The use of maps on smartwatches

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September, 2019

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Cartography M.Sc.

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Enschede, The Netherlands, September, 2019

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the joint Master of Science in Cartography

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ABSTRACT

Smartwatches are becoming more popular, allowing the user to access and communicate online information with others immediately while moving. Whether location-based or not, smartwatches can also provide spatio-temporal information to the user and display maps on the screen. These maps could be used for wayfinding or accessing location-based information such as weather alerts for the user's current region. The small screen size limits the amount of information that can be accessed by the user looking at the map, as well as the overview that can be obtained. This thesis research addresses this issue by proposing and executing exploratory use and user requirement analysis with the intention of deriving recommendations for the communication of spatio-temporal information through smartwatches, focusing on the design and use of maps on smartwatches. To achieve this goal a mixed methods approach centred around the Tobii Pro Glasses 2 mobile eye-tracking system. Other research techniques applied are the observation, thinking-aloud method, interviews and questionnaires. General recommendations for the use of maps on smartwatches are related to the geographic questions the map should answer.

ACKNOWLEDGEMENTS

Foremost, I would to express my deepest gratitude and appreciation to my thesis supervisor, Dr. Corné van Elzakker, for providing invaluable guidance, insights, suggestions and tremendous support. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my master thesis.

Besides my advisor, I would like to thank the rest of my thesis committee: Dr. Menno-Jan Kraak and Thomas Gründemann for their encouragement, insightful comments, and hard questions.

I would also like to extend my thanks to all the nine test participants for taking the time to participate and for your valuable feedback. The completion of this thesis could have not been possible without you.

The completion of this thesis brings to the end of this two years journey. Therefore, I would like to thank everyone involved in this programme from TU Munich, TU Vienna, TU Dresden and ITC. Thanks to every single one of you for these two unforgettable years. In addition, I would like to extend my thanks to my classmates.

My deepest appreciations go to my family and friends. There are no words to express my gratitude for your unconditional support, love and encouragement throughout the entire master's programme.
I would like to thank my husband, Dauren, for his kindness and support he has shown during the past two years.

I dedicate this thesis to the memory of my grandmother, Nagima Isanbergenova, who always believed in my ability to be successful in the academia. You are gone but your belief in me has made this journey possible.

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1. INTRODUCTION

1.1. Background

Spatial information is a special kind of information that is traditionally communicated to the user using a communication tool such as a map display (Van Elzakker & Delikostidis, 2010). Evolution of technology has made possible dynamic, interactive, and demand-driven solutions for the communication of spatio-temporal information on the screens of wearable devices such as smartwatches. This thesis focuses on the special characteristics of communicating spatio-temporal data through smartwatches, to provide potential recommendations on the improvement of this communication.

1.2. Motivation and problem statement

In recent years smartwatches are becoming more popular, allowing the user to access and communicate online information with others immediately while moving (Lee, Kim, Ryoo, & Shin, 2016). Smartwatches unit sales worldwide are projected to reach 89.1 million by 2022, doubling the number of sales from 2018 with 43.5 million units sold (Wanjari & Patil, 2017). The appeal of a smartwatch is the possibility to quickly access timely and location-based information with minimum interference between the users and their current activity (Cecchinato, Cox, & Bird, 2017). Smartwatch devices can be used for timekeeping, monitoring heart rate, tracking activity and providing notifications (URL1). In addition to this, smartwatches are usually equipped with built-in GNSS/GPS capabilities, which allow the user to access location-based information. Whether location-based or not, smartwatches can also provide spatio-temporal information to the user and display maps on the screen. These maps could be used for wayfinding or accessing location-based information such as weather alerts for the user's current region. There are several limitations when it comes to the design of maps for smartwatches such as limited screen size, limited battery supply and small hardware size (Rawassizadeh, Price, & Petre, 2015). The small screen size limits the amount of information that can be accessed by the user looking at the map, as well as the overview that can be obtained.

The problem is that hardly any research has been done on the design, use, and usability of map displays on smartwatches nor on the communication of spatio-temporal information through smartwatches in general. Therefore, the focus of this research will be on the usability of maps on smartwatches and which factors influence that usability, in order to identify potential design concerns and give recommendations for the communication of spatio-temporal information through smartwatches.

1.3. Research identification

1.3.1. Research objectives

The overall objective of this project is to provide recommendations for the communication of spatio-temporal information through smartwatches, focusing on the design and use of maps on smartwatches. The recommendations for the design could be further used by smartwatch app developers to efficiently communicate the spatio-temporal information to the users to provide effective, efficient and satisfactory location-based apps.

1.3.2. Research questions

1. What is the state-of-affairs with respect to the provision of spatio-temporal information through smartwatches?
    a. What spatio-temporal information is currently communicated through smartwatches and for which purposes?
    b. How is spatio-temporal information currently communicated through smartwatches?
    c. Which maps are being used for the communication of spatio-temporal information through smartwatches? What are their characteristics?
    d. What are the purposes of maps on smartwatches?
    e. Who is the target audience?
    f. What are the potential strengths and weaknesses of maps on smartwatches.
2. What is the usability of current maps on smartwatches?
3. Which recommendations can be provided for the communication of spatio-temporal information through smartwatches?
    a. In which cases and for which purposes are maps useful to convey spatio-temporal information?
    b. In which cases and for which purposes is it better to use other ways of communication (eg. text, audio or haptics)?
    c. How should a map be designed for an effective, efficient and satisfactory communication of spatio-temporal information?
    d. How should an application be designed for an effective, efficient and satisfactory communication of spatio-temporal information?

1.4. Innovation aimed at

Despite the rapid development of wearable technologies that can potentially improve people's lifestyles, the adoption of these devices has been relatively slow compared to smartphones (Kalantari, 2017). Due to the fact that smartwatch usage is still in the early adopters stage of the technology adoption cycle, there have been hardly any papers published on user and design research for maps on smartwatches.

1.5. Outline

In order to answer the research questions, methods related to the User-Centered Design process (van Elzakker & Ooms, 2017) will be applied. However, the research will mainly be limited to the requirement analysis. The requirement analysis will be derived from observing the participants who interact with cartographic applications on smartwatches. The research stages are shown in the workflow below (Figure 1-1).

