desires of users as much as possible, it is important to think about how to align these different requirements into one system.

2.3 Electronic Navigation Systems

While one of the most used approaches for supporting navigation via smartphone or computer is map-based, there are many different ways to provide navigation aid. Sometimes approaches are mixed with each other, as for example a map-based navigation with notifications via tactile feedback or by adding voice guidance. When a map is provided for the navigation, there is also often the option to switch into a turn-by-turn based navigation which may use a different point of view or handles the orientation of the map differently. The use of a certain navigation system is highly dependent on the navigation scenario and the resultant boundaries of interaction and visualization possibilities. Furthermore, the preferred navigation aid varies between users and even a single user tends to prefer a different kind of information dependent on the level of confidence and the environment [33]. Additionally, a distinction has to be made if the user wants to prepare for the navigation or wants to use a tool during the navigation task itself. Also the locomotive speed of the user plays an important role when designing navigation systems, since for example a tool which works for pedestrian navigation might perform very bad when used during a car drive.

The different kinds of electronic navigation aids can be broken into map-based, text-based, voice-based, tactile, augmented reality as well as a combination of those [51], as will be discussed in the following sections.

2.3.1 Map-based Navigation

Navigation via a map is one of the oldest approaches for navigation and has been used even before the existence of smartphones and computers. In the last decades the interface for the map shifted from being on a paper to a screen, which allows not only to provide a lot more information but also to interact with the map in more meaningful ways than a paper would allow [45]. Furthermore, devices allow to constantly update the map material, which ensures more up-to-date map visualizations and route planning. Due to the advances in technology and the spread of computers, smartphones and the internet, electronic devices have become widely used as a means of navigation. A lot of the navigation systems on these devices utilize maps for navigation, as for example

Google Maps[2] and Apple Maps[3]. Some of the current navigation systems even support different representations of the map, as for example a topographic and a satellite view. Most navigation systems however do not only show the map but also allow to search for locations and areas, zoom in and out, scroll the map as well as orientate the map. Beside the navigation itself maps are also used for planning routes beforehand. When it comes to route planning, map-based systems are utilized for all kinds of transportation like walking, driving and cycling.

That being said, map-based systems tailored for the navigation task itself are often combined with other approaches, as for example tactile feedback in form of vibrations or voice as additional guidance [63, 2, 47]. Also the visualization of the map as well as how it is orientated can differ greatly between applications. Especially the orientation can have a big impact on the performance during navigation tasks, where north-up and track-up represent the two most prominent ways for aligning the map.

When it comes to presenting a map the shown area plays an important role. There has to be considered a trade-off between providing an overview and details. One of the most crucial details are decision points, as Agrawala pointed out: "*For many routes, the lengths of roads can vary over several orders of magnitude, from tens of feet within a neighborhood to hundreds of miles along a highway. When a constant scale factor is used for these routes, the shorter roads shrink to a point and essentially vanish. This phenomenon is particularly problematic near the origin and destination of routes where many quick turns are often required to enter or exit a neighborhood.*" [1, p. 2].

Beside how much of the area should be shown, it also has to be questioned in which form it should be presented. All navigation systems, even beyond map-based approaches, abstract the information of the environment in some way. Depending on the objective of the navigation aid as well as the environment and means of transportation, the best balance between the level of abstraction and fidelity should be chosen. Agrawala [1] parameterized different map representations by fidelity, some of which are listed in the following list from highest to lowest fidelity:

- Photographs of the area
- Road map
- Route map in 1D
- Line map for a subway
- Turn-by-turn directions as text

So while for example turn-by-turn directions via text provide a very high abstraction, a satellite imagery of the map area on the other hand has a higher fidelity. The granularity

[2] https://www.google.at/maps
[3] https://www.apple.com/ios/maps/

of the abstraction varies not only between but even within the mentioned types. Meilinger et al. [39] for example compared the effectiveness of a floor plan with a schematic version for an indoor environment. In an experiment where participants had to locate themselves as well as navigate, they found that users looked longer on the floor plan than on the schematic map. They argued that the increased amount of information on the floor plan reduced the speed of users processing the required information for their task. It should be noted though, that in some areas the schematic map was not clear enough in regard to stairs, while the floor map provided information about the local environment which helped participants to orientate. Overall they summarized: "*We conclude that providing unambiguous turning information (route knowledge) rather than survey knowledge is most crucial for wayfinding in unknown environments.*" [39, p. 381].

North-up vs. Track-up Orientation

With the north-up approach the map is statically orientated so that the north of the map is always at the top. The track-up approach on the other hand keeps the heading of the path aligned with the top through rotation. Some studies have shown that while the north-up approach may provide a better overview, the track-up approach can lead to a better performance during navigation tasks [60].

Saeger et al. [57] compared in their study physical, automatic and manual map rotation with a north-up alignment. Participants were told to align the track-up orientation themselves when testing the physical and manual condition. Similar to other studies they found that the participants perceived the north-up approach to be difficult. Some users also found the manual map rotation to be tedious, increased their required mental workload and had to focus more on the rotation than the actual navigation task itself. Some users further mentioned that it is more easy to get lost due to the manual orientation. It should be noted though, that the opinions regarding automatic versus manual map rotation diverged among the participants. While some participants preferred to have control over the orientation, others perceived it as to big of a hassle. Overall the track-up orientation was described as easy to understand and use.

2.3.2 Text-based Navigation

Navigation aids via text are less often used standalone but are rather mixed with or integrated into other systems. Generally two forms of text-based navigation can be distinguished, where the first one is represented by instruction sets and the latter as descriptive text. While a descriptive text can be useful for a "Traditional Thinker" the instruction sets may be preferred by the "Quick Answer Thinker" [67]. It should be noted that when using text-based aid via instruction sets, the accuracy of the GPS plays a more crucial role. Users tend to rely on these instruction when offered and try to follow them. When the location is not precise the wrong instruction may be presented, which can cause the user to take a wrong turn. When using text in a descriptive way on the other hand, users plan their route themselves and thus are less prone to the negative impact of location inaccuracies [63].

One of the bigger drawbacks of text-based navigation aids is that users usually have to stop walking in order to read the text or are otherwise distracted, which can be dangerous in a pedestrian environment [18]. Thus, there are efforts to decrease the required attention of the user, especially by the use of tactile feedback or voice instruction which in some cases can remove the need of interaction altogether.

Overall, it can be concluded that text should not be the only source for navigation aid but combined with other systems. Stark et al. [63] for example recommend that a dynamic map is better suited than providing textual instructions.

2.3.3 Tactile Navigation

Even outside the context of navigation, studies have shown that using tactile feedback in addition to visual feedback can positively impact the performance of tasks, as summarized by Burke et al. [5]. Thus, it comes to no surprise that tactile feedback has also found a lot of use in navigation systems. It should be noted though that there has to be made a distinction on how tactile feedback is actually used. On the one hand it can be used as a notification in order to grab the attention of a user, but also as a mean to convey the actual navigation information itself. While in the first case the notification is not the core component but merely a supplement, as for example to a map view, in the latter case the tactical feedback can actually pose as the main component of the application.

As already mentioned, tactile feedback for navigation purposes is nowadays part of many mobile navigation systems. But it is not limited to smartphone or smartwatch supported navigations aids. Pielot et al. [46] for example conducted a study with the use of a paper map in combination with a tactile belt, which is capable of producing vibrations at different locations with varying strength. Depending on the current heading of the user and the direction they should walk, the belt vibrates with a certain strength at the particular direction angle as visualized in figure 2.2.

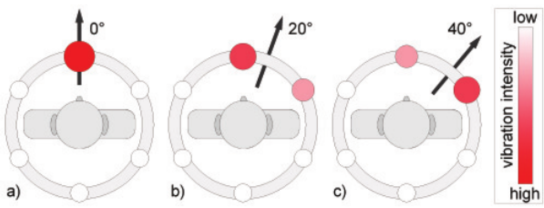


Figure 2.2: Belt with vibrations depending on direction (from [46, p. 3, figure 4])

In the study they compared the use of a paper map with the use of a paper map plus the mentioned tactile belt in regard to a navigation task. They hoped that the additional assistance of the tactile cues via the belt would ease the navigation for the user. By conducting a field trial they found that the tactile feedback gave users additional reassurance about their path and users had to check the provided map less often.

Bosman et al. [4] created a prototype named GentleGuide which uses haptic output as the mean for pedestrian navigation aid in indoor environments. This prototype consists of two devices which are worn on each wrist. A vibration on the left or right wrist indicates the user to go in that particular direction, while vibrations on both devices simultaneously with different length notified about reaching the destination or taking a wrong turn. They found that users perceived the prototype as positive and thus they concluded that the approach of using haptic feedback is promising, though the loss of orientation has been a mentioned concern.

Vi-Bros also employs a non-visual approach by providing an interface with sole tactical feedback [34]. In comparison to GentleGuide they didn't want to artificially add an extra physical device, like for example by using two smartwatches. Accordingly, they chose to use a smartphone in combination with a smartwatch which is a combination that can be considered a plausible possession of a user. The user carries the smartwatch on the left hand and holds the smartphone in the left hand. These positions were chosen since their first experiment showed the most promise for this combination. Furthermore different vibration patterns for left and right convey the navigation instructions. A field test was conducted by the use of the "Wizard of Oz technique" which compared Vi-Bros with a commercial visual navigation application in an indoor environment. While the participants found Vi-Bros intuitive, they were less confident regarding the route and had problems with estimating the remaining distance to their destination. Although the lack of confidence might be a problem that has to be considered, users perceived the tactile feedback easier to use than checking the visual map.

Dobbelstein et al. [11] go even further with tactile feedback as a mean for navigation. They proposed a prototype which uses vibro-tactile feedback via a smartwatch coupled with a wristband which contains four embedded motors capable of generating vibrations. Furthermore, the route is not pre-defined but just conveys a sense of direction the user has to walk. This system allows users to explore the area on their own will, while still maintaining a navigation destination. In the conducted experiment which consisted of a navigation task all participants were able to find the destination without the help from the instructor. They found that users had no problems in identifying the general direction and the vibrations represented a continuous reassurance, though exact angles were difficult to convey and sometimes vibrations were missed.

While until now only navigation systems have been presented which use tactile feedback to lead the user in a direction or notify the user about a decision point, vibrations can also be used in other ways during the navigation. Chippendale et al. [7] for example developed a prototype for visually impaired people in an indoor environment which vibrates in order to warn the user of a wet floor. It should be noted though that too many vibration patterns for numerous distinctive events might increase the learning curve of a user or make them difficult to distinguish.

Generally it can be said that the two most prominent ways to use tactile feedback are as a cue to notify the user that a decision is required for example at a turning point or to convey the information of the instruction itself. Studies have shown that using tactile feedback for pedestrian navigation can be a viable solution which reduces the amount of required interaction and reduces the level of distraction [47]. Though, there are also some downsides when using tactile feedback as the sole means of navigation. Depending on the system users missing the tactile feedback or misinterpreting the information can be of great concern since they have to rely on these instructions. There are some countermeasures which can be applied, as for example introducing certain patterns for different directions as well as adding preamble tactile feedback in order to provide the user with more assurance about the source of the feedback [34]. These additions however enhance one further disadvantage, namely that users have to learn these patterns in the first place.

So there is clearly a trade-off to be made, which should especially be looked up-on when tactile feedback is the sole source of navigation information. On the other hand adding simple tactile cues as secondary information or just as notifications seems to inherit less of these mentioned downsides, though users might have to check the primal source of information more often.

2.3.4 Voice Navigation

Similar to tactile feedback voice can be used in addition to other systems like map-based navigation, but can also be used standalone for navigation aid. Opposite to tactile feedback voice is able to convey more information naturally without the need of users to learn patterns. So while voice can work in a more precise way when instructing the user, the semantics and exact wording of the played voice holds a very important role.

Rehrl et al. [51] compared in their research metric and landmark-based instructions for voice guidance via a field study where participants used both systems. While they could not find any significant differences in walking times when comparing both instruction sets, the landmark instruction performed better regarding the error rate. Overall they found that navigation via voice-only showed a positive effectiveness regarding the navigation task, though it should be mentioned that they did not use the actual location of the user to trigger the voice instruction but triggered them manually. Since the correct timing and location for voice commands is very important the experience might differ if the GPS is not working very accurately.

In a further experiment, a map, voice and augmented-reality based smartphone application were compared against each other in the context of pedestrian navigation [52]. Results showed that while the augmented reality variant didn't work that well, the voice based application represented a viable form of passing navigation information to the user. One inherent problem of voice-based navigation, as mentioned earlier, is that the GPS has to work continuously since the user has to be informed about intersections at the correct location. This problem has been dealt with by using sensitive-areas around the coordinates of decision points. Overall they found that the map-based as well as voice-only navigation worked very well and users were familiar with both systems, which was also supported by the qualitative results they received by conducting a NASA-TLX and a questionnaire. Contrary to that, Goodman et al. [18] found that voice-only guidance does not work very well for older people, but should be mixed with other navigation aids.

2.3.5 Augmented Reality

Augmented reality is the most recent of the mentioned technologies and while not very popular as consumer products yet, it is getting increased focus in research for all different kinds of applications, where some researchers also predict a future for augmented reality in cartography [56]. That being said, the advancement of smartphones with bigger screens and more processing power in recent years allowed augmented reality to run not only on computers but also on smartphones. In contrast to virtual reality, augmented reality provides the view of the real-world environment enhanced with augmented components whose characteristics can depend on inputs of sensors. Thus, in the application of navigation systems augmented reality can be used to extend the view of the user by adding virtual information. Virtual reality on the other hand provides an artificial environment the user can interact with, which due to its nature seems less viable for navigation tasks in real world environments.

As already mentioned earlier Rehrl et al. [52] compared a map-based, voice-only and augmented reality approach for navigation via a smartphone. For the augmented reality version they provided the user with an AR view which rendered depending on the user's location as well as the bearing of the user, as illustrated in figure 2.3.

Figure 2.3: AR interface on smartphone (from [52, p. 82, figure 2-B])

They used a concept called "follow-me" which utilizes a virtual path represented by a green line as shown in figure 2.3. Results of the user study showed that augmented reality performed significantly worse than the voice-only and map-based approaches in regard to the required duration as well as in the NASA-TLX. One big issue that has been discovered is the actual handling of the smartphone during the navigation task. Since users were required to hold the smartphone into the air and look though it, they were less aware of their environment and thus more prone to stumble. The handling also increased the required task load of users. They also found that the 3D view of the augmented reality approach was very prone to location inaccuracies, which can hardly be prevented by commercial tools due to the nature of the GPS. In their conclusion they noted that: "*To summarise, although AR technology is ready to be used as interface for pedestrian navigation applications on smartphones, the technology is still suffering from* *usability and hardware problems leading to higher uncertainty of navigating persons.*" [52, p. 93].