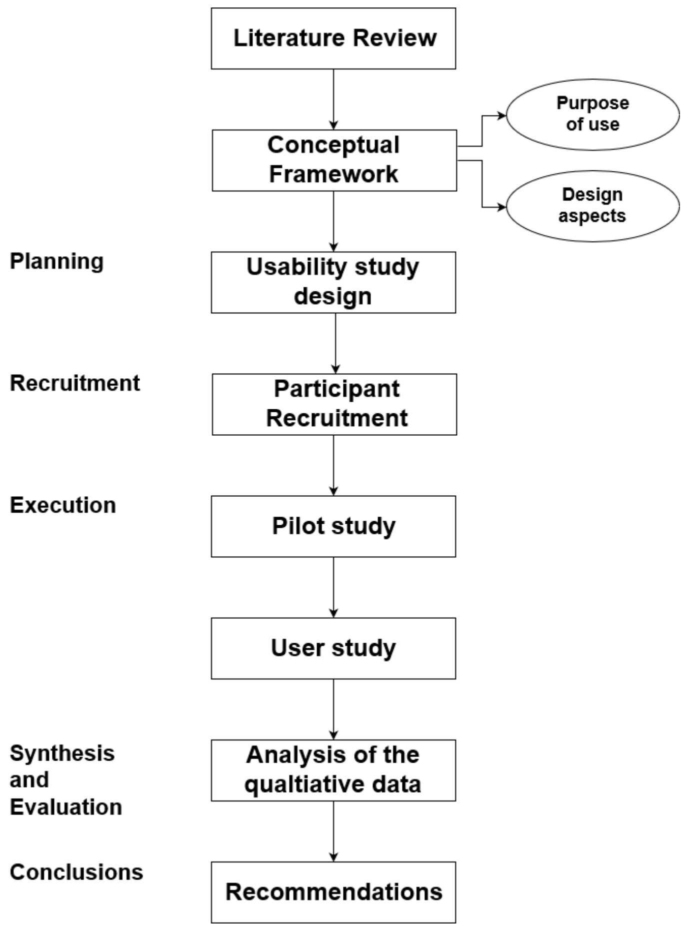


Figure 1-1 Research workflow

In the **first chapter**, the introduction and motivation are presented. In addition, the research objectives and research questions that this thesis will try to answer are stated.

In the **second chapter**, the literature review describes in more detail the current state of smartwatch apps in both industry and academia. The chapter is divided in four main parts: (1) characteristics of smartwatches (2) inventory and evaluation of smartwatch applications (3) usability aspects of smartwatches (4) current research on spatial smartwatch applications. In the first subchapter the hardware characteristics of smartwatches are described. The second subchapter deals with an inventory of the smartwatch applications, which will shed a light on how spatio-temporal information is communicated on smartwatches. The third subchapter deals with the usability aspects of the smartwatches such as small screens, limited battery life and small hardware size. And finally, in the fourth subchapter the existing usability studies are described and evaluated.

The **third chapter** explains the adopted methodology to perform the usability tests, including a review of the thinking aloud and eye tracking techniques.

The **fourth chapter** focuses on the implementation. It describes the user study in detail, from the selection of the participants to the pilot study and the actual tests.

In **chapter five**, the results of the usability study are presented.

In **chapter six**, the results of the usability study are analyzed, interpreted and evaluated. Moreover, the recommendations for the potential improvement of communicating geographic information on smartwatches are presented.

Lastly, in **chapter seven**, an overview of the work performed for this thesis, as well as recommendations for future research are provided.

2. LITERATURE REVIEW

2.1. Introduction

To start investigating the usability of maps on smartwatches, a closer look on smartwatch applications should be taken. What is a smartwatch? What are smartwatch characteristics? What applications are currently available on smartwatches that communicate spatio-temporal information? Which applications communicate the spatio-temporal information through maps? What are the usability aspects of smartwatches? What related user studies have been done so far. These are some important questions that this chapter is dealing with. This chapter is a literature review regarding smartwatches and smartwatch applications that communicate spatio-temporal information.

The chapter starts with a definition of a smartwatch, briefly talks about the history of smartwatches and describes some key smartwatch characteristics. Then an inventory of current smartwatch applications communicating spatio-temporal information is presented, later focusing more specifically on the applications that utilize maps to communicate spatial and spatio-temporal information. Further, the usability aspects of smartwatches are described. Lastly, some related user studies that have been performed with maps on smartwatches are discussed.

2.2. What is a smartwatch?

Like a traditional watch, a smartwatch is designed to be worn on a wrist. Unlike a traditional watch, the smartwatch is not only used as a chronograph, but also as a small wearable computer with an array of sensors and processors (Rawassizadeh et al., 2015). A smartwatch is "a wrist-worn device with advanced computational power, that can connect to other devices via short range wireless connectivity; provides alert notifications; collects personal data through a range of sensors and stores them; and has an integrated clock" (Cecchinato, Cox, & Bird, 2017).

The idea of putting a small computer on one's wrist is not new. Smartwatch history goes back several decades into the past, starting with early digital watches and organizers, such as Seiko TV Watch in 1982, Seiko MessageWatch in 1995, Swatch/HP's Webwatch, the Microsoft Smart Personal Objects Technology, and the Fossil's PalmOS powered Wrist-PDA (McMillan et al., 2017). However, the technology at the time was expensive and not powerful enough to provide the full functionality, hence the attempts to promote smartwatch usage have failed (Rawassizadeh et al., 2015). Now after technological developments in miniaturization, extension of battery life and diminishing costs for various sensors and processors, the usage of smartwatches is moving from specialist market to mainstream (Rawassizadeh et al., 2015).

In 2022, it is projected that 89.1 million (Figure 2-1) smartwatches will be shipped worldwide, up from 43.5 million units in 2018 (IDC, 2019). Despite their popularity, smartwatches are still relatively new to the commercial mobile device family and smartwatch ownership is still at the early adopter stage on the technology adoption lifecycle (Davie & Hilber, 2016; Liu et al., 2017). The 'early adopters' is a class of consumers who will adopt the product and make up 13.5% of the market (Rogers, 2010).
The lack of adaptation of smartwatches in general population can potentially be due to the lack of the "killer app", an application that differentiates smartwatch from smartphones (Visuri, Sarsenbayeva, Berkel, & Goncalves, 2017).

According to the Ericsson ConsumerLab (Ericsson ConsumerLab, n.d.) report, the composition of the users of wearables is evolving. In their report, they identify the ages of both new and experienced users. The majority of the new users of wearables are adults in the 25-34 age bracket. However, in the experienced (experience with smartwatch) users category the age groups are more evenly spread out.