The required accuracy was also mentioned by Kluge et al. [28], who referred to it as a key role for future advances of AR in the navigation sector. They also developed a prototype for pedestrian navigation with the use of augmented reality view next to a map-based view and landmarks as a further aid. An eye tracker allowed them to collect data about the use of the two approaches. They found that while the map-based view was used more frequently between two decision points, the AR view saw heavier use at decision points themselves. They concluded that "*[...] the AR display provides the user a more detailed navigation at decision points whereas the map display allows a better overview.*" [28, p. 393]. Furthermore, they identified that landmarks helped users to orientate themselves with less effort.

2.4 Navigation via Smartwatches

Smartwatches are often used as an extension to the smartphone. This holds also true for the purpose of navigation. SubwayPS, a positioning system specialized in underground navigation, provides additional information like the current or next station as well as the estimated time of arrival [64] via a smartwatch. Another example is a shopping assistant for visually impaired people where the smartwatch vibrates in case of a wet floor [7]. The already discussed interface Vi-Bros also makes use of a smartwatch in combination with a smartphone, in order to convey information about directions via tactile feedback [34].

Stainsby [62] also conducted an experiment in order to evaluate if adding a smartwatch to a smartphone for pedestrian navigation makes the navigation easier. In his work he developed an application for a smartwatch which shows a map as well as the user's location and the path. The results of a field trial showed no significant difference in regard to the walking duration when adding a smartwatch. Stainsby found that the screen of the smartwatch was too small and the brightness not sufficient enough for an outdoor environment, which made the map hard to read and thus reduced users' satisfaction.

So while the results of the use of a smartwatch as a companion to a smartphone for navigation aid vary, there seems to exist a use case for it. In the following, navigation systems which mostly rely on the smartwatch for wayfinding are discussed.

Kerber et al. [26] proposed a navigation system for the smartwatch called EdgeTouch which tries to overcome the already mentioned "fat-finger problem" induced by the small screen size. In their research they compared a static peephole map application with a dynamic one. In the static peephole map application the user is able to interact with the map via direct touch inputs, while in the dynamic approach users are capable of scrolling the area by moving the arm which prevents the screen from being covered by the interactions. In an experiment they compared these two solutions by letting participants search for parking lots on a map. While they did not find any significant differences in the error rate or in the conducted NASA-TLX between the two applications, the task completion time was slower when using the dynamic peephole application. Thus they concluded that in contrast to their hypothesis the dynamic peephole application provides a significantly worse performance at least in regard to the completion time. They argued that the reasons for these results could on the one hand be based on the reduced interaction possibilities allowed by arm movements in comparison to direct touch inputs and on the other hand on the overshooting of the target when using the dynamic peephole application.

Another approach is to use the existent screen size as much as possible instead of increasing it artificially. This can be accomplished by presenting the map in a way that it fully utilizes the available space, as for example Wenig et al. [68] did with their prototype named StripeMaps. Instead of letting the user rotate the map, StripeMaps transforms the map into a one-dimensional stripe, which is accomplished by folding the map at the intersection points and letting the route always bear to the top of the screen. The application also allows the user to scroll ahead. In their study, which compared the developed StripeMaps with and without an orientation indicator as well as a 2D-map and turn-by-turn instructions in an indoor navigation scenario, they found that StripeMaps required less walking duration than the other solutions and participants rated StripeMaps better in the NASA-TLX as well as in the SUS. They concluded that linearizing the 2D-map into a 1D-map can provide benefits for pedestrians in regard to pure map navigation, though it has yet to be researched how viable it is for orientation.

A further example for indoor navigation via a smartwatch can be found in the work of Wenig et al. [69]. They developed a concept called ScrollingHome which represents an image-based navigation aid. In the application users are able to vertically scroll through images which show their route. These images show the environment from a first person view and are in a second prototype further augmented with a 3D visualization of the path. In their evaluation they compared their developed prototypes with StripeMaps. They found that the image-based approach is capable of performing better than StripeMaps regarding the walking duration. While ScrollingHome worked very well for indoor navigation, they mentioned that users becoming lost can be a problem. They concluded that for the purpose of orientation a map-based approach might be a better aid.

As a last example for a smartwatch-based navigation aid, the concept of McGookin et al. [38] shall be discussed. In their work they propose a design for a navigation aid for runners. Strictly speaking their study is not concerned with navigation in the context of wayfinding since there is no destination or pre-defined route and thus they refer to it as "undirected navigation". Their concept called RunNav consists of a colored segmented circle shown on a smartwatch, where the color of each individual segment represents how viable this area may be for a runner. Based on this information, runners are able to decide in which direction to go next for the most pleasant running environment.

2.5 Summary

While there can be found a lot of research about navigation, wayfinding via a smartwatch is due to its novelty not that well studied. There especially seems to exist a research gap regarding the design as well as the viability of landmarks for smartwatch-based pedestrian navigation systems. That being said, many findings of similar fields like smartphone-based navigation seem to be applicable to smartwatches as well, though some considerations regarding the limited size and interactions have to be taken into account. The choice of a suitable aid depends highly on the environment, means of transportation and situation, but also varies amongst users. So while map-based navigation is one of the most prominent ones, it may not be the best in a certain situation. Many navigation systems also mix different approaches, for example by adding tactile feedback in form of vibrations or instructions via voice. One aspect of navigation, which can be found among most types of navigation, is the importance of decision points and how navigation system help users at these locations. An approach that can aid at these decision points are landmarks which have been proven to increase the confidence of users. It should be noted that while landmarks are often centered around decision points, they can also be used along the route to reassure users about their path. When using landmarks the selection of such as well as when to show them to the user has to be considered carefully. Though, as already discussed, guidelines and methods were developed which help to choose and identify viable landmarks.

CHAPTER 3

Methodological Approach

This chapter discusses the methods and tasks which have been performed for the master's thesis. The first step is represented by the literature review with the goal to research the current state of research on pedestrian navigation with a focus on navigation via electronic devices. While this master's thesis is concerned with pedestrian navigation via a smartwatch, due to its novelty, other kind of navigation aids have to be explored as well. Navigation via smartphones is of special interest since it is rather well researched and due to the similar screen sizes shares a lot of the advantages and disadvantages with smartwatches. Therefore many concepts of navigation aid for smartphones could be considered viable in the context of smartwatches as well and easier adopted to smartwatches than for example navigation aids for computers. It should also be noted that there is no initial bias during the literature review towards a certain navigation concept in order to broaden the understanding of possibilities as much as possible.

The literature review is followed by a concept study where mockups for pedestrian navigation via a smartwatch are created in order to test different user interfaces and interactions. The concept study follows a user-centered design approach and aims to receive qualitative feedback about the developed concepts in order to gather a foundation for the final designs. Thus, the concepts are tested with participants in a field trial and qualitative interviews are conducted. The participants are recruited from the author's personal group of peers in the proximity of the location of the executed field trial. While the interviews are conducted in German or English, depending on the preference of the participant, quotes in this thesis are always translated to English by the author.

Based on the outcome and findings of this user study as well as the literature review the final prototypes are designed and implemented as applications for an Android smartwatch. The prototypes are tested in a real world environment by participants, who have to navigate along given routes. In order to gather information about the self-reported sense of direction of the users a SBSOD is conducted. During the navigation task data like the required time and amount of usage of the smartwatch are measured. Furthermore, a semi-structured interview as well as a NASA-RTLX are conducted in order to obtain feedback about the prototypes and the perceived workload of participants. The collected information is finally used to evaluate the prototypes and their viability. When testing for significant results, for example differences between the prototypes, the appropriate statistical methods are used for each case and the outcome is presented.

The following list provides a simplified overview in chronological order of the applied tasks:

1. **Literature Review**
   In order to form a sound basis for the latter methods a literature review is conducted.
2. **Initial Concepts**
   Based on the literature review concepts are developed and mockups created.
3. **Concept Study**
   The mockups are used in a field trial in which participants have to navigate along routes.
4. **Final Design**
   On the basis of the concept study the designs are finalized.
5. **Implementation**
   The final designs from the previous step are implemented as applications for a smartwatch.
6. **Evaluation**
   In order to identify the viability of the prototypes users navigate along routes with the assistance of the developed prototypes. Furthermore, assessments and interviews are conducted.
7. **Critical reflection**
   The data and feedback which are collected during the evaluation are analyzed and discussed.

CHAPTER 4

Concept Study

The main object of the concept study is to develop concepts, evaluate them in a field trial and use the feedback to further improve them. In the following, the basic concept for a smartwatch-based navigation aid is proposed. Deviates of this concept are then tested during a field trial. The last sections contain the findings of this evaluation as well as the proposed final designs.

4.1 Concept

Based on the literature review, a concept has been developed. The concept can be described as a combination of a map view and a direction view, which is further enhanced by the use of vibrations and landmarks. While the mixture of a map view and direction view on the one hand ensures an overview, on the other hand it also provides more detailed information about decision points. Furthermore, landmarks are embedded in both kinds of views, so that users can relate to objects in the real world and thus are able to easier identify decision points. In order to notify users that they soon have to turn tactile feedback via vibrations is used. In the following, the aforementioned components are presented in more detail.

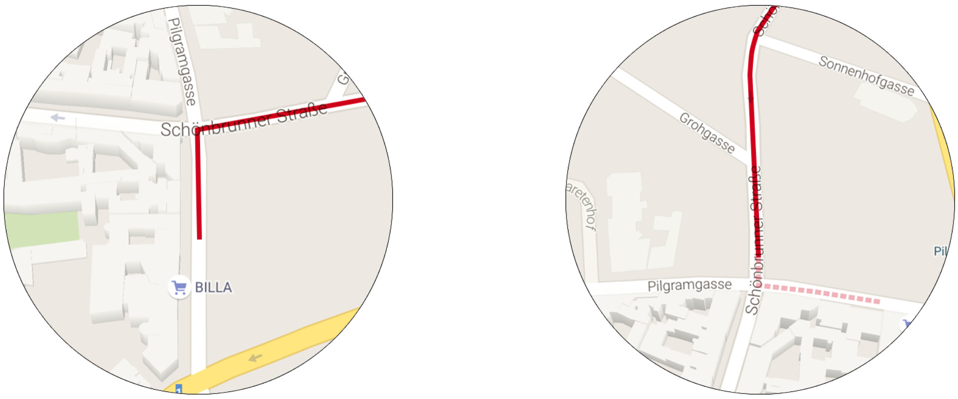
4.1.1 Map View

Despite the screen restrictions, a map should still be available to the user. While a map requires a lot of space and thus may be abandoned due to the small screen of the smartwatch, studies suggest that maps can help users to orientate themselves [69]. Since staying on the correct route and the assurance of users during the navigation are one of the most important aspects of a navigation aid, having a map seems crucial even for a smartwatch-based navigation system. Beside the environment, the map also shows the current location as well as the route in form of a colored line.

While smartphones and computers allow a high amount of map interaction, due to the limited size of a smartwatch scrolling and zooming are not supported. The use of several buttons can also not be considered feasible on such a small screen. This implicates that the zoom has to be picked very carefully, dependent on the distance to the next decision point.

North-up vs. Track-up

Generally there are two prominent ways to orientate the map. The first one consists of the north-up orientation, where the next path segment is always aligned to the top. This behavior is illustrated in figure 4.1. The second orientation mode is north-up, where north is always located at the top of the screen.



(a) Orientation before turn.

(b) Orientation after turn.

Figure 4.1: Examples for track-up behavior which aligns the next path segment to the top.

Studies have shown that while north-up provides a better overview, track-up leads to a better navigation performance [60]. Whereas this would suggest to use track-up for a smartwatch-based navigation aid, the preference of orientation will be evaluated by testing both orientations in the field trial.

4.1.2 Direction View

The importance of decision points for navigation can be found in various researches and thus a direction view further supports users at these critical locations [27]. According to Wen et al. [67] it can be very beneficial to provide minimized information for certain user groups. Thus, while the aforementioned map view provides an overview of the environment, a direction view gives quick access to information about the next turn direction.

The direction view is located at the bottom of the screen and takes about 20% to 32% of the available screen height, dependent on the visualization and amount of information shown. It provides information about the distance between the current location and the next turn, the turn direction, as well as a landmark, if appropriate. While the distance is shown in textual form, the turn direction is represented by an arrow. The arrow uses an 8-sector model, where 7 directions can be used for providing route directions, while the 8th is used as the reference direction, as proposed by Klippel [27]. Each sector and thus corresponding line represents a slice of 45°. Figure 4.2 illustrates all possible variants of the arrow.

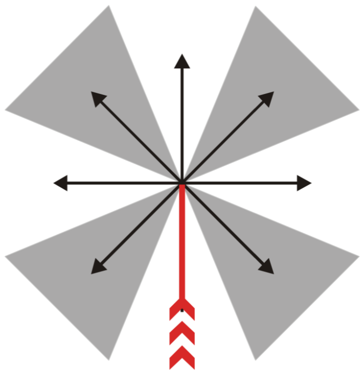


Figure 4.2: 8-direction model for arrow visualization. (from [27, p. 113, figure 53])

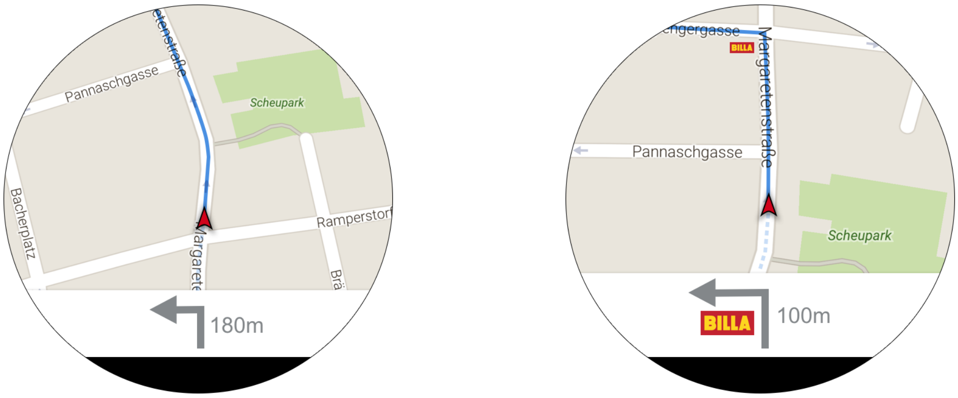
4.1.3 Landmarks

As studies have shown, landmarks can provide a benefit to users during the navigation [51]. Therefore landmarks are embedded in the map as well as in the direction view, if reasonable.