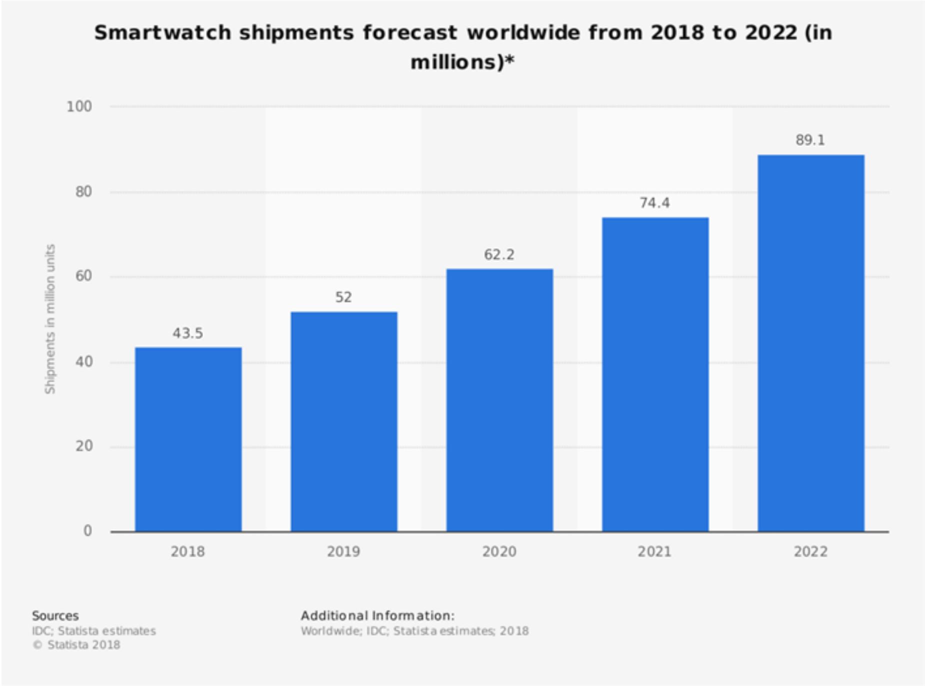


Figure 2-1 Worldwide unit shipments of smartwatch/smart wristwear from 2018 to 2022.

2.3. Smartwatch characteristics

Smartwatches are gaining multiple standalone features such as internet connectivity that don't require users to rely on the mobile phones. Some companies such as Samsung and Sony are launching smartwatches as complementary interface for their mobile devices while other companies like Apple adapting a hybrid approach (Rawassizadeh et al., 2015). Latest Apple Watch Series 3 and 4 are connected to the cellular network and can function even if the phone isn't nearby (URL2).

Current smartwatches enable users to synchronize notifications such as SMS, email, WhatsApp, weather notifications, interact with applications and display information on the screen (Visuri et al., 2017). Smartwatch usage is currently centered around notifications, activity tracking and timekeeping (McMillan et al., 2017). Overall, checking notifications, especially in a more discrete way compared to smartphones, is perceived as the main functionality of the smartwatch (Visuri et al., 2017). In addition, smartwatches can collect biological, environmental, and behavioral information due to the constant skin contact with the user (Rawassizadeh et al., 2015). Everyday activities such as how many steps were taken, heart rate, distance travelled and temperature can be easily monitored using a smartwatch.

To allow interactions, the smartwatch enables touchscreen taps, voice inputs and gestures, as well as buttons, rotating bezel, and digital crown for mechanical input (Kerber, Kiefer, & Löchtefeld, 2016). Despite having these interaction methods available, the main interaction remains through the touch screen. However, the small size of the display results in the fat-finger and occlusion problems. The fat-finger problem is caused by the relatively large size of a user's fingers in contrast to the size of the screen (Arefin Shimon et al., 2016).

The occlusion problem describes the obstruction of the target area by the user's finger, hence leaving the user without the visual feedback (Baudisch & Chu, 2009).
Smartwatches are considered as low-interaction devices (Maier & Wörndl, 2015). In comparison with smartphones, smartwatches are used more briefly and more frequently throughout the day with the average usage sessions lasting less than 5 seconds (Visuri et al., 2017).

The main advantages of having a smartwatch is their mount location and constant connection to the skin (Rawassizadeh et al., 2015). The mount location of the device on the wrist affords freedom for interactions when performing tasks such as driving, hiking, exercising. In addition, a smartwatch helps to be less distracted by smartphones and maintain continuous engagement in cognition with real-world contexts in situations in the physical environment (Chun, Dey, Lee, & Kim, 2018). The constant connection to the skin allows the recording of the owner's physical activities and location (Rawassizadeh et al., 2015). Many smartwatches have built-in GPS receivers, although on some smartwatches a combination of the GSM, Wi-Fi, and GPS is used for localization services to reduce the power consumption (Rawassizadeh et al., 2015).

The most popular operating systems for wearables are WatchOS, Android/WearOS, Tizen, Fitbit OS, Garmin OS. In 2015 Apple entered the market and has dominated the market ever since with 9.2 million units shipped in the fourth quarter of 2018 (Figure 2-2). Besides Apple, the main players of the smartwatch market are Samsung, Fitbit and Garmin (Strategy Analytics, n.d.). It's important to note that Fitbit and Garmin are considered as fitness trackers with some smartwatch functionalities (URL3). The main purpose of the fitness trackers is monitoring and data gathering, while smartwatches are built for information communication (URL4).

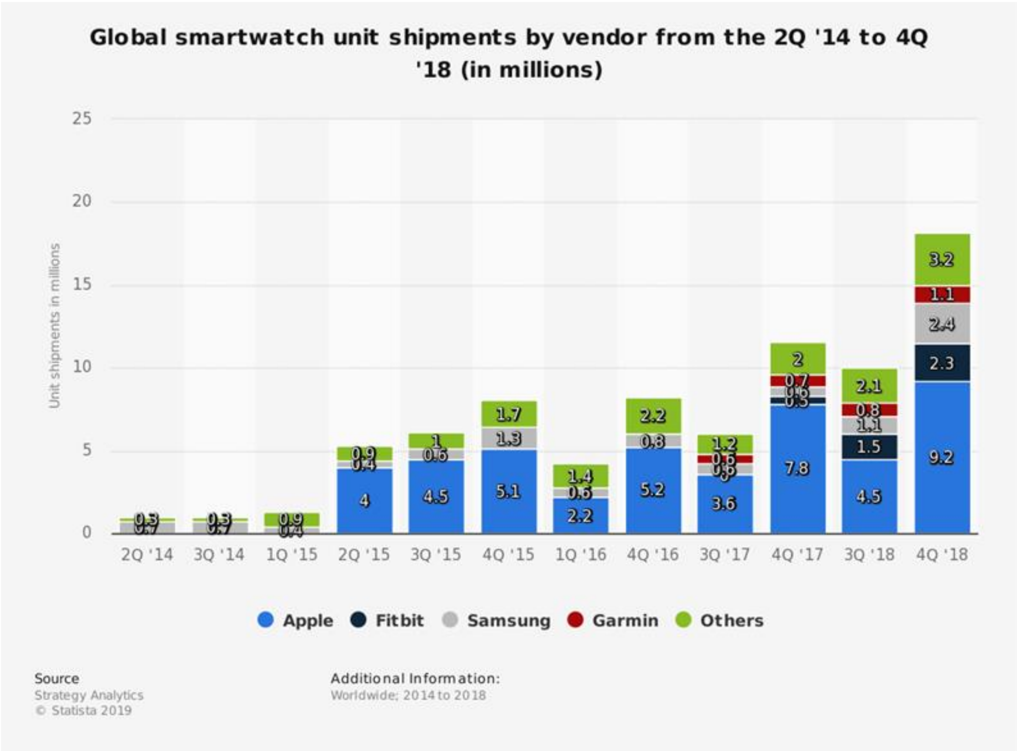


Figure 2-2 Global smartwatch unit shipments by vendor from the second quarter of 2014 to the fourth quarter of 2018.

Smartwatches suffer from three major constraints: screen size, small hardware and limited battery capacity (Rawassizadeh et al., 2015). The typical battery capacity for the smartwatches is one to three days, and two to four weeks for fitness trackers (URL5). Small screen size results in limited input/output and small hardware means weaker computing capability (Rawassizadeh et al., 2015). The screen display size is varying around 1.1 in (28.1 mm) for Samsung Galaxy Watch Active and 1.78 in (44mm) for Apple series 4. It's important to note that the dimensions of the smartwatches do not equal the display size, so for example, Apple Watch with the dimensions 44 mm has a larger display area (44 mm display with 368 x 448 pixels resolution) than Samsung Galaxy Watch (33mm display with 360 x 360 pixels resolution) (URL6).

2.4. Inventory of smartwatch applications communicating spatio-temporal information

According to a large-scale study (Chauhan, Seneviratne, Kaafar, Mahanti, & Seneviratne, 2016) of popular smartwatch applications, Apple's app store had more than 10,000 smartwatch applications, Google Play had 4000 apps for Android Wear devices, and Samsung Gear Store had over 1000 apps. Although, Android Wear was rebranded as Wear OS in 2018 to become compatible with both Android and iOS phones (URL7). The majority of applications for smartwatches are comprised by personalization applications for smartwatch faces. Google Play distinguishes the category Travel & Local for applications that utilize maps and navigation, Apple uses Travel and Navigation category, and Samsung puts them in Lifestyle category.

An inventory of the applications that communicate spatio-temporal information was created. Although some of the Garmin and Fitbit fitness trackers have smartwatch functionalities, the main purpose of the fitness trackers is to collect information, rather than information communication. Hence, WatchOS, WearOS and Tizen operating systems were chosen to create an inventory of the smartwatch applications that communicate spatio-temporal information. The applications were selected from the Apple App Store (URL8), Google Play Store (URL9) and Samsung Galaxy Store (URL10). The applications were divided by use purpose: biking, running, travel, hiking, skiing, golfing, taxi/driving, weather, general navigation and social navigation.

Category	WatchOS	WearOS	Tizen
Biking	Strava, Map My Ride By Under Armour, Cyclemeter Cycling Running GPS, Komoot – Cycling & Hiking Maps, iBiker Cycling & Heart Trainer, Bike NYC – CitiBike Map	Strava, Bikemap – GPS Bike Route Tracker & Map for Cycling, Ghostracer – GPS Run & Cycle, Cycle Now: Bike Share Trip Planner, MyRunningApp GPS Running Bike	Strava, Bike&Go
Running	Nike+ Run Club, Strava Running, Endomondo, RunGo, Runkeeper, Runtastic, MapMyRun, Nike Run Club, WorkOutDoors, Strava Running, Map My Walk by Under Armour, Relive: Run, Ride, Hike & more, Couch to 5k-Run Training, iRunner Run & Jog Tracker, RunGO – The Best Routes to Run, Running Trainer: Audio Coach	Runkeeper, Runstastic, Endomondo, Wear Run Pro, Ghostracer, Zombies, Run!, Endmondo, Strava Running, Wear Run Pro, Nike+ Run Club, Map My Run, Runmore 5K Trainer	Map My Run, Endomondo, Strava, Personal Fitness Coach, Run4Gear, GearS3Running
Travel	TripAdvisor, Citymapper, Brtitish Airways, Find Near Me, Yelp, Foursqare City Guide, Hotwire, App in the Air, Cleartrip, TripIt: Travel Planner, Roadtrippers – Trip Planer, Topo Maps+ , Mapstr-The Map of Your World, Sygic Travel Maps Offline, Footpath Route Planner, Polarsteps, Honolulu Travel Guide, Quebec City Travel Guide, World City Guides & Maps	Foursquare City Guide, App in the Air, Citymapper	City Navigator, App in the Air for Samsung, Places