It should be noted that only landmarks are selected and chosen which are in the proximity of decision points. While landmarks along routes could potentially help to reassure users about their path, the relation to the decision point would get lost. This could confuse users when identifying where exactly along the route the presented landmark should occur, which might lead to users not finding certain landmarks.

Landmarks are only shown when the user is capable of seeing them. Thus, a landmark may become visible on the smartwatch when the user progresses along the route and comes in its proximity. Furthermore a landmark is only used when there is no other landmark which could be confused with the used one. The adoption of the direction view in regard to the distance is illustrated in figure 4.3. Although showing a landmark long before it is visible to the user could potentially reduce the number of times the user has to take a look onto the smartwatch, the cases in which a user may get confused, because he or she cannot spot the landmark quick enough, or that there are similar landmarks beforehand which provoke a wrong turn, have to be considered.

The visualization of the landmark plays a very important role since the user has to match it with the object in the real world. If this match fails, the user cannot use



(a) User is far away - landmark is not shown. (b) User is close - landmark is shown.

Figure 4.3: Adaption of the visibility of landmarks to the distance. The landmark becomes visible as the user comes closer.

	Image	**Drawing**	**Sketch**	**Icon**	**Symbol**	**Words**
Shop (Name)			(+)	+		
Shop (Type)				+	+	+
Function/Name	+	+	+			+
Visual Aspect	+	+				

Table 4.1: Design proposals for landmarks (based on [13, p. 13, table 3])

the landmark for the purpose of navigation, or worse, may make a false decision on its basis. The representation of the landmarks is based on the research of Elias et. al [13] which distinguishes landmark buildings into four different categories. The first category represents shops which are referenced by their trade name while the second category contains shops which are referenced by the type of their function. The third and fourth category comprehend buildings which are described by their general function or their outstanding visual aspects, respectively. Furthermore, design proposals are provided for landmarks for each category, as shown in table 4.1.

The same visualization of a landmark is used in the map view and the direction view so that the user is able to match them against each other, though the landmarks in the direction view will be bigger in order to make them more identifiable.

Yet another important aspect is the positioning of the landmark in the direction view. In order to make the landmark referable for the user, the position of the object in the real world, the landmark in the map view and the landmark in the direction view have to match each other. In the case of the direction view, this means that the position of the landmark needs to be in a certain relation with the position of the arrow. For example, if the next path segment has a right turn with a shop on the right side before that turn, the landmark has to be placed to the right and below the turning point of the arrow.

Further examples of the landmark positioning are illustrated in figure 4.4.

(a) Landmark left. (b) Landmark top. (c) Landmark right.

Figure 4.4: Visualization of landmarks according to their positioning in the environment.

It has to be mentioned that landmarks should not be used at all costs, but rather when they provide a meaningful benefit to the user. Showing landmarks which are hardly recognizable or findable in the real world would not only represent unnecessary but potentially misleading information.

4.1.4 Vibrations

Vibrations are used as notification, in order to grab the attention of the user for certain events which require an action on the user's end. These events include reaching the destination and getting close to a decision point.

Many navigation systems use tactile feedback in order to also convey the direction [34]. Thus it could be considered to use different patterns for directions at decision points, one for turning left and one for turning right. The benefit of this approach would be that users potentially don't need to check the smartwatch at a decision point. However, in this case it would be very important that those patterns cannot be confused with each other, since this would cause the user to make a wrong turn. That being said, the idea of using different patterns for turning directions is discarded. While there certainly could be benefits gained, the possibility of users relying on this feedback but missing or misinterpreting some vibrations resulting in less confidence in the overall system is considered too high.

4.2 Test Routes and Mockup Applications

Two mockup applications were implemented for a smartwatch which differ in the orientation of the map where the first one uses track-up and the second one north-up orientation. Furthermore, the track-up application shows a map which is tilted by 20°.

Since only the user-interface should be tested, influences from sensors should be nullified and the prototypes should be created in a feasible time frame, mockup images were used instead of a live map view. For each concept a route was chosen and mockups were prepared. The route for the track-up concept starts at Pilgramgasse 17, 1050 Vienna and ends at Schwarzhorngasse 9-11, 1050 Vienna, while the route for the north-up concept starts at Schwarzhorngasse 9-11 and ends at Emil-Krakil-Gasse 4-6. The most important criterion for the selection of the routes was to have two very similar routes, so that the approaches could be compared with each other without too much influence from the differences between the routes. Both routes are about the same length of one kilometer and an expected walk duration of 12 minutes each. The first route has five turns while the second route has six. Both routes have turns with equally good landmarks close-by and one turn each without a landmark. For the applications 13, respectively 16 mockup-images were prepared. For each path segment an image at the start and at the end were chosen. For longer path segments additional images for in between were added.

(a) Route for track-up oriented application.

(b) Route for north-up oriented application.

Figure 4.5: Routes of the concept study.

Furthermore, an application for a smartphone was developed. The smartphone application contains buttons which allow the instructor to switch between the images. It also provides a synchronization indicator which informs the researcher, if the change of the selected image has been received by the smartwatch application. The smartwatch application itself mostly consists of an array of images, where only one image is shown at a time. The smartwatch listens to the smartphone application in order to determine which image should be shown to the user and depending on the image if a vibration has to be performed.

The location from the GPS, which would normally be required to update the information on the smartwatch, is replaced by mocking it via manual signals evoked by the researcher on certain key locations which have a correlation with the mockup images used. Since static images are used, the prototypes do not contain a live compass.

Due to the nature of the prototypes, there are some limitations which have to be taken into account when evaluating the user feedback. Since static images are used, the screen may not update as often when compared to using a live map view, dependent on the amount of mockups created and used. Thus, the participants may observe that their position is farther before or behind their actual position. Furthermore, since there is no live compass, participants may find it harder to orientate themselves. Also there is no handling for the case that a user takes a wrong turn.

4.3 Experimental Design

The main objective of the concept study is to gather feedback early on, so that problems can be found and addressed and improvements be made before the actual implementation phase. Therefore, a *"Wizard of Oz experiment"* is conducted where mockups are presented to the user on a smartwatch and exchanged at certain locations. Thus, it is not required to fully implement prototypes, while users still perceive the experiment as very real.

Two deviates of the proposed concept are evaluated, which only differ in the orientation of the map. The first one uses track-up orientation which automatically aligns the upcoming path to the top of the screen. The second one uses north-up orientation where the north is always located at the top of the screen. For each of the two deviates a route is assigned, where the track-up orientation is used on the first route and the north-up orientation on the second route. Testing both approaches next to each other allows to compare the advantages and disadvantages against each other. Furthermore, the preference of users can be easier identified by the means of comparison.

The experiment is conducted with six participants separately and consists of the following three procedures:

1. The first procedure represents a short recorded interview in which the participant is asked questions about the current knowledge and usage of navigation systems in general as well as particular in regard to smartwatches.

2. Afterwards, the second procedure takes place during which the participant is lead to the starting point of the first route where the prototype with the track-up orientation is used. A short introduction of the smartwatch itself and the prototype application is conducted and the smartwatch with the pre-installed prototype application is given to the participant. During the navigation task the participant receives no hints and the instructor walks behind the participant so that there can be no guidance of any kind. There are no questions asked during the navigation task in order to not distract the participant. If the participant takes a wrong turn or misses a turn, he or she will be informed. When the participant reaches certain locations the instructor switches to the next image on the smartphone, which instructs the smartwatch of the participant to show that image and depending on the image a vibration is triggered. Between the first and the second route a short break will be taken so that the participant can rest and be informed about the next

prototype. After the break the navigation is continued on the second route where the prototype with the north-up orientation is used. When the participant reaches the destination of the second route the navigation task is complete.

3. The third procedure consists of the concluding interview which is recorded, where the participant is asked questions about the performed navigation task. It should be identified, if there were any kind of problems, what the participant liked or disliked, how the prototype applications were used, which of the approaches of the prototypes he or she preferred, how the combination of map and direction view was perceived, if the landmarks were beneficial, if the task was mentally wearisome and if there are some improvements the participant would like to see.

4.4 Findings

In this section the results and evaluation of the performed experiment will be introduced. The findings are broken down into certain aspects and issues, which were raised during the concept study. As the qualitative interviews can provide detailed insights into the navigation process via a smartwatch, the findings are used to alter and improve the designs appropriately.

4.4.1 Combination of Map View and Direction View

While the way in which the two prototype applications were used by the participants varied a lot, the combination of the map view with the direction view at the bottom was well received by all participants. Whereas one participant mainly used the map itself for the navigation, most participant relied heavily on the direction view regardless which of the two prototypes was used. The time required for both routes combined spanned from about 19 to 25 minutes which matches the expected time frame.

Since no meaningful issues regarding the overall application itself could be found, the basic concept of containing a map view and a direction view will not be altered in the final design.

4.4.2 Track-up and North-up Prototypes

The preferred prototype varied between the participants. While most participants agreed that the track-up prototype may be the better one for navigation, one participant didn't particularly care, because he just used the direction view, and two other participants preferred the north-up prototype because that's how they also navigate via their smartphones. Though, both mentioned that the track-up version may be better for most other users.

Due to the preferences and statements of the participants the prototypes will be narrowed down to the track-up version, since it seems to work better for navigation. While the north-up orientation has its benefits, especially for users which like to have more control and want to navigate by themselves rather than be fully guided by a navigation system, it doesn't fit well in the context of navigating with a smartwatch, where the presentational and interactional possibilities are highly limited. Due to the small screen size of the smartwatch it may be a better approach to let the smartwatch handle the guidance and provide the user only with the information that is required at each moment, without burdening the user with mental rotations of a small part of the route. The preference of users to have the map aligned to their direction was not only the general feedback from the concept study, but has also been discovered by other researchers, as for example Gartner et al. [16]. Furthermore, one could argue that there is a discrepancy between a north-up map view and the direction view which shows directions in a track-up manner. It should be noted though, that if a smartwatch application aims to provide a map for exploration instead of navigation the north-up approach might be very feasible.

4.4.3 Landmarks

The integration of landmarks in the map view and the direction view was generally perceived as a benefit for the navigation.

- While most participants used the landmarks heavily, some concentrated more on the vibrations or street names. Overall participants favored landmarks over street names.

- All participants found the visualization of the landmarks pleasant, but two participants had problems identifying one particular lettering.

- One participant found it misleading that one certain landmark was shown in the direction view while the landmark was located far before the actual turn. Four participants thought it was better to show landmarks only when they were also visible to them, while two would have liked to see landmarks on the smartwatch even before they are visible to them in reality, so that they wouldn't have to check the smartwatch again before the decision point. One participant brought up that showing landmarks when not already visible may be irritating, in particular if there are several landmarks of the same type before the intersection.

Because most participants used the landmarks a lot and deemed them very useful, they will be kept in the ongoing development. However, landmarks should only be presented to the user when they are located in the proximity of a decision point and when they are visible to users in order to provide meaningful expectations and prevent any confusion. Still, the visualization of landmarks has to be determined from case to case. It is important to choose a visualization which provides recognizability while still maintaining consistency across different kinds of landmarks.

4.4.4 Overview and Interaction

Every participant mentioned that an overview of the whole route would be a necessity for them, though some mentioned that it might be sufficient to have an overview on the smartphone which can be checked when planning the route and then using the smartwatch from there on. Some participants also said that they would like to be able to scroll and zoom, mostly because they are accustomed to that feature from their smartphones. One participant mentioned that while she expected to be able to scroll, it appeared not to be necessary for the navigation itself. The tilting used in the track-up prototype was not noticed by any participant but one, who felt positive about it, but also mentioned that it may cost some overview.

The feedback suggests that the smartwatch should also provide an overview of the route which contains the area between the start and end location. This might not only reassure the user of the correct route, but also help estimate distances. While some users expected to be able to scroll and zoom, it seems to not be required for the purpose of navigation and introduces new problems due to the screen size. Furthermore, the introduction of an additional overview might already constitute a sufficient replacement for a zoom functionality. Thus, while an overview will be added, scrolling and zooming won't be supported in the final designs.

4.4.5 Vibrations

The vibrations at decision points were perceived as very useful. One participant in particular merely looked onto the smartwatch by remembering the next direction at the start of each path segment and using the vibrations as the sole indicator to turn at decision points. It should be noted that this participant missed the last turn, since he did not notice the corresponding vibration. Two participants indicated that it would be nice if one could navigate just via vibrations without looking onto the smartwatch at all, but one of them also mentioned that he would not want to rely on vibrations for turn instructions.

While it seems tempting to provide a system which relies heavily on vibrations for direction communication, it has to be considered that the vibration patterns for the directions would have to be very diverse in order to be differentiable by the user, since otherwise the error rate and thus uncertainty may rise. Users would furthermore be required to learn different patterns for different directions in order to use such a system.

4.4.6 First Path Segment

The first path segment of each route represented the greatest struggle for most participants, since they had to take their time to find out in which direction they have to go. Some participants mentioned that some kind of compass which indicates their bearing would be helpful.

The required time and confusion by the participants when starting the first path segment as well as their statements coincides with the assumption that a bearing indicator has to be shown. The heading of the user shall therefore be represented by an arrow at the current location of the user in the map view. Thus, the user can relate the current bearing to the direction of the path he or she has to take.

4.5 Final Design

As a result of the findings from the concept study, two final designs are proposed which comprehend the required features and user interface. The designs are based on the previously created prototypes, the gathered feedback, as well as the literature review. While some aspects have already been discussed in great detail in the initial concept, this section provides an overview of the final outcome.

The core concept of the smartwatch applications is based on the combination of a map view and a direction view. While the map view provides an overview of the area, the direction view features the most important information at the current location. The goal of this approach is to combine the benefits of both views, where the map view gives the user a sense of environmental awareness and consistency, while the direction view offers simple and easy to comprehend instructions regarding navigation. Although it may seem counterintuitive to reduce the available space of the map view for the direction view, the goal is that the user does not heavily rely on the map view, but rather just uses it as a means of reinsurance. Wood et al. [72] for example conducted a study with different map sizes and recommended a minimum size of 9° which is about equal to 7cm at a distance of 45cm. Since the map size is limited by the smartwatch and thus cannot be increased, the presented approach tries to diminish the disadvantage by moving the focus of the navigation from the map to the direction view, which is less burdened by the size restrictions of a smartwatch. Furthermore, the map view uses a track-up approach which aligns the currently relevant path segment always to the top of the map. This will be discussed in more detail in section 4.5.1.

The two approaches covered in the following sections distinguish themselves mainly by the use of landmarks as well as the indication for subsequent turns. While the basic approach also has the map and direction view, the advanced approach is enhanced by the use of landmarks and an advanced turn indicator.

4.5.1 Basic approach

The basic approach consists of the map view, the direction view, vibration for notifications as well as an overview of the route and information about the arrival time. These components are explained in more detail in the following sections.