Hiking	AllTrails: Hike, Run & Cycle, Map My Hike by Under Armour, Elevation – Sea Level Map, Gia GPS Hiking, Hunting Maps, ViewRanger: Hike, Ride or Walk, Topo Map & Hiking Tracker, Cairn: Hiking & Outdoors Trails, Maps 3D PRO – Outdoor GPS	Locus Map Watch, ViewRanger: Trail Maps for Hiking, Biking, Skiing	BackCountry Navigator, Locus Map Watch
Skiing	Slopes, Steamboat Ski and Resort, Jackson Hole, SNOCRU Skiing & Snow Tracking, Ski Tracks	Ski Tracks, Ski Pursuit	Samsung Health, Ski Pursuit
Golfing	Hole19, Tag Heuer Golf, UDisc Disc Golf	Hole19, Golf GPS Rangefinder: Golf Pad	Hole19, Golf Navi Pro, Golfwith: Smartcaddie
Taxi/ Driving	Uber, mytaxi, Easy, a Cabify app, PlugShare (EV charger locator app), iParkit Garage Parking	Uber, ParKing, Find My Parked Car - Automatically Locate Car	Uber, Find My Car
Weather	Carrot Weather, Dark Sky Weather, Yahoo Weather, The Weather Channel, Weather Underground, AccuWeather, WeatherNerd, WeatherLive, NOAA Radar Pro, WeatherBug, Earthquake+Alert, Map & Info, eWeather HD – Weather & Alerts, The Weather Network, Weather & Radar, Volcanoes: Map, Alters & Ash, My Earthquake Alerts Pro, Weather and Radar Pro, Sickweather, Pollen Forecast Pro, Earthquake Monitor, Rain Alarm- Weather Radar	Accuweather, MyRadar, ByssWeather for Wear OS, The Weather Channel, Weather 14 Days – Meteored, Dark Sky, NOAA Weather International, Weather Maven for Wear OS, RadarScope	Storm Radar, Weather, GPS Weather Radar, Lightning Map
General Navigation	Maps, ETA – Arrie on time,Transit, New York Subway MTA Map, Tube Map – London Underground, Gygic GPS Navigation & Maps, Moovit: Train & Bus Times, Coordinates – GPS Formatter, 2GIS – Offline maps, Transit Navigation, Yandex.Maps, NYC Bus Checker, iMaps+ for Google Maps	Google Maps, Offline Map Navigation - Live GPS, Transit Now MBTA, AC Transit, SFMTA Muni, La Metro	HERE WeGo, Navigatior PRO, Navigator – Voice Navigation, GMaps – Google Maps with Navigation, Navigator Standalone, Navigator Companion, GPS Tracking Google Map, Navigator Lite, Traffic Assistant
Social Navigation	Find My Family, Phone, Friends; Glympse – Share your location, Scout GPS, ETA, Maps & Traffic, Mappen – Make Something Happen;		Glympse – Share GPS location

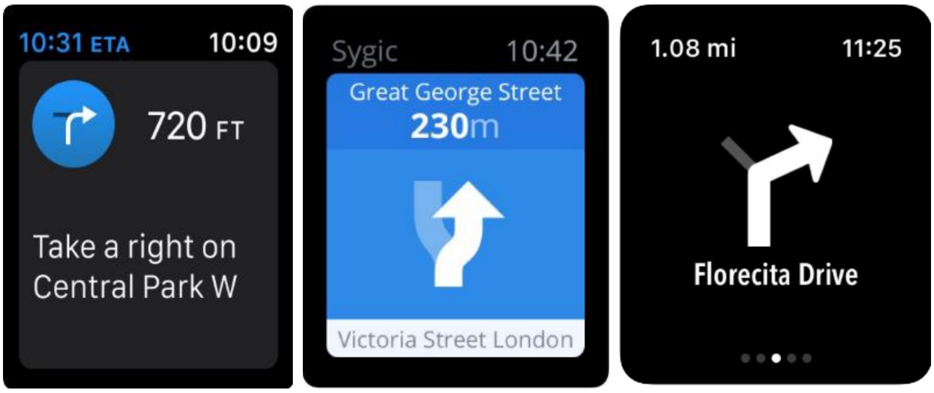
Table 2-1 Inventory of the smartwatch applications that communicate spatio-temporal information.

2.5. Use of maps on smartwatches

Smartwatch applications presented in Table 2-1 can be divided in four main categories based on the presentation of spatio-temporal informaiton: applications using only text (Figure 2-3), applications using text and symbols as main tools to present the spatio-temporal information as shown in Figure 2-4, applications that are utilizing both text and maps as shown in Figure 2-5, and applications that use maps as primary to tool to communicate spatiotemporal information as shown in Figure 2-6.

a. b. c.

Figure 2-3 Smartwatch applications using only text to present spatio-temporal information: a) Outdoor Run b)Zombies, Run! c) Gaia GPS



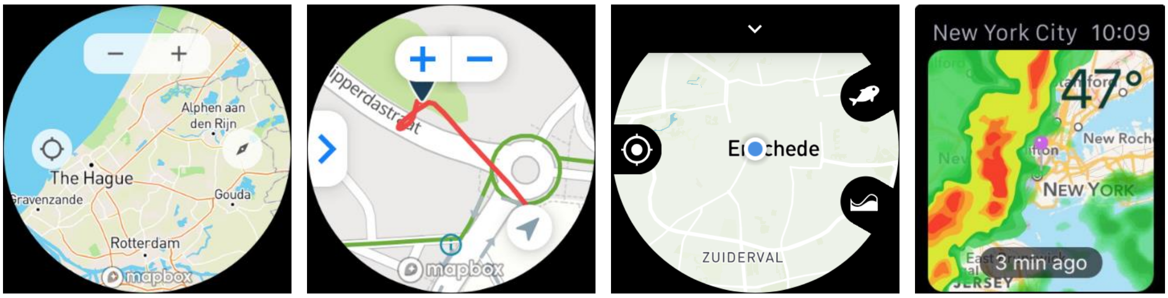
a. b. c.

Figure 2-4 Applications using only text and symbols to communicate spatio-temporal information: a) Maps (WatchOS) c) Sygic GPS Navigation and Maps d) Footpath Route Planner

a. b. c.

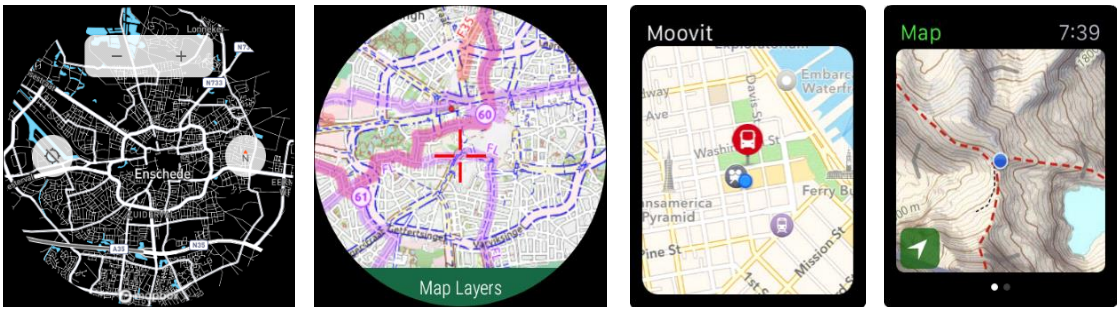
d. e.

Figure 2-5 Applications using both text and maps a) Runtastic b)Watch Routes c) Google Maps d) Earthquake e) Workoutdoors



a. b. c. d.