Map View

The map view contains a topographic map and also includes the route from the start until the end location. The path behind the user has a different color, in order to distinguish it from the path the user still has to follow. The location of the user which is received by GPS, is represented by a triangle which also indicates the bearing of the user. The visualized bearing allows the user to relate his or her direction to the direction of the path, which helps with orientation, especially when starting a path or on complex intersections. Furthermore, in case of the second prototype a landmark is shown when appropriate.

The map uses track-up orientation, where the next path segment is always aligned to the top of the screen. The map is rotated automatically and thus no user interaction is required. This behavior also works very well combined with the direction view which inherently uses a similar system, since the shown direction is based on the turning point of the path segment and not on a cardinal direction or the bearing of the user. Thus, from the user's perspective the turn direction of the arrow matches with the turn direction of the path on the map at the decision point. For example, if the direction view presents a left pointing arrow, it is ensured that on the intersection the path on the map also takes its course to the left. It should be noted that with the north-up approach this would not be the case in some situations, since the path segment could for example aim to the bottom of the screen and the turn direction of the arrow and the path on the map would be reversed to each other.

One important aspect is that the default zoom of the map has to be picked very carefully. While a high zoom shows more details of the map, a low zoom provides a better overview of the path. In most cases it is desirable to choose a zoom which shows the path until the next decision point. If the path is very long though, the selected zoom may become a burden by obfuscating too many details and thus should be higher. If the user is very close to a decision point on the other hand, a defined maximum zoom should be used in order to prevent the map from zooming in too much.

Direction View

The direction view is located at the bottom of the screen with a height of about 20% to 32% of the available screen height. The actual height of the direction view is dependent on the information that needs to be shown at a certain location and the resulting visualization of its components. An arrow indicates the next turn direction the user has to take. Beside the arrow the distance until the next decision point is displayed. In addition to the previously tested concepts the street name is shown as well. If the street name is too long to be displayed, it should be shortened by punctuations. In case of the second prototype a landmark is displayed if available.

As mentioned beforehand, because the direction view reduces the space of the map view, its size should be chosen very carefully, otherwise the map view may become to small to be helpful for the user. Thus, the direction view should be as minimalistic as feasible, while still maintaining a viable representation of the required information.

Overview and Arrival Information

The application consists of three pages which can be switched by the user via swiping. While the first page represents the main screen which contains the map and direction view, the second page displays an overview of the route. The third page displays the addresses of the start and destination as well as the estimated arrival time.

Interaction

Due to the small touch area any form of interaction should be very limited. Thus, the only interaction supported by the prototypes is the swiping between the pages as described above. Users are not able to zoom or scroll and therefore any map transformations have to be performed automatically.

Notifications

In order to notify users about upcoming decision points as well as the destination tactile feedback in form of vibrations is used. 40 meters before each decision point and the destination a one second long vibration is triggered.

4.5.2 Advanced approach

The advanced approach contains all functions and behaviors of the basic approach, but adds landmarks to the map and direction view. Furthermore, non-subsequent turns are indicated differently than subsequent turns in order to further help users identify decision points.

Landmarks

As mentioned in section 4.5.1, the map view and direction view present a landmark when appropriate. If a landmark should be shown depends on several factors. First of all, only landmarks near decision points shall be considered which can also be feasible coupled with turn instructions. While landmarks along paths may be useful as well, their location on the route is difficult to communicate, which may confuse users when they are not able to find them. For the same reason, a landmark should only be shown when the user is capable of seeing it. This means that in some circumstances a landmark is not presented until the user gets closer to the decision point.

In order to make the landmark identifiable for the user the position of the landmark in the map view and direction view has to relate to the location of the object in the real world. If for example the landmark is on the right side of the street, the presented landmark in the direction view is also positioned right to the arrow.

For the visualization of the landmark the recognizability has to be taken into account. If the landmark offers a strong trademark, the logo may be used. Otherwise a symbol which represents the function of the landmark might be considered a better representation.

Subsequent turns

In order to ease the decision of a user if a turn has to be made, subsequent and non-subsequent turns are distinguished. If the next turn on the way is not part of the designated path, the arrow in the direction view is dotted. If in the other case the next turn should be taken by the user, the arrow is filled.

CHAPTER 5

Implementation

This chapter will cover the implementation of the prototypes which are based on the findings of the previous chapter. While the main focus is concerned with the design and functionality of the prototypes, the basic structure and some important aspects of the implementation will be presented as well. Android Wear[1] is chosen as the operating system due to the availability of two Android smartwatches. The minimum Android API level is set to be 22. While a high Android API level is beneficial for the development, since new Android features can be used, the downside of limiting the eligible devices does not matter for this thesis since the users will be provided with the smartwatch during the field trial. It should be noted that in principle the design concepts work for other operating systems like iOS as well, though the design and interaction guidelines of the particular operating system have to be taken into account.

5.1 Routes

In order to compare the two approaches against each other during the evaluation, each user has to walk with both prototypes. Since walking the same route with both prototypes would influence the user experience of the used prototypes, each prototype has to be tested on a new route from the user's point of view. Hence each prototype has to support both routes and the used prototype for a route is alternated from user to user.

5.1.1 Route 1

The first route starts at Kuefsteingasse 20 1140 Vienna and ends at Huglgasse 24, 1150 Vienna. It is 1154 meters long, requires approximately 15 minutes to walk, has 6 turns and provides three usable landmarks. Figure 5.1 illustrates the first route including the location of the landmarks.

[1] https://developer.android.com/wear/index.html

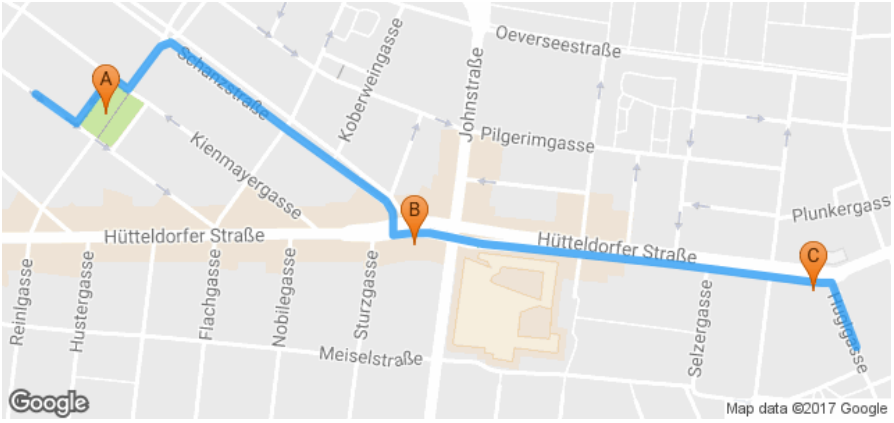


Figure 5.1: Route 1 of evaluation.

5.1.2 Route 2

The second route starts at Huglgasse 24 1150 Vienna and ends at Vogelweidplatz 9, 1150 Wien Vienna. It is 1076 meters long, requires approximately 13 minutes to walk, has 6 turns and provides three usable landmarks. Figure 5.2 illustrates the second route including the location of the landmarks.

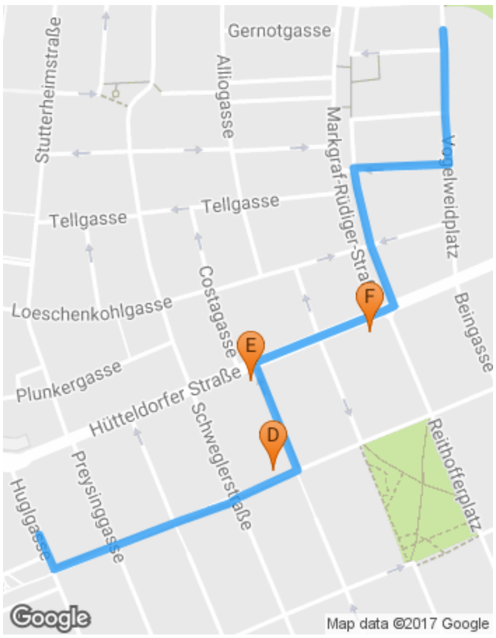


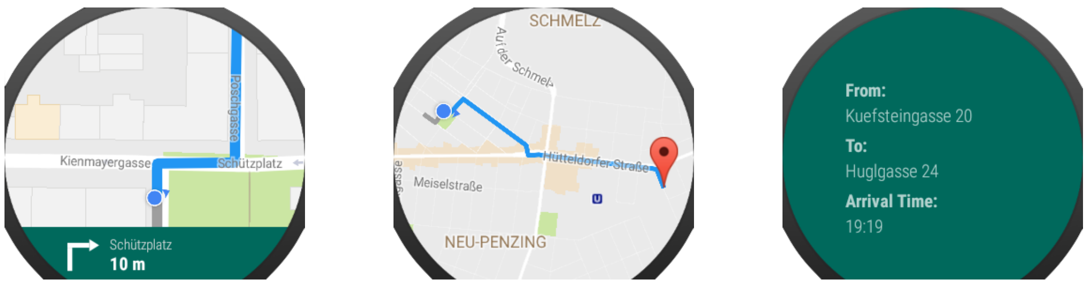
Figure 5.2: Route 2 of evaluation.

5.2 Prototypes

Two prototypes have been developed during the implementation, where the second prototype can be seen as an advancement to the first one. While both prototypes look and behave the same in most aspects, the advanced prototype includes landmarks at decision points and visually differentiates subsequent and non-subsequent turns. In the following, the basic and advanced prototypes shall be introduced.

5.2.1 Prototype: Basic

The user interface of the prototype consists of three pages, as shown in figure 5.3. The pages can be navigated via a swipe with the finger. The first page represents the main part of the application including the map and direction view, while the second and third page contain an overview of the route and additional information like arrival time. The map view uses track-up orientation where the next path segment is always aligned to the top of the screen. The path ahead is drawn as a thick blue line onto the map, while the path behind is gray. A symbol is shown at the current location of the user. This symbol furthermore indicates the heading of the user, however, only very approximately. When the location of the user moves, the map automatically scrolls in order to keep the location symbol at the bottom of the screen. Dependent on the distance between the location of the user and the next decision point, the application calculates a zoom which shows the path until the next decision point. There are some exceptions to this rule though, which will be discussed in more detail later. When the user reaches a decision point or the destination the smartwatch vibrates once.

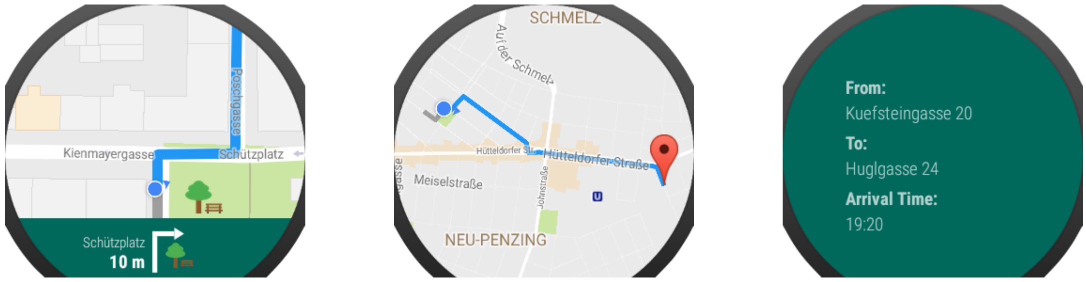


(a) First page. (b) Second page. (c) Third page.

Figure 5.3: Overview of the user-interface of the basic prototype.

5.2.2 Prototype: Advanced

As outlined in the previous chapter, the advanced prototype extends the basic prototype by the use of landmarks as well as the distinction of subsequent and non-subsequent turns. As can be seen in figure 5.4, these enhancements only affect the first page, while the latter two pages behave and look the same for both prototypes.



(a) First page. (b) Second page. (c) Third page.

Figure 5.4: Overview of the user-interface of the advanced prototype.

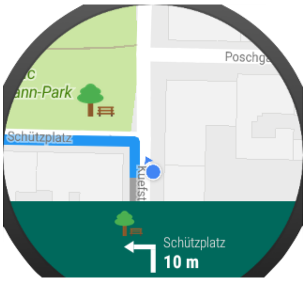
5.2.3 Landmarks

As mentioned earlier, the two routes contain three landmarks each. Figures 5.1 and 5.2 show the locations of the landmarks on the routes. Furthermore, table 5.1 lists all landmarks where the first route consists of a park, a bank and a grocery store, while for the second route a bakery, a florist and a grocery store are used. For the grocery stores, the bank and the bakery the respective logos are utilized since they are well known brands. For the florist and the park symbols are used, for the first one the reason being that the florist does not have a strong branding.

Route	Identifier	Name	Type	Representation	Image
1.	A	Park	Park	Symbol	
	B	Erste Sparkasse	Bank	Logo	
	C	Billa	Grocery store	Logo	
2.	D	Der Mann	Bakery	Logo	
	E	Florist	Florist	Symbol	
	F	Hofer	Grocery store	Logo	

Table 5.1: Landmarks used in the developed applications.

Figure 5.5 presents screenshots of the smartwatch for all six landmarks on the first and second route. As illustrated, the position of the landmark in relation to the position of the arrow in the direction view represents the location of the landmark on the actual map in regard to the path. So while for example in figure 5.5a the image of the park is left and above of the arrow, since the next path segment is also left and below the park on the map, in figure 5.5c the logo of the grocery store is right inside the arrow because it is located on the right side of the path before the decision point.

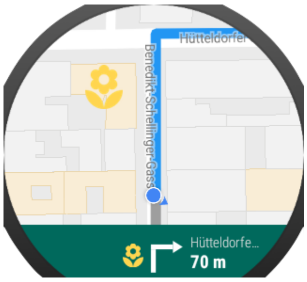


(a) Route 1 - landmark A.

(b) Route 1 - landmark B.

(c) Route 1 - landmark C.

(d) Route 2 - landmark D.



(e) Route 2 - landmark E.

(f) Route 2 - landmark F.

Figure 5.5: Positions of the landmarks in relation to the locations of the landmarks on the map.

5.2.4 Subsequent turns

The second addition of the advanced prototype beside the landmarks is that it has a more detailed visualization about the next turn the user has to take. If for example a user has to take the right turn at the next decision point but there are other right turns beforehand, the arrow consists of a dotted line. When the user gets closer and thus there are no wrong turns until the correct decision point the line of the arrow changes to solid. This behavior is visualized in figures 5.6a and 5.6b.

(a) Dotted line for non-subsequent turns.

(b) Solid line for subsequent turns.

Figure 5.6: Visualization of the differentiation of turns.

5.3 Application Structure

As already mentioned, Android Wear was chosen as the operating system. Beside "Google Play Services for wearable, maps and location"[2] the following libraries were used: "Android logging library Timber"[3] and "Google Maps Android API utility library"[4] as an extension to Google Maps. For gathering data about the routes the "Google Maps Direction API"[5] was used.

It should be noted that due to the lower processing power of a smartwatch in comparison to a smartphone, the performance of the application should be considered. Thus, generally code should be written which performs as effective as feasible [3].

The basic structure of the applications, as illustrated in figure 5.7, can be divided into the input, output and processing blocks. The input consists of the path data, the GPS listener and the compass listener, while the output is composed by the map view, the direction view and the vibration manager.

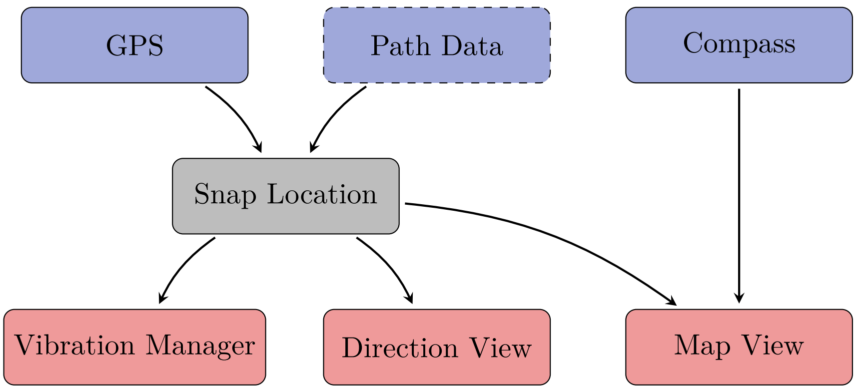


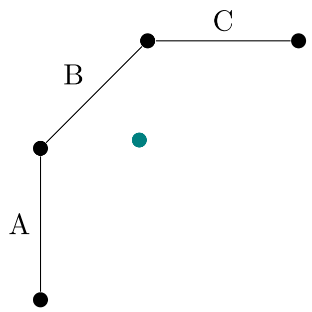
Figure 5.7: Basic structure of the prototypes.

The GPS listener relays location changes of the user and combined with the path data the snap location is calculated which represents the estimated location of the user on the path. Since the calculation of the snap location plays a very important role in the applications it is outlined in section 5.3.1. On the basis of the snap location the direction view as well as the map view are updated. The direction view shows the appropriate turn direction, the distance until the next turn, the next street name as well as a landmark if present. The map view on the other hand requires the snap location in order to scroll and zoom to the proper map area and update the landmark on the map. Furthermore, the compass is used to adjust the bearing of the user on the map.

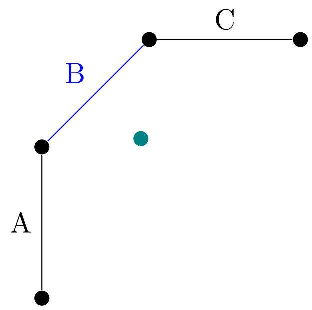
[2] https://developers.google.com/android/guides/overview
[3] https://github.com/JakeWharton/timber
[4] https://github.com/googlemaps/android-maps-utils
[5] https://developers.google.com/maps/documentation/directions/

5.3.1 Snap Location

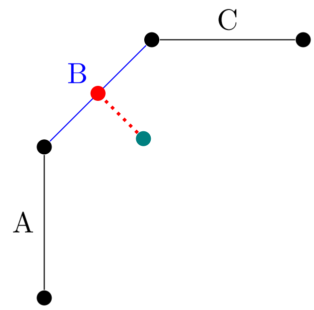
Calculating the location on the path in relation to the location of the user is one of the most important parts of the applications, since this information is required for all further actions, as for example zooming and scrolling to the location on the map, showing the next turn, distance and street name as well as presenting the appropriate landmark. Also, the moment of triggering a vibration before a turn depends on the accuracy of this calculation.



(a) Path and location.



(b) Selection of nearest path segment.



(c) Calculation of snap location.

Figure 5.8: Calculation of the snap location.

Every time the location of the user changes the snap location has to be calculated. The steps for this calculation are illustrated in figure 5.8. At first, the application is notified about the location update. In the next step, the nearest segment to the user location is calculated. Once the actual segment has been identified the nearest point on the segment in regard to the user location is computed. This point represents the estimated location of the user on the path and is referred to as the snap location.

5.3.2 Map Area

Another important aspect of the application is to show a reasonable area of the map. On the one hand, the zoom should not be too high since the awareness of the surroundings as well as of the the mental orientation would be reduced. On the other hand, the zoom has to be high enough in order to provide a clear focus on the path ahead and show appropriate details like the street network, street names as well as building outlines and still be easily recognizable by the user.

In order to achieve these mentioned requirements the following rules for choosing the map area and zoom level were established:

1. Map bounds and zoom level should be chosen such that the area contains the user's location and the next decision point. If not possible due to the subsequent restrictions it should contain at least the user's location and the path ahead.

2. A defined maximum zoom level should not be exceeded.
3. A defined minimum zoom level should not be undercut.
4. The zoom should only be updated when the difference to the last zoom exceeds a certain threshold.

The first requirement ensures that if possible an area until the next decision point is shown, which is very important since users are not capable of zooming or scrolling. As already mentioned, the zoom level should not be too high or too low in order to ensure that the map area still provides a sufficient overview and enough details at the same time. The last rule asserts that the zoom level doesn't update all the time but at certain intervals defined by a threshold. For the maximum and minimum zoom level values of 18 and 12 have been chosen, while the threshold for zoom level updates is 1.

The figures in 5.9 illustrate examples of the aforementioned behavior. Between figures 5.9a and 5.9b the zoom level does not change since the threshold is not exceeded. In the last figure 5.9c the user gets close enough to force a zoom level which exceeds the threshold and thus the map view is more zoomed in.

(a) Zoom level 15. (b) Zoom level 15. (c) Zoom level 16.

Figure 5.9: Zoom levels for varying distances between the location of the user and the next decision point.

The code snippet 5.1 which is part of the *NavigationActivity* class demonstrates how the limits of the minimum and maximum zoom as well as the threshold are applied. The variable *oldZoom* is the currently used zoom, while *zoom* is the newly calculated zoom which is chosen by fitting the path segment from the current location until the next decision point into the map bounds.

```
public void updateCamera(LatLng latLng, double bearing, double distance,
    boolean isNewStep) {

   ...

   float zoomThreshold = 1;
   float zoomMax = 18;
   float zoomMin = 12;
```

```
    if (Math.abs(oldZoom - zoom) < zoomThreshold && !isNewStep) {
      zoom = oldZoom;
    } else if (zoom < zoomMin) {
      zoom = zoomMin;
    } else if (zoom > zoomMax) {
      zoom = zoomMax;
    }

    ...

}
```

Listing 5.1: Calculation of the zoom level.

5.3.3 Track-Up

The applications use a track-up instead of a north-up orientation, which means that the next path segment always points to the top from the user's location. The figures in 5.10 illustrate the track-up orientation as the user's location updates along the path. The map is always turned in a way such that the path emanates from the snap-on location in the top direction, while it may turn later in a different direction.

(a) Near decision point. (b) Close to decision point. (c) After decision point.

Figure 5.10: Visualization of the track-up orientation.

The heading of the path can be calculated due to the fact that even between two decision points there are many locations encoded in order to render the path. The code snippet 5.2, which is taken from the SphericalUtil class of a Google Maps extension library[6], presents the calculation of the heading, where the snap-on location of the user and the next location on the path are used as inputs.

```
public static double computeHeading(LatLng from, LatLng to) {
  double fromLat = Math.toRadians(from.latitude);
  double fromLng = Math.toRadians(from.longitude);
  double toLat = Math.toRadians(to.latitude);
  double toLng = Math.toRadians(to.longitude);
  double dLng = toLng - fromLng;
```

[6] https://github.com/googlemaps/android-maps-utils

```
  double heading = Math.atan2(Math.sin(dLng) * Math.cos(toLat),
    Math.cos(fromLat) * Math.sin(toLat) -
    Math.sin(fromLat) * Math.cos(toLat) * Math.cos(dLng));
  return MathUtil.wrap(Math.toDegrees(heading), -180.0D, 180.0D);
}
```

Listing 5.2: Path heading calculation[6]

5.3.4 Bearing

In order to visualize the bearing of the user, which is indicated by a blue arrow at the user's location, the orientation of the smartwatch has to be calculated. This is done by using the magnet field sensor as well as the accelerometer of the smartwatch.

During the implementation it has been discovered that on rapid rotations the bearing overshoots. Thus a low-pass filter is used to smooth the updates of the bearing. The code snippet in 5.3 represents the low-pass filter with an alpha value of 0.15. The change from the returned value to the previously returned one is proportional to the difference between the last two inputs.

```
private float[] lowPassFilter(float[] newValues, float[] oldValues) {

  if (oldValues == null) {
    return newValues;
  }

  for (int i = 0; i < newValues.length; i++) {
    oldValues[i] = oldValues[i] + 0.15f * (newValues[i] - oldValues[i]);
  }

  return oldValues;
}
```

Listing 5.3: Low-pass filter for the bearing of the user.

5.3.5 Collected Data

During the evaluation the walking duration, the amount of smartwatch usage as well as the interaction shall be examined. Hence, the prototypes need to log this data during the navigation tasks. The collected data consists of the following three events:

- Location updates
- Screen on/off changes
- Page changes

For the location updates a maximum interval of eight seconds is chosen with a minimum displacement of five meters, which ensures that there is sufficient data to recreate the traveled path. The screen on/off event is logged each time the screen goes on or off. This can happen by wrist movements as well as by tapping the smartwatch. While this data may not represent when the user actually required the smartwatch very accurately, it should still be sufficient enough to get a sense about the amount of usage. Furthermore, an event is saved when the user switches between the three pages. It should be further noted that for all three kinds of events the timestamp as well as the latitude and longitude of the user's location are logged, as can be seen in table 5.2.

Event-Type	**Timestamp**	**Latitude**	**Longitude**	**Screen-on**	**Page**
location	20170215_123137	48.2010769	16.3145795	false	0
screen	20170215_123531	48.1992018	16.318013	true	0
page	20170329_060004	48.2001421	16.3303939	true	2

Table 5.2: Examples of collected events.

When the data is captured it is immediately sent to the connected smartphone. From the smartphone the data can then be saved as a CSV file for later analysis.

CHAPTER 6

Evaluation

In this chapter the two implemented prototypes shall be evaluated. The first three sections report the design of the evaluation, the recruitment of the participants and the routes of the field trial. The next section is concerned with the data which was gathered during the field trial. The last section discusses the results of the data and the findings in regard to the research questions of this thesis.

6.1 Experimental Design

The goal of the evaluation is to obtain a basic comprehension about the usability of the developed prototypes as well as about the differences between the prototypes. Information and feedback is gathered by collecting data during the navigation task as well as by the execution of a questionnaire, an assessment and a qualitative interview.

During the evaluation each user navigates along two given routes using the implemented applications. Which application is used for a certain route is alternated in order to ensure that at the end of the evaluation each application is used the same amount of times on each route.

Before the actual field trial each user is instructed, is given the smartwatch with the installed applications and the first application is started by the administrator. When the user reaches the destination of the first route the administrator starts the other application and the user begins navigating the second route. In the case of a user taking a wrong turn during the navigation he or she is corrected by the administrator and the incident is noted. Furthermore, the location including a timestamp is automatically saved in a periodic manner. In order to get a sense about when and how often users interact with the applications the location and timestamp are also recorded each time the display of the smartwatch goes on or off.

Beside the navigation task the field trial consists of a questionnaire, an assessment as well as an interview. The questionnaire is represented by the Santa Barbara Sense-of-direction scale or short SBSOD [22]. The SBSOD aims to provide information about the self-assessment of sense of direction via fifteen questions as listed in appendix A.2. Each question can be answered by a scale of one to seven where one means strongly agree and seven strongly disagree.

For the assessment the NASA-RTLX is used which rates metrics as for example the mental and physical demand [21]. This assessment provides insight into the cognitive workload of the two applications and helps to compare them against each other by the use of defined metrics. The questions of the NASA-RTLX are listed in appendix A.3. It should be noted that the raw version of the NASA-TLX is used, in which the subscales have not to be weighted by the user, in order to decrease the burden and required time for the participants [20].

To broaden the understanding of the applications' viabilities a semi-structured interview is conducted with the user [73, 31]. While the interview starts with questions about the general use and preferences regarding navigation systems, the main focus is on the used applications during the navigation tasks. The interview covers the topics listed below.

- Pre-Knowledge
  - Navigation systems in everyday life and especially in regard to smartphones and smartwatches
  - Familiarity with smartwatches
- Applications
  - Impressions
  - Usage
  - Viability
  - User interface
  - Encountered problems
- Comparison
  - Preferred application
  - Landmark perception
  - Comparison to navigation via a smartphone
- Enhancements and suggestions

6.2 Participants

For the evaluation sixteen people were chosen as participants. Due to the small sample size the age span is kept very homogeneous with ages ranging between 24 and 33 years, as shown in table 6.1. This reduces the number of variables which may be induced by different prerequisites from a younger or older generation. The proportion between males and females is equal. Participants were chosen which live in the proximity of the location of the user study in order to reduce their required travel time. It should be noted that the participants were recruited from the author's personal group of peers who were also somewhat interested in that subject and included the six participants of the concept study.

Participant	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
Age	27	27	25	29	25	28	27	30	28	28	27	33	28	24	27	28

Table 6.1: Participants of the evaluation.

6.3 Routes

As already mentioned in the previous chapter, two routes are necessary since each user has to navigate with the basic as well as the advanced prototype and reusing the same route for both prototypes would influence the user experience between the prototypes. This also ensures that in case one route is easier than the other it does not bias a particular prototype since both routes are used the same amount of times with each prototype. Still, it is beneficial to have two routes which can be compared to each other and thus routes are chosen which match each other as much as possible by the following metrics:

- Route distance
- Number of turns
- Number of usable landmarks
- Difficulty of intersections

The routes are furthermore chosen at a location which minimizes the chance of recognizability and the end of the first route is located close to the start of the second route in order to reduce the duration for the user. The routes are 1154 and 1076 meters long and have six turns respectively. Each route contains three usable landmarks, where the first route includes a park, a bank and a grocery store, while the second route has a bakery, a florist and a grocery store. The routes as well as the images used for the landmarks are presented in the previous chapter via the figures 5.1 and 5.2 for the routes and table 5.1 for the landmark visualizations.