Figure 2-6 Applications using primarily maps a) Maps (WearOS) b) Bikemap c)Fishbrain d)NOAA Radar Pro



a. b. c. d.

Figure 2-7 Basemaps a) Maps b) View Ranger (WearOS) c) Moovit d)Topo Maps+

The first and second category of applications shown in Figure 2-3 and Figure 2-4, use text and symbols to display duration, pace, speed, elevation, distance, and directions. Typically, most of the screen is one solid color and the information is shown with the high contrast color in large font size.
The third category (Figure 2-5) uses compartmentalized layout, part of the screen real estate is occupied by maps and another part is occupied by the text and symbols to provide additional The first and second category of applications shown in Figure 2-3 and Figure 2-4, use text and symbols to display duration, pace, speed, elevation, distance, and directions. Typically, most of the screen is one solid color and the information is shown with the high contrast color in large font size.
information. Typically for these applications the background map has light less saturated basemap and the additional textual information is shown in high contrast colors.
The fourth category, shown in Figure 2-6, uses maps as main tool to communicate spatio-temporal information. Some of the applications have zooming buttons at the top of the screen and self-location buttons on the edge of the screen. The basemap for these applications can be very different: some basemaps are simple and generalized, some have a lot of information (Figure 2-7).

Most of the basemaps in smartwatch applications use raster basemaps. One applications that uses vector base is WorkOutDoors (see Figure 2-5e).

2.6. Usability aspects of maps on smartwatches

Limited screen size of smartwatches and low battery are the main usability constraints for the users. The average screen size of the smartwatch is only a tenth to a quarter of the size of a typical smartphone screen (Perebner, Huang, & Gartner, 2019). Usability of wearable devices is more challenging when people are interacting with visually rich content such as maps. Chun et al. (2018) have discovered from their qualitative study on smartwatch usability that users assessed smartwatches as providing the lowest usability when performing map navigation tasks. Although map navigation is one of the most frequent uses of smartwatches, according to the study the wearable devices did not provide the expected results for the users. In fact, an earlier study (Dillemuth, 2009) already showed that small digital maps proved to be problematic for answering questions about relative distance and direction.

Already in the early 2000s, various techniques such as Double Scrollbar, Grab & Drag, and Zoom Enhanced Navigator, have been explored to solve the problem of interaction and visualization on a small screen of mobile devices (Burigat, Chittaro, & Gabrielli, 2008). At the time, displaying a detailed map on a small screen of a mobile device seemed challenging. Although the techniques that have been shown to be effective in solving the problem of screen size on mobile devices are not
guaranteed to provide a solution for the smartwatch screen problem, it is useful to explore those solutions.

The study of Burigat & Gabrielli (2008) also has been done to explore the large information load on small spaces to visualize information from the desktop computers to mobile devices and PDAs. Generally, solutions for visualizing the information on a small screen are: restructuring of the information space, traditional scrolling/panning and zooming techniques, Overview&Detail approaches, Focus&Context approaches, and off-screen visualization (Burigat et al., 2008). Additional recommendations for mobile map design are shown in Table 2-2 (Ricker & Roth, 2018), which provides a summary of Muehlenhaus (Muehlenhaus, 2013) and Roth et al. (Roth et al., 2018) recommendations.

Map Composition & Layout	Constraint
maximize the screen real-estate used for the map view	screensize
use full-screen dialog windows for text & interface menus	screensize
Scale & Generalization	**Constraint**
present only task-relevant information	bandwidth; screensize
generalize basemap	bandwidth; screensize
include salient landmarks for orientation	mobility
increase default map scale (i.e., zoom in)	screensize
constrain smallest map scale (i.e., max zoom out)	mobility
provide visual affordance for off-screen content	screensize
load map progressively, using tiles	bandwidth
cache essential information on load	bandwidth
use vector tile sets	bandwidth
Projection	**Constraint**
center map on user's location	mobility
update user's position on the map	mobility
reorient view so that forward is up	mobility
Symbolization	**Constraint**
emphasize wayfinding	mobility
use self-explanatory icons for POIs	mobility; screensize
increase contrast within visual hierarchy	viewing conditions
increase brightness and saturation of map features	viewing conditions
increase size of interactive point symbols	touchscreen
include vector and imagery basemap options	mobility
Typography	**Constraint**
use sans serif fonts	screensize
increase text size and tracking	screensize
divide long sections of text into multi-window blocks	screensize
keep text upright as user rotates map	handheld
Map Elements	**Constraint**
hide legend, help, and supplementary info by default	screensize
include persistent north arrow for egocentric view	mobility
allow text and audio options for descriptions/directions	screensize
Interaction	**Constraint**
include post-WIMP widgets only	multi-touchscreen
provide visual affordances for interactive widgets	multi-touchscreen
support double-tap and pinch for zoom	multi-touchscreen
support grab-and-drag for pan	multi-touchscreen
support two-finger twist for rotate	multi-touchscreen
include +/- zoom buttons to zoom with one hand	multi-touchscreen
enable voice recognition for keying interactions	voide

use sound and vibration for interaction feedback	handheld
allow the user to tap anywhere to close popups	multi-touchscreen
support tap and hold for advanced options	multi-touchscreen
include search for user's current location	battery; mobility
include calculate wayfinding routes	mobility
support an offline or (for responsive) printable version	bandwidth; battery

Table 2-2 Note. Adapted from Ricker, B., and Roth, R.E., 2018.

Slaughter suggests that zoom, pan, and pitch variables can be automated and controlled by other information such as user location, user speed, and defined route distances. Moreover, when designing a map for mobile use to consider map purpose and target audience, as well as environmental, speed, and time factors (Slaughter, "nd").