6.4 Results

In this section the results of the evaluation shall be examined. At first the SBSOD is presented which is independent from the actual navigation tasks and provides an overview of the self-reported sense of direction of the participants. Later on, the required walking durations as well as the walking speeds are inspected as well as the amount of usage of the smartwatch and the errors participants made during the tasks. In the end the NASA-RTLX is discussed which provides insights into how participants perceived the two prototypes. In order to broaden the understanding of the viability of the prototypes the conducted semi-structured interviews are examined which will also explore how participants interacted with and used the applications.

6.4.1 SBSOD

Each participant conducted the SBSOD which provides some basic understanding about the self-reported sense of direction of all participants [22]. In order to make the data more easy to compare the ratings of the positively stated questions 1, 3, 4, 5, 7, 9 and 14 are reversed. The means of the ratings for each question are calculated among all participants, as shown in table 6.2 where all questions from the SBSOD as listed in appendix A.2 are referenced. Note that a higher value indicates a better self-assessment for the particular question. When calculating the mean of all questions for each participant and comparing these means, the results indicate that there are no significant differences among the participants ($m = 4.19$, $sd = 1.00$). It can thus be assumed that the chosen group of participants is somewhat homogeneous. When comparing female ($m = 3.88$, $sd = 1.02$) with male ($m = 4.50$, $sd = 0.95$) participants the male users show a higher self-reported sense of direction, which can also be found in other studies [52].

Question	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**
Mean	4.31	4.88	3.38	4.75	3.25	4.75	4.25	4.81
SD	1.49	1.63	1.45	1.73	2.05	2.02	1.61	1.60

Question	**9.**	**10.**	**11.**	**12.**	**13.**	**14.**	**15.**
Mean	5.06	2.81	2.94	4.81	4.00	4.31	4.56
SD	1.06	1.64	1.57	1.42	1.63	2.15	1.63

Table 6.2: Results of the SBSOD.

6.4.2 Walking Duration

The walking durations are determined for each route separably since the routes are not equal in their length and thus the required duration for the navigation task may vary. Table 6.3 contains the mean durations as well as the standard deviations for both routes grouped by the used application. In the following, the walking duration of each route is compared with an estimated duration. The basic prototype and advanced prototype shall additionally be compared against each other in regard to the walking duration.

Route	**Prototype**	**Mean[s]**	**SD[s]**
Route 1	Basic	799.3	58.8
	Advanced	831.5	94.1
Route 2	Basic	842.1	78.1
	Advanced	769.6	73.9

Table 6.3: Walking duration means and standard deviations by routes and prototypes.

Comparison with an estimated duration

In order to answer the question if the applications are viable, one has to show that the required duration of users is in reasonable bounds. For a reference duration the Google Maps Directions API[1] is used which estimates 879 seconds for the first and 773 seconds for the second route.

It can be calculated if the samples are significantly different from the estimated values from Google by using a one-sample t-test. A significance interval of 0.05 is chosen and the nulhypothesis assumes that there is no difference while the alternative hypothesis implies that there is.

$H_0 : \mu = \mu_0$ and $H_1 : \mu \neq \mu_0$

The calculated values for both routes are as follows:

- Route 1: $t(15)$ = -3.280, p = 0.005
- Route 2: $t(15)$ = 1.595, p = 0.132

For the first route the difference is significant where the mean of the required duration is lower than the estimated duration from the Google API, while for the second route a significant difference can not be shown. This means that it can be assumed that both prototypes do not inflict longer mean durations than the estimated values.

Furthermore, the same test can be applied to all combinations of routes and prototypes. The results of these tests are presented in table 6.4. The table shows that there only can be found a significant difference for the first route when using the basic prototype where the mean of the required duration is lower than the estimated duration. For all other variants a significant difference cannot be shown.

[1] https://developers.google.com/maps/documentation/directions/

Route	**Prototype**	$t(7)$	p
Route 1	Basic	-3.838	0.006
	Advanced	-1.428	0.196
Route 2	Basic	2.502	0.41
	Advanced	-0.129	0.901

Table 6.4: Results of t-tests for walking durations for each route and prototype.

Comparison between the two prototypes

Next, the basic prototype and advanced prototype shall be compared against each other. As shown in table 6.3 for the first route users required in average less time with the basic prototype, while for the second route on the other hand users were faster when using the advanced prototype. The most reasonable explanation for this discrepancy can be found in the different walking speeds of the participants. If for example one user walks very slow and the basic prototype is used first, the durations for the first route with the basic prototype and for the second route with the advanced prototype will be very high. When calculating the mean walking speed among both routes for each user and splitting users by the prototype they used for each route, the mean walking speed for users starting with the basic prototype is 1.43 while for users starting with the advanced prototype it is 1.34. This indicates that the walking speed of users is not balanced across the scenarios of which prototype is used on which route.

In order to check if there is a significant difference between the means of the basic and advanced prototype a two-tailed two-sample t-test is conducted for each route. A significance interval of 0.05 is chosen and the nulhypothesis assumes that there is no difference between the duration means of the basic and advanced prototype while the alternative hypothesis implies that they are different.

$H_0 : \mu_0 = \mu_1$ and $H_1 : \mu_0 \neq \mu_1$

With the use of the two-tailed two-sample t-test values for each route are calculated as follows:

- Route 1: $t(14)$ = -0.822, $p = 0.425$
- Route 2: $t(14) = 1.907$, $p = 0.077$

The nulhypothesis cannot be rejected for either of the routes and thus a significant difference between the duration means of the two prototypes cannot be shown.

As mentioned before, one problem with comparing the basic and advanced approach within each route separately is that the variance of the user's walking speed can highly influence the results. In order to overcome the issue induced by separating the routes, a further method for evaluating the data is introduced which uses the calculated ratios of the durations between the two routes for each user. Since from participant to participant the used prototype was alternated for the first and second route, two scenarios can be defined. In the first scenario a participant used the basic prototype for the first route and the advanced prototype for the second route, while in the second scenario the advanced prototype is used for the first route and the basic prototype for the second route. For each scenario the portion of how much time the first and second route required in relation to the total duration can be calculated with the formula:

$ratio_{route\text{-}1} = \frac{duration_{route\text{-}1}}{duration_{route\text{-}1}+duration_{route\text{-}2}}$.

A ratio of 0.5 indicates that the duration for both routes is equal, while a lower ratio means that the first route required less time and a higher ratio that the first route required more time than the second route.

The benefit of using ratios instead of the durations themselves is that the calculated values are independent of the individual walking speeds of the participants and therefore the ratios can be compared between participants with a much lower variance. As mentioned, the scenarios were alternated and thus eight participants were part of scenario 1 and scenario 2 respectively. From these two participant groups the mean ratio for their respective scenario can be calculated. The two scenarios and their calculated mean values are illustrated in figure 6.1.

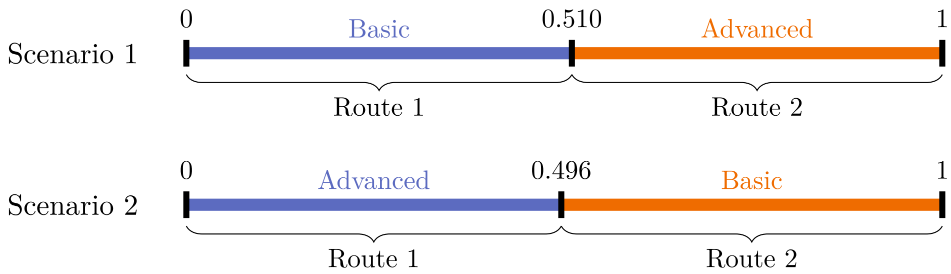


Figure 6.1: Ratios of the durations for each scenario.

When comparing the scenarios against each other, as illustrated in figure 6.1, it can be seen that in the first scenario, where the basic prototype is used for the first route and the advanced prototype for the second route, the ratio is higher than for the second scenario. Thus, it could be concluded that the advanced prototype gives an advantage against the basic one.

In order to check if the advanced prototype provides a significant benefit, a one-tailed two-sample t-test is conducted with a significance interval of 0.05 and a nulhypothesis which assumes that the duration ratio of the first scenario (μ_0) is lower than or equal to the ratio of the second scenario (μ_1) while the alternative hypothesis implies that the ratio of the first scenario is higher than the ratio of the second scenario.

$H_0 : \mu_0 \leq \mu_1$ and $H_1 : \mu_0 > \mu_1$

The nulhyopothesis can be rejected since the one-tailed two-sample t-test reveals that: $t(14) = 1.889$, $p = 0.04$. This means that the advanced prototype provides a significantly lower duration than the basic prototype when comparing the ratios.

Figure 6.2 visualizes the difference between the ratios of each user and the mean ratio of all users, where the 0% line at the horizontal center of the plot represents the mean ratio and the bars represent the difference. The lower eight bars in blue represent the first scenario where the basic prototype is used for the first and the advanced prototype for the second route, while the upper eight bars in orange showcase the second scenario. A negative bar value signifies that the first route has been walked faster than the second route in regard to the mean ratio, while a positive bar value indicates the opposite.

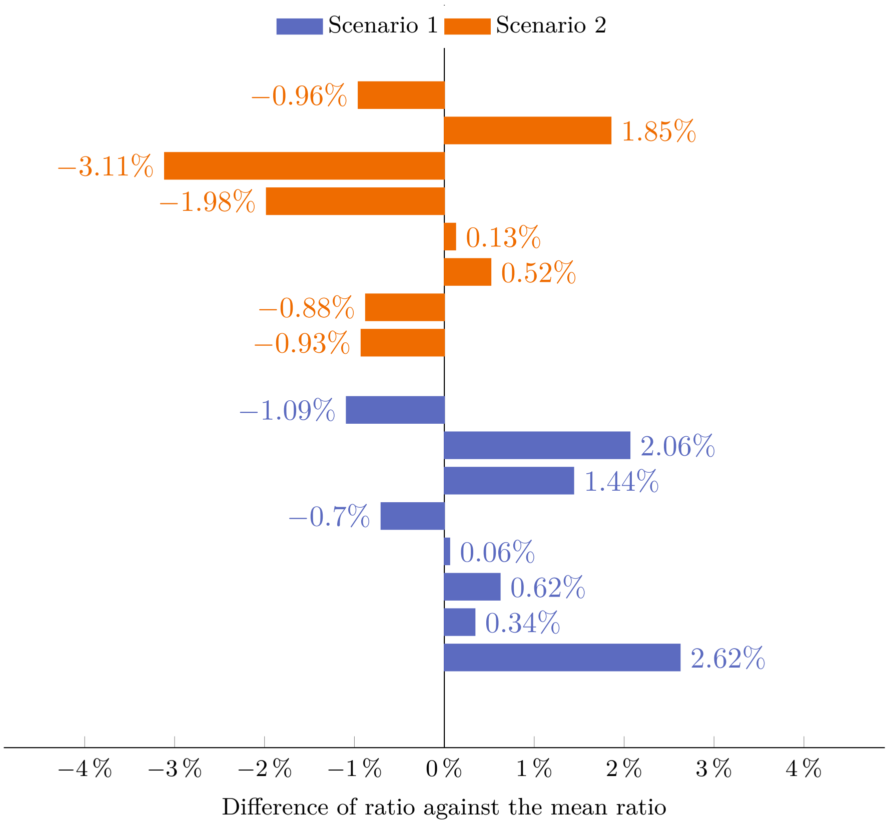


Figure 6.2: Difference of route duration ratios for each participant.

6.4.3 Walking Speed

Beside the walking durations, as presented in section 6.4.2, the walking speeds can also be examined and compared. The walking speeds can be calculated by dividing the length of the respective route, which are 1154 and 1076 meters long, with the required durations. The mean walking speeds for both routes grouped by the prototype are illustrated in figure 6.3.

Furthermore, the walking speed estimations from Knoblauch et al. [29] can be used as an additional comparison. They found mean walking speeds of 1.51 m/s for younger and 1.25 m/s for older pedestrians as well as 15th percentile walking speeds of 1.25 m/s and 0.97 m/s respectively. Since the age group of this evaluation falls into the younger category only the former estimation of 1.51 m/s shall be used, which is also visualized in figure 6.3.

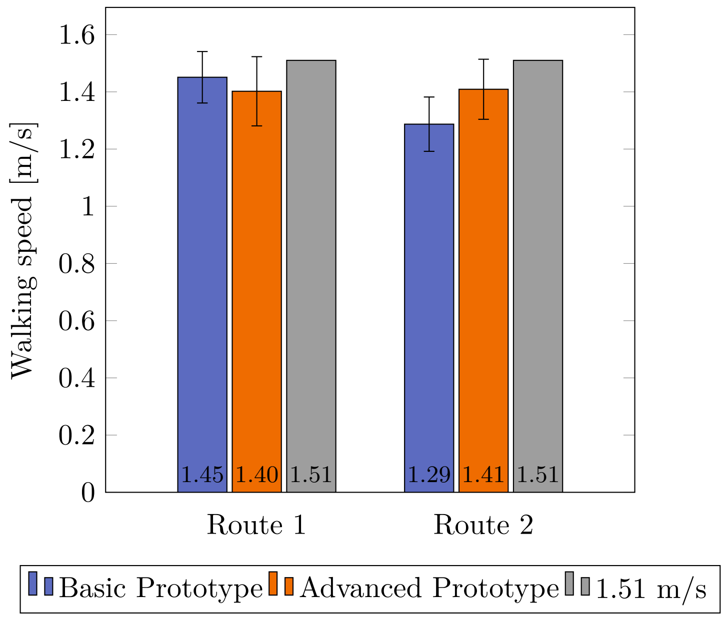


Figure 6.3: Mean walking speeds for route 1 and 2 with the basic prototype, advanced prototype and 1.51 m/s as reference. Vertical error bars represent the 95% confidence intervals.

As illustrated in figure 6.3, participants were faster with the basic prototype on the first route and the advanced prototype on the second route, as already mentioned in section 6.4.2. When comparing the walking speeds of the prototypes with the walking speed from Knoblauch et al. [29], the walking speeds of the two prototypes are lower for both routes. In the case of the basic prototype on the second route the difference to the estimated walking speed can even be considered significant, as a one-sample t-test shows. It should be noted though that the found walking speeds of Knoblauch et al. do not include influences like traffic and traffic lights which reduce the reported walking speeds and thus makes the data difficult to compare accurately.

6.4.4 Screen-on

As mentioned, during the user study it was captured when the screen of the smartwatch goes on and off. The resulting data makes it possible to calculate how long the smartwatch was active as well as how often it went from inactive to active. The gathered data can be used to get a sense about how often users needed to use the application, which indicates the number of times the user required information. It should be noted though that this information can only be used as a rough estimation. While the smartwatch can be turned active and inactive via clicks, it also switches by the use of wrist motions which induces some kind of randomness. Additionally, the smartwatch vibrates before each decision point which creates a bias for users to look at the smartwatch and thus turn the screen on.

The means and standard deviations of the screen-on duration and count are presented in 6.5, grouped by the route and used prototype. These values indicate that for both routes users used the smartwatch less when using the basic prototype.

		Duration		**Count**	
Route	**Prototype**	**Mean[s]**	**SD[s]**	**Mean[s]**	**SD[s]**
Route 1	Basic	119.8	125.9	19.4	7.1
	Advanced	143.4	111.6	24.0	13.0
Route 2	Basic	121.4	110.2	23.3	13.3
	Advanced	97.1	92.4	19.9	8.8

Table 6.5: Means and standard deviations of screen-on duration and screen-on count by routes and prototypes.

As done for the walking durations in section 6.4.2 the ratios should be examined as well in order to reduce the variance of the users. The ratios for the screen-on duration as well as the screen-on count are presented in table 6.6 where in the first scenario the basic prototype is used for the first route and the advanced prototype for the second route and conversely for the second scenario. The first scenario generated lower ratios for the screen-on duration as well as the screen-on count than the second scenario. This is to be expected since as shown in table 6.5 the ratios for the two measurements was lower with the basic prototype for both routes.

	Duration		**Count**	
Scenario	**Mean**	**SD**	**Mean**	**SD**
Scenario 1	0.540	0.064	0.503	0.081
Scenario 2	0.577	0.136	0.510	0.068

Table 6.6: Means and standard deviations of screen-on duration and screen-on count ratios by scenarios.

Since from the shown values it could be inferred that the basic prototype provides a slightly better performance in regard to the amount of usage of the smartwatch, it should be tested if there actually is a significant difference. Accordingly, a two-tailed two-sample t-test is used with a significance interval of 0.05 and a nulhypothesis which assumes that the screen-on duration ratio or screen-on count ratio of the first scenario is equal to the ratio of the second scenario and an alternative hypothesis which implies that they are different.

$H_0 : \mu_0 = \mu_1$ and $H_1 : \mu_0 \neq \mu_1$

With the two-tailed two-sample t-test the following values are calculated:

- Screen-on duration ratio: $t(14)$ = -0.694, p = 0.499
- Screen-on count ratio: $t(14)$ = -0.179, p = 0.860

As the calculated values indicate the nulhypothese cannot be rejected for either of the attributes, which means that no significant difference in the smartwatch usage could be shown when comparing the basic and advanced prototype. So while the data at first glance seems to indicate that the basic prototype requires less interaction with the smartwatch, it could not be shown to be significant. Furthermore, the standard deviations as shown in table 6.6 are quite high, which confirms the mentioned warning not to interpret the data too directly. Due to how the mechanism for turning the screen on and off works as well as the influence of the vibrations, the presented data should be looked upon as a rough estimation.

In figures 6.4a and 6.4b heatmaps of the locations where the screen of the smartwatch was active are illustrated, where a darker shade of red represents that more users had the screen on at this location. As can be seen, there are hotspots around all decision points, which had to be expected because this is where the smartwatch vibrates and users check the smartwatch for instructions. Furthermore, on longer paths between two decision points users checked the smartwatch in order to reassure that they were on the right track and to get information about the next turn to take. It should be noted that while not visible in the figures the heatmaps of the basic and advanced prototype do not differ.

(a) Route 1 (b) Route 2

Figure 6.4: Visualization of the screen-on heatmap. A darker shade indicates that more participants had their smartwatch turned on at the particular location.

6.4.5 Errors

When participants make an error during the navigation the event is noted by the instructor. Two participants made an error where they walked straight for a few meters at a decision point instead of taking the turn. One incident occurred when using the basic prototype and the other with the advanced prototype. It should be noted that in the case of the advanced prototype there was no landmark at that particular decision point which might have made an impact. For both incidents the errors were corrected by the participants themselves without intrusion from the instructor. Both participants mentioned that they did not take the turn because the marked location on the map had been behind their actual location and thus they thought they were not yet there. It should furthermore be noted that if the cause of the errors was indeed the GPS, then the vibrations at the decision points didn't trigger since the application wasn't aware that the user was close enough. Beside the wrong visual location on the map, this might be an even bigger issue when it comes to an inaccurately reported location, since participants mentioned that they relied on the vibrations quite heavily.

6.4.6 NASA-RTLX

As already discussed, the NASA-RTLX is used in order to assess the subjective attributes of both prototypes used during the navigation tasks. Each user had to fill out the NASA-RTLX for the first and second route separately and thus both prototypes are covered for each user. The collected data provides some insight into the perceived qualities of the applications and makes the qualitative attributes of the two prototypes comparable.

Figure 6.5 illustrates the mean values of the subscales of the conducted NASA-RTLX assessment grouped by the two prototypes. As shown, all mean values are lower for the advanced prototype when compared with the basic prototype, with the exception of the physical demand which is equal. This indicates that overall users were more satisfied with the advanced prototype which includes landmarks as well as the distinction of subsequent and non-subsequent turns. The users' reasons for this bias will be discussed in more detail later when the qualitative interviews are examined. While most participants rated the advanced prototype better, a few rated it worse because they used the advanced prototype only on the second route. Some of them mentioned that because they started with the advanced prototype they were already more familiar with the basic one during the walk. Thus it has to be mentioned, that while the bias towards the second route due to the already gained experience from the first route balances itself across all samples, it has to be taken into consideration when examining the data of a single user.

Since the NASA-RTLX instead of the NASA-TLX is used, in which users do not have to weight the subscales themselves, the weightings as shown in table 6.7 were chosen. Using these weightings in combination with the gathered data the task load indexes 10.06 for the basic and 6.23 for the advanced prototype are calculated, which indicates that the perceived workload for the advanced prototype is lower than for the basic prototype.

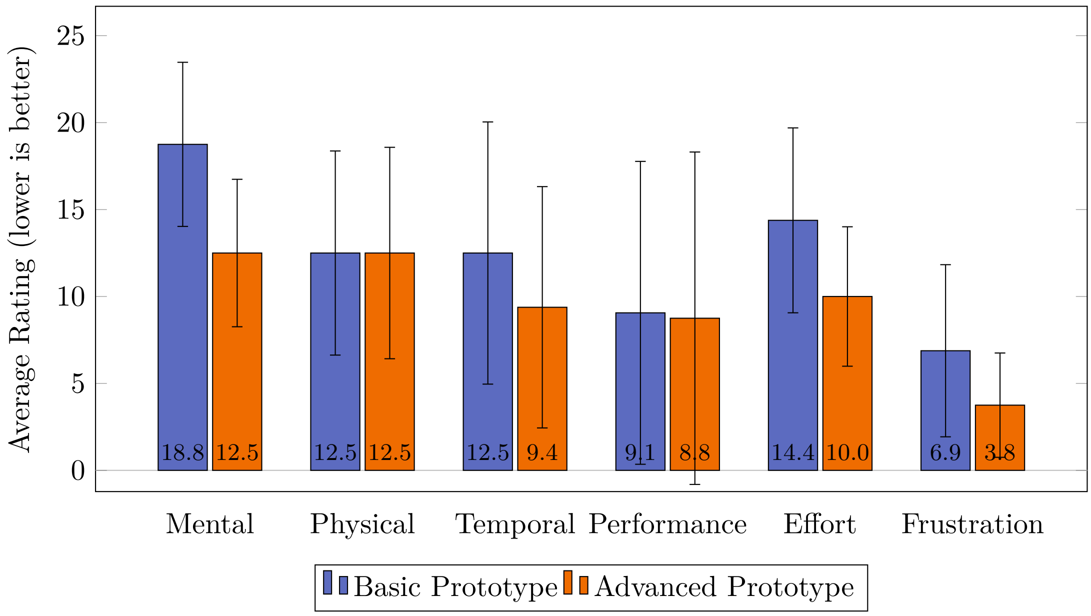


Figure 6.5: Mean values of NASA-RTLX subscales for the basic prototype and advanced prototype. Vertical error bars represent the 95% confidence intervals.

Subscale	**Weighting**
Mental Demand	5
Physical Demand	0
Temporal Demand	1
Performance	3
Effort	2
Frustration	4

Table 6.7: Weights of the NASA-RTLX.

Because it seems the ratings of the subscales for the advanced prototype are all lower across the board it shall be tested if the difference is actually significant. Hence, a one-tailed Mann-Whitney U test is performed for each of the six subscales with a chosen significance interval of 0.05. The nulhypothesis assumes that the subscale for the basic prototype (μ_0) is less than or equal to the one for the advanced prototype (μ_1) while the alternative hypothesis means that the subscale for the advanced prototype is lower.

$H_0 : \mu_0 \leq \mu_1$ and $H_1 : \mu_0 > \mu_1$

The calculated U and p values are presented in table 6.8 which shows that the nulhypothesis can only be rejected for the mental demand subscale. Thus, it can be found only for the mental demand subscale that the rating is significantly lower, while for the other five subscales the difference is not significant.

Subscale	U	p
Mental Demand	78.5	0.028
Physical Demand	127.0	0.485
Temporal Demand	107.5	0.212
Performance	118.0	0.339
Effort	95.5	0.107
Frustration	103.0	0.152

Table 6.8: Results of the one-tailed Mann-Whitney U test for the NASA-RTLX subscales.

Furthermore, when combining the ratings of all subscales a one-tailed Mann-Whitney U test results in: $U = 3886.5$, $p = 0.028$. It can be concluded that the ratings for the advanced prototype are significantly lower than for the basic prototype when considering all subscales of the NASA-RTLX.

6.4.7 Interviews

As mentioned, semi-structured interviews were conducted with all sixteen participants. Please note that since most interviews were performed in German quotes had to be translated to English.

Pre-Knowledge

All users were already familiar with navigation systems like Google Maps, Apple Maps as well as navigation systems for cars such as TomTom and most of them use navigation systems on their smartphones regularly. While eight participants already had a smartwatch in their hands beforehand, including the six participants from the concept study, only one of them owns one himself.

Overall Impression

The general impression of the participants regarding the prototypes was very good. All of the users found the applications to be reliable, though, some pointed out that their location was not as accurate as it could have been which represented the most named concern of the users. Participant L mentioned that the navigation was much more enjoyable than he initially thought: "*I did expect it to be much more complicated, because of the small display I did not anticipate that it would be so easy.*"

User Interface

The user interface of both prototypes was described as very clear and self-explanatory. This was something that had also been observed during the navigation task itself since users got familiar with the application very fast and understood without any problems how the application worked as well as the meaning of the elements of the user interface.

Participant K especially mentioned that the low amount of interaction required for the navigation task made the application very easy to use, when asked if she had any problems: "*I didn't have the feeling that I had any problems or complications since interaction was hardly required, which I find positive because while I'm on the way and while I'm walking I don't want to be forced to interact and don't want to align the map myself.*"

Regarding the map and the zoom level participant A mentioned that being able to see the path until the next decision point was very helpful, since you get a feeling about how far you have to walk.

Vibrations

The vibrations before decision points were perceived as very positive and useful by many participants who felt they could rely on the vibrations for the next instructions and thus had to check the smartwatch less often for route information. While some participants used street names to orientate themselves during the navigation with the basic prototype, many just waited for the vibration to occur and checked the smartwatch for further instructions, as participant F mentioned when asked how she used the applications: "*I did orientate by the street names once but apart from that I only paid attention to the vibration, then took a look onto it and checked where I had to go.*" One user further noted that a more diverse and longer pattern for the vibration at the destination could have been chosen.

Bearing Indicator

While not all participants took advantage of the bearing indicator, the ones who did, used it only at the beginning of the route in order to check in which direction to start walking. Afterwards, the automatic rotation of the map combined with the direction arrows was sufficient to orientate themselves. It should be noted that some users mentioned that the bearing indicator was not very accurate and lagged behind their rotation movement.

Pages

Users mainly remained on the main screen which contains the map view and direction view and rarely used the other screen pages for the overview and arrival information, though participant K noted: "*What I perceived as good is that I don't have to zoom out, but simply can go to the route overview.*" The interview also revealed that hardly any users wished for a zoom function to be available.

Comparison between Basic and Advanced Prototype

Each of the participants preferred the advanced prototype over the basic prototype, where all but participant P gave the landmarks as their reason for doing so. Participant P found that the distinction between next turns which should be and should not be taken was the most critical aspect when differentiating the two prototypes. Overall the landmarks were perceived as viable and profitable by all participants. Users found the landmarks easier to use and better ascertainable than reading street names since they were easily recognizable and could be spotted from farther away in general. Most participants used the landmarks whenever there was one available, as participant K noted: "*The first version with the landmarks was much better because at least for me the landmarks helped a lot in not having to look at the display but just needing to know for what I had to lookout for and also don't watch for street names.*" Participant M also mentioned that finding the way by landmarks is more natural and also the usual manner in which people describe routes. In addition since users checked their environment for the next landmark during the walk they observed their surroundings more consciously. Furthermore, landmarks provided additional certainty that users were on the correct path since they provided a reference point. It should be noted though that one user mentioned that the landmark for the florist added some confusion for him, because he could not spot the store from afar. While some participants mentioned that the differentiation for the next turn to take with the dotted and non-dotted arrow was useful for them, many of the users rarely took advantage of this visualized indicator. It should also be noted that no participant mentioned a difference in the amount of interaction with the smartwatch when comparing the two prototypes.

Comparison with Navigation via Smartphone

When asked if users preferred the used prototypes via the smartwatch over their usual ones on their smartphones most participants found the smartwatch version to be more beneficial. Many users saw a big advantage in having the navigation assistance on their wrist since they did not have to take the smartwatches out of the pocket or unlock them each time they wanted to check for route information, as for example participant J noted: "*The handling of the smartphone is more cumbersome. I have to take it out of the pocket, need to turn the display on, enter my unlock code and then I have the map open. This is a advantage of the smartwatch since there I raise my arm and tap the display and the thing I want to see is immediately active.*" Additionally, the vibration on the wrist allowed participants to have an easy noticeable notification when attention on their part was required. One participant mentioned it could be especially useful for routes a potential user has no knowledge about since in that case users tend to check their navigation systems more often. The only downside participants mentioned when comparing against navigating via the smartphone was the smaller screen size and thus less existent overview. One general concern that was found amongst some users is that the smartwatch was a bit clumsy on the wrist due to its bigger size when compared with a regular watch.

6.5 Discussion

This master thesis is concerned with the question if pedestrian navigation via smartwatch is viable and hence how such a system could be designed and behave as well as if the use of landmarks provides a benefit for the navigation task.