2.7. User studies

One of the current challenges of the location-based services development is communicating relevant (spatio-temporal) information to users in an optimal way to facilitate their decision-making and activities in space (Huang, Gartner, Krisp, Raubal, & Van de Weghe, 2018). The related work for usability research to convey spatio-temporal information has been limited to research on smartwatches for navigation purposes such as StripeMaps (D. Wenig, Schöning, Hecht, & Malaka, 2015), ScrollingHome (D. Wenig, Steenbergen, Schöning, Hecht, & Malaka, 2016), SAMMI (Paleari, Huet, & Duffy, 2015), Pharos (N. Wenig et al., 2017), Angkot Malang (Brata, Pinandito, Ananta, & Priandani, 2018). StripeMaps (D. Wenig, Schöning, Hecht, & Malaka, 2015) and Scrolling Home (D. Wenig, Steenbergen, Schöning, Hecht, & Malaka, 2016) both transform a two-dimensional route map to a one-dimensional "stripe". The user study tests were done to compare cartographic approaches for smartwatch maps, with the focus on indoor pedestrian navigation. Although, standards maps did not reach the same performance as StripeMaps, they still performed better than the turn-by-turn directions. ScrollingHome provided one-dimensional image-based indoor navigation instructions on smartwatches. One of the findings of ScrollingHome research, is that there is no need to provide explicit directional instructions for image-based navigation on smartwatches. Pharos (N. Wenig et al., 2017) is a pedestrian navigation approach, which utilizes the global landmark-based navigation. The user study highlighted the benefits of smartwatches for pedestrian navigation in general. The study revealed that due to the low positional accuracy, the user was provided information about the next decision point, which lead to low confidence and could potentially prevent the users from building spatial knowledge of their environment. Angkot Malang study utilized a smartwatch as a secondary mobile device that was used for public transport navigation. A comparison between a traditional map-based smartphone and a smartwatch application was done. Although the experience was similar for both applications, the traditional map-based application was rated higher than the proposed step-by-step smartwatch interface.

A user experience study (Rovelo, Abad, & Camahort, 2015) has been done to improve navigation assistance adding tactile and auditory feedback as an alternative to the visual navigation assistance. The results show that tactile guidance cues performed worse due to participants being unable to detect the vibration patterns (Rovelo et al., 2015). Another user study (Perebner et al., 2019) for designing landmark-based pedestrian navigation systems for smartwatches have concluded that vibrations before decision points to prompt turning actions, a combination of map view and direction view, track-up (instead of north-up) orientation of the map view, and inclusion of landmarks at decision points were perceived as very useful.

Another study (Montuwy, Cahour, & Dommes, 2019) has investigated the performance and user experience of various navigation aids such as paper/digital maps, AR glasses, bone conduction headphones and a smartwatch. A smartwatch (with haptic vibrations and visual instructions) and bone conduction headphones (with auditory instructions) performed better than the digital/paper map and AR glasses. The time required to perform the navigation task as well as the number of instances of inattention were lower when using smartphones and headphones. Also, the smartwatch and headphones were appreciated for being more discrete in providing navigation assistance.

2.8. Conclusion

This chapter outlined the theoretical background of this research, introducing the current issues and solutions regarding the usability of maps on smartwatches. Moreover, the solutions regarding the representation of spatio-temporal information on mobile screens were explored. A few attempts have been done in the past to explore the usability of maps on smartwatches, however most of them were focused on testing the usability of smartwatch applications for navigation purposes only. It was found, that there is a need of further investigating the users' needs and preferences for the communication of spatio-temporal information through smartwatches. This thesis research aims to fill this gap by application of use and user requirement analysis to develop recommendations for use and design of maps on smartwatches. In the next chapter, the methods selected for use in this research are discussed.

3. METHODOLOGY

3.1. Introduction

This chapter describes the design adopted by this master thesis to achieve the aims and objectives specified in the first chapter. Section 3.2 is going to focus specifically on the conduct of the research: the chosen research methods such as eye tracking, observation and think-aloud, as well as the semi-structured interview will be discussed.

3.2. Methods of user research

Usability studies that have been discussed in the previous chapter involve both qualitative and quantitative methods of data collection. Quantitative method offers an indirect assessment of the usability of the design by quantifying the performance of the users on certain tasks such as task-completion times, number of errors (Budiu, 2017). Quantitative usability studies don't point out what changes need to be made to improve the design, let alone the problems that users encountered. On the contrary, the qualitative method offers a direct assessment of the usability by observing the user to get insights on the issues. Qualitative studies enable developing categories and uncovering patterns between them (Suchan et al., 2010). Due to the lack of the previous research for use and design of maps on smartwatches, there is a need to obtain very rich data regarding the user's preferences and needs, hence the qualitative research methods have been selected. The advantage of using the qualitative methods is that they create full and detailed data that allow multiple contexts for understanding the phenomenon (Flick, 2010).

The techniques that were chosen to be used in this research are questionnaire, observation with audio and video recording, think aloud, eye tracking and semi-structured interview. A questionnaire will be posted online to pre-select the participants and discover the potential test person's background. Observation allows the collection of the information in the context of use by watching the participants to avoid the distortion and invalidity of the data caused by the retrospection (van Elzakker & Wealands, 2007). The video recording will be used to capture the user's interaction with the smartwatch to ensure that the research results are verifiable. Also, during the observation method the eye tracking method will be used to record the eye movements. After the user has finished the tasks, semi-structured interviews will be conducted.

3.2.1. Online survey for pre-selecting participants

Questionnaires will be given out to test participants to find out their characteristics and preferences. Using a questionnaire allows to collect demographic data and assess previous interactions with the smartwatch. An online structured questionnaire will be sent out through email to the Faculty and students at The International Institute for Geo-Information Science and Earth Observation (ITC).

The main purpose of the questionnaire is to pre-select the potential test persons, based on their previous experience/ownership of a smartwatch, as well as they previous experience with maps on smartwatches. It is important to recruit users from various potential users groups and to make sure that participants are engaged (van Elzakker, 2018). The test subjects have to be future or current users who also want to answer the spatio-temporal questions in their lives (van Elzakker, 2018). Hence the preference will be given to the participants with prior experience with smartwatches and maps on smartwatches.

3.2.2. Observation and think aloud

According to Gorman and Clayton (2005), observation studies are those that "involve the systematic recording of observable phenomena or behavior in a natural setting." Through observation the processes that underlie the events can be understood and the perspectives of the users discovered. This technique allows deeper understanding of processes opposed to the quantitative methods. Observing the problem-solving behavior while it takes place allows to rule out the distortions and invalidity caused by memory errors on the side of subjects and the inclination of the subjects to rationalize their problem-solving behavior (van Elzakker, 2004).

The users will be given a set of map use tasks and asked to voice their thoughts while executing the task. Think aloud method helps to understand the thought process of the users as they attempt to answer spatio-temoral questions with the help of smartwatches. Think aloud method involves the analysis of the recorded verbal protocols (van Elzakker, 2004). The thinking aloud audio will be recorded with the eye tracking equipment, these recordings will be used to derive protocols.

Thinking aloud is a conscious action and it requires some amount of attention, hence the test subjects have to divide their attention and effort between two actions: solving the map task and thinking aloud (Kjeldskov & Stage, 2004). Although the users need some time to familiarize themselves with the verbalization of their thoughts, the method in general does not disturb their thought process (Schobesberger, 2012).