In order to answer the first question it has to be shown that the required duration when using the prototypes is in reasonable bounds. Furthermore, the qualitative aspects from a user's standpoint have to be taken into consideration. The proposed applications do seem to represent viable solutions for a smartwatch-based navigation aid. When comparing the durations required by users with the estimated durations, they are in reasonable ranges to each other for both routes. While it could only be shown for one route that the proposed solutions are significantly faster than the estimations from Google, for the other route it can at least be assumed that the solutions are not significantly slower. Furthermore, participants perceived the applications to be very viable and reliable and were overall very satisfied during the navigation. This could be observed by the NASA-RTLX assessment as well as by the conducted interviews. The core of the application which is represented by the combination of the map view and the direction view was perceived as very positive. While the map view provides a good overview of the environment, the direction view gives the most important information on a quick glance. The other pages for the overview and the additional information were not used a lot. This indicates that the shown map area and the zoom level were chosen very sufficiently. One participant especially mentioned that being able to see the path until the next decision point was very pleasant. While the general use of navigation systems naturally varies from user to user, all participants were able to use the proposed applications by their means and were satisfied in doing so.

The second question is concerned with the viability when adding landmarks as supplemental information for the navigation. When the ratios of the durations between the routes are compared, it can be shown that the advanced prototype provides a benefit. The conducted NASA-RTLX assessments furthermore show that participants rated the advanced prototype better than the basic one. In addition to that, all of the participants when asked declared that they preferred the advanced prototype and all but one gave the landmarks as their main reason in doing so. Thus, it can be concluded that landmarks provide a significant benefit for pedestrian navigation when the perceived qualitative attributes are taken into account.

CHAPTER 7

Conclusion

In this work, designs for a smartwatch-based pedestrian navigation system have been proposed and implemented for an Android smartwatch. By using a user-centered design approach two prototypes were defined which consist of a map view as well as a direction view. While the map view provides an overview of the environment and the route, the direction view aims to convey simple instructions in form of arrows for the next decision point. Furthermore, tactile feedback via vibrations are utilized, in order to notify the user about the proximity of the next decision point. The second prototype extends this functionality by the addition of landmarks and the visual distinction of subsequent and non-subsequent turns via solid and dotted arrows. The implemented prototypes were evaluated during a field trial in which participants walked two routes by the use of each prototype.

7.1 Major Results

The most important result of this thesis is that smartwatch-based navigation can be considered a viable solution for pedestrians. Participants were able to walk the routes in a reasonable time frame with very few errors which were corrected by the participants themselves.

Furthermore, the navigation with the smartwatch proved to be very effortless with a low mental workload. This may be caused by the low amount of interaction with the smartwatch required by the user. While the support of scrolling and zooming seems to be desirable, since it is embedded in many already existing navigation systems, it might not be suitable for the small screen of a smartwatch. That being said, the results indicate that it is not even required for providing a good navigation experience. The combination of the map view and the direction view achieved the desired effect of providing assurance and clear instructions. It should be noted that choosing a suitable zoom level represents an important factor for the map view. The approach of showing the path from the current location until the next decision point whenever feasible, proved to be a good solution. Furthermore, vibrations before decision points represent a good addition which prevents users from missing decision points and reduces the number of times users have to check their smartwatches.

The addition of landmarks for navigation purposes can further reduce the perceived workload of pedestrians. Looking out for landmarks is easier than reading street names and landmarks can be discovered from farther away. Two important aspects when using landmarks that have to be considered are: which landmarks should be used and when should they be shown. While landmarks in general increase the assurance of users, landmarks which cannot be found generate the opposite effect. If users are unable to recognize or find the landmark, the correctness of the current path is questioned. Thus, it is proposed to show landmarks only when they are clearly recognizable as well as in visual range. While the distinction of subsequent and non-subsequent turns found no big usage among the participants, some used them in combination with the map view in order to determine if an action is required. The low utilization may be caused by an insufficient visual distinction, which may be improved.

One aspect that has be considered when using tactile feedback and forms of instruction-based approaches is that these heavily rely on an accurate position. While a wrong indicated position on the map view can be problematic, the impact on the instructions and feedback is far more serious. If the location of the user is not accurate, a vibration might trigger when it should not, or doesn't trigger when it should, which can cause users to leave the designated path.

7.2 Future Work

The proposed solutions represent a solid base for further exploring smartwatch-based pedestrian navigation. Especially the second prototype which incorporates landmarks shows a lot of promise in that field. Obviously these concepts can be further refined and adjusted and a bigger field trial with the use of more sophisticated routes could be conducted. Furthermore, a lot of areas around these concepts and beyond exist that could be explored, such as:

- **Tactile feedback for conveying directions:** As already discussed in this work, tactile feedback can on the one hand be used in order to convey information or just to notify the user that attention is required, as for example before decision points. Whereas in this thesis the latter approach was used, informing pedestrians via vibration patterns about the exact direction they have to take might have a positive impact. Users would be required less often to take a look onto the device, thus letting them walk more freely. There are several aspects that have to be considered though. First of all it has to be evaluated how many different directions should be mapped to certain vibration patterns. In the simplest form two different vibration patterns for left and right might be sufficient. This approach however does not only increase the learning curve but also increases the impact of missing vibrations. If users start to rely on vibrations for their decisions, missing a vibration could cause users to take no action. This problem is further complicated by inaccurately reported locations since vibrations may be triggered too late, too early or not at all.

- **Landmarks along routes:** While in this work landmarks were only used in the proximity of decision points, it would be valuable to explore the effect of landmarks along the route as well. If the landmarks should also be presented in the proposed direction view, their position has to be chosen carefully, otherwise pedestrians may not be aware of where the landmark should be located along a path segment. That being said, including landmarks only in the map view itself may also prove to be a viable approach.

- **Automatic selection of landmarks:** Since landmarks seem to provide a positive impact on pedestrian navigation their selection and use should be further explored. In this thesis the landmarks were carefully picked in order to ensure that they are well recognizable and visible. For larger scale projects or navigation in a commercial context this is not viable though. Therefore, landmarks have to be selected automatically during the route planning or navigation. It should however be considered that simply using landmarks which are located on the route would lead to the selection of some bad landmarks. In order to ensure a robust selection of valuable landmarks the system needs to take into account the visibility and recognizability of landmarks. It should be noted that such research would not only benefit smartwatch-based navigation, but pedestrian navigation in general.

- **Comparison with smartphone-based navigation:** Smartphone-based navigation is widely used these days. Thus, it would be of interest to directly compare the smartphone with the smartwatch for pedestrian navigation. While a significant difference regarding the walking duration should not be expected, this work leads to assume that pedestrians would prefer the smartwatch as their navigation aid.

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Acronyms

AR Augmented Reality.

GPS Global Positioning System.

NASA-RTLX NASA Raw Task Load Index.

NASA-TLX NASA Task Load Index.

SBSOD Santa Barbara Sense-of-Direction Scale.

SUS System Usability Scale.

VR Virtual Reality.

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APPENDIX A

Appendix

A.1 Consent Form

TECHNISCHE UNIVERSITÄT WIEN

Einverständniserklärung zur Teilnahme an der Studie 'Pedestrian Navigation on a Smartwatch'

Einverständniserklärung

Name TeilnehmerIn (Druckbuchstaben): …………………………………………

Geb. Datum (optional): …………………

Ich wurde von der verantwortlichen Person dieses Forschungsprojektes (Martin Perebner) vollständig über Wesen, Bedeutung und Tragweite des Forschungsprojektes aufgeklärt.

Ich bin damit einverstanden, dass in diesem Forschungsprojekt Daten von mir aufgezeichnet werden. Mir ist bekannt, dass meine Daten anonym gespeichert und ausschließlich für wissenschaftliche Zwecke verwendet werden.

____
Datum

____
Unterschrift TeilnehmerIn

A.2 SBSOD

SANTA BARBARA SENSE-OF-DIRECTION SCALE

Sex: F M Today's Date:________________
Age:_______ V. 2

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

1. I am very good at giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for where I left things.

strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.

strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My "sense of direction" is very good.

strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).

strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.

strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

9. I am very good at reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.

strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.

strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips.

strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.

strongly agree 1 2 3 4 5 6 7 strongly disagree

15. I don't have a very good "mental map" of my environment.

strongly agree 1 2 3 4 5 6 7 strongly disagree

A.3 NASA-TLX

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

A.4 Code Example

The shown class *NavigationPresenter* represents one of the core components of the applications. It is used for the basic as well as the advanced application where the mode is toggled by the *BuildConfig*. The class is responsible for reacting appropriately to location and bearing changes by calling the respective update-methods of the *NavigationView*. While the *NavigationView* itself is responsible for how the navigation should be visualized, the *NavigationPresenter* decides based on the inputs and further calculations what should be displayed.

```java
package com.martinperebner.androidwearnavigation;

import android.location.Location;
import com.google.android.gms.location.LocationListener;
import com.google.android.gms.maps.model.LatLng;
import com.google.maps.android.SphericalUtil;
import com.martinperebner.androidwearnavigation.gps.GpsTracker;
import com.martinperebner.androidwearnavigation.models.Step;
import java.text.SimpleDateFormat;
import java.util.ArrayList;
import java.util.Date;
import java.util.List;

/**
 * Created by Martin on 26/10/16.
 */

public class NavigationPresenter implements LocationListener, CompassTrackerWear.
CompassListener {

  private static final int VIBRATION_THRESHOLD = 40;

  private NavigationView navigationView;

  private GpsTracker gpsTracker;
  private CompassTracker compassTracker;

  private List<Step> steps;
  private List<LatLng> path;

  private Location currentLocation;
  private Step currentStep;
  private long lastStepVibration;

  private final boolean landmarkEnabled = Config.LANDMARK_ENABLED;
  private final boolean bearingEnabled = Config.BEARING_ENABLED;

  public NavigationPresenter(NavigationView navigationView, List<Step> steps, GpsTracker
 gpsTracker,
      CompassTracker compassTracker) {
    this.navigationView = navigationView;
    this.steps = steps;
    this.gpsTracker = gpsTracker;
    this.compassTracker = compassTracker;
    this.lastStepVibration = -1;

    this.path = new ArrayList<>();
    for (Step step : steps) {
      List<LatLng> stepPoints = step.getPoints();
      if (!path.isEmpty() && path.get(path.size() - 1).equals(stepPoints.get(0))) {
        this.path.addAll(stepPoints.subList(1, stepPoints.size()));
      } else {
        this.path.addAll(stepPoints);
      }
    }
  }

  public void attachView() {
    gpsTracker.setLocationListener(this);
    if(bearingEnabled) {
      compassTracker.setCompassListener(this);
    }
  }

  public void detachView() {
    gpsTracker.setLocationListener(null);
    if(bearingEnabled) {
      compassTracker.setCompassListener(null);
    }
  }

  public void mapReady() {
    navigationView.showDestinationMarker(steps.get(steps.size() - 1).getEndLocation());
  }

  @Override
  public void onLocationChanged(Location location) {
    if(location == null) {
```

```
      return;
    }

    Location newLocation = new Location(location);
    if (bearingEnabled && currentLocation != null && currentLocation.hasBearing()) {
      newLocation.setBearing(currentLocation.getBearing());
    }
    currentLocation = newLocation;

    LatLng currentLatLng =
        new LatLng(currentLocation.getLatitude(), currentLocation.getLongitude());
    LatLng[] nearestPointResult = PathUtils.nearestPointOnPath(currentLatLng, path);
    LatLng snapLatLng = nearestPointResult[0];
    LatLng snapPathLatLngFirst = nearestPointResult[1];
    LatLng snapPathLatLngSecond = nearestPointResult[2];

    int splitIndex = path.indexOf(snapPathLatLngFirst);
    List<LatLng> previousPath = new ArrayList<>(path.subList(0, splitIndex + 1));
    List<LatLng> nextPath = new ArrayList<>(path.subList(splitIndex + 1, path.size()));

    double currentPathHeading = -1;
    if (nextPath.size() >= 1 && !nextPath.get(0).equals(snapLatLng)) {
      currentPathHeading = SphericalUtil.computeHeading(snapLatLng, nextPath.get(0));
    } else if (nextPath.size() >= 2) {
      currentPathHeading = SphericalUtil.computeHeading(snapLatLng, nextPath.get(1));
    }

    List<LatLng> previousPathInc = new ArrayList<>(previousPath);
    List<LatLng> nextPathInc = new ArrayList<>(nextPath);
    if (!previousPathInc.get(previousPathInc.size() - 1).equals(snapLatLng)) {
      previousPathInc.add(snapLatLng);
    }
    if (nextPathInc.size() > 0 && !nextPathInc.get(0).equals(snapLatLng)) {
      nextPathInc.add(0, snapLatLng);
    }

    Step newStep = null;
    for (Step step : steps) {
      for (int i = 0; i < step.getPoints().size() - 1; i++) {
        if (step.getPoints().get(i).equals(snapPathLatLngFirst) && step.getPoints()
            .get(i + 1)
            .equals(snapPathLatLngSecond)) {
          newStep = step;
          break;
        }
      }
    }

    if(newStep == null) {
      return;
    }

    boolean isNewStep = !newStep.equals(currentStep);
    currentStep = newStep;

    double nextTurnDistance =
        SphericalUtil.computeDistanceBetween(currentLatLng, currentStep.getEndLocation()
);

    double remainingDistance = nextTurnDistance;
    int currentStepIndex = steps.indexOf(currentStep);
    if(currentStepIndex != -1 && currentStepIndex < steps.size()-1) {
      for(int i=currentStepIndex+1; i<steps.size(); i++) {
        remainingDistance += SphericalUtil.computeDistanceBetween(steps.get(i).
getStartLocation(), steps.get(i).getEndLocation());
      }
    }
    double remainingTime = remainingDistance / 1.25;
    Date arrivalTime = new Date(new Date().getTime() + (long)(remainingTime * 1000));
    SimpleDateFormat timeFormatter = new SimpleDateFormat("HH:mm");

    navigationView.updateMapLocation(currentLocation);
    navigationView.updateDirectionView(currentStep, nextTurnDistance);
    if(landmarkEnabled) {
      navigationView.updateMapLandmark(currentStep.getLandmark(), currentStep.
getLandmarkPlacement());
    }
    navigationView.updateMapPath(previousPathInc, nextPathInc);
```

```
    navigationView.updateCamera(currentLatLng, currentPathHeading, nextTurnDistance,
isNewStep);
    navigationView.updateArrivalTime(timeFormatter.format(arrivalTime));

    if((lastStepVibration != currentStep.getId() && nextTurnDistance <
VIBRATION_THRESHOLD)
        || (isNewStep && lastStepVibration < currentStep.getId()-1)) {
      lastStepVibration = currentStep.getId();
      navigationView.vibrate();
    }
  }

  @Override
  public void onCompassChanged(float azimuth) {
    if (bearingEnabled
        && currentLocation != null && Math.abs(currentLocation.getBearing() - azimuth) >
 5) {
      currentLocation.setBearing(azimuth);
      navigationView.updateMapLocation(currentLocation);
    }
  }
}
```