3.2.3. Eye tracking

Eye tracking has been long known and used to study the visual attention of the users (BMS Lab, n.d.). Eye tracking is one of the most precise and objective methods of usability studies, which can help to understand questions concerning user's strategy of the information searching (Brychtova et al., 2012).

There are two main eye tracking systems: screen based and wearable eye trackers (URL11). Screen based eye-trackers are attached to or built in a desktop computer screen. The main advantage of the screen based eye-tracker is the use of desktop screen coordinates when analyzing the data. However, the research on maps on a smartwatch needs to be done in a proper context, i.e. whilst the test persons are on the move (and not in a research lab). Therefore, a mobile wearable eye tracker is chosen to record the gaze of the test participants.

The eye-tracking technology allows to track the users' eyes through an untethered headset unit. These units give users complete freedom of movement and they can track everything that the user looks at (Schall & Romano Bergstrom, 2014). The main assumption behind the use of the eye tracking method in usability research is the eye-mind hypothesis, which suggests that the visual attention patterns reflect cognitive strategies of the individual (Wang et al., 2019).

Previous studies on smartwatches that have been performed haven't considered the mobile nature of the smartwatch. Qualitative study on the usability of the smart watch interface by Wu and colleagues (2016) has been performed in a static area in the lab. In this research, mobile eye tracking equipment will be used to observe the user in the proper context.

Modern eye trackers can accurately record two types of eye movements: gaze fixations and saccades. Gaze fixation occurs when eye is focusing on the target for a short period of time and saccade is a rapid movement of the eye between two fixations (Wang et al., 2019). Saccades and fixation could be quantified as duration for each fixation, number of fixation and saccade amplitude (Wang et al., 2019). Wu and colleagues (2016) have discovered that fixation duration combined with the fixation point number were useful in revealing users search for information on a smartwatch. In their study the smartwatch interface usability test was carried using the eye-tracking technology.

3.2.4. Semi-structured interview

The interview with test participants can take two forms: structured and unstructured. During an unstructured interview a lot of in-depth information can be gathered when there is little known information, however the answers from different respondents are not comparable (van Elzakker, Delikostidis, & van Oosterom, 2008). Hence, semi-structured interviews have been selected as an alternative.

3.3. Conclusion

This chapter the methodology that will be used in the user research was discussed. A combination of mixed methods approach centred around the mobile eye-tracking system. Other research techniques applied are the observation, thinking-aloud method, interviews and questionnaires. The case study and the implementation will be presented in the following chapter 4.

4. IMPLEMENTATION

4.1. Introduction

Chapter 4 focuses on applying in practice the steps described in the methodology chapter. The case study of this thesis is undertaken in the city of Enschede, the Netherlands. In this chapter, the data collection process for the user study will be described. This includes the information regarding the questionnaire for the participants selection, the applications selected for testing and the equipment used for data collection.

4.2. Study location

The usability test was undertaken in Enschede, the Netherlands (see Figure 4-1). Enschede is a small city located in the Eastern part of the Netherlands just a few kilometers from the German border with a population of 158,261 inhabitants (URL12). The majority of the user study took place in the city center, around the Oude Markt.

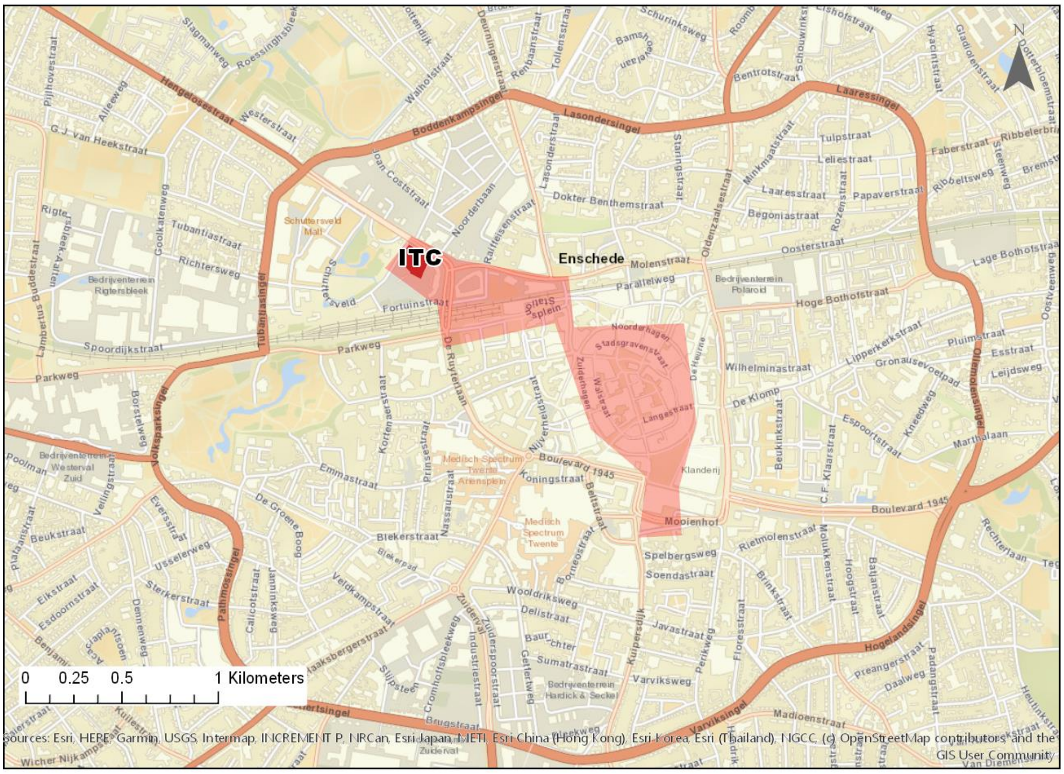


Figure 4-1 A map of city of Enschede. The starting point is The International Institute for Geo-Information Science and Earth Observation (ITC). The limits of the case study area shown in red.

4.3. Identifying applications for testing

An inventory of smartwatch applications utilizing maps was done in Table 2-2. Due to the limitations of the equipment or risks associated with the use of mobile eye tracking while running, biking, several categories of applications were eliminated. Moreover, some applications didn't perform well with the existing equipment. From the remaining applications, the six applications were selected. The selected applications were available at no charge. In order to help answering research questions regarding the design, interface and functionality aspects of the smartwatch maps, the following applications involving maps were selected (see Figure 4-2).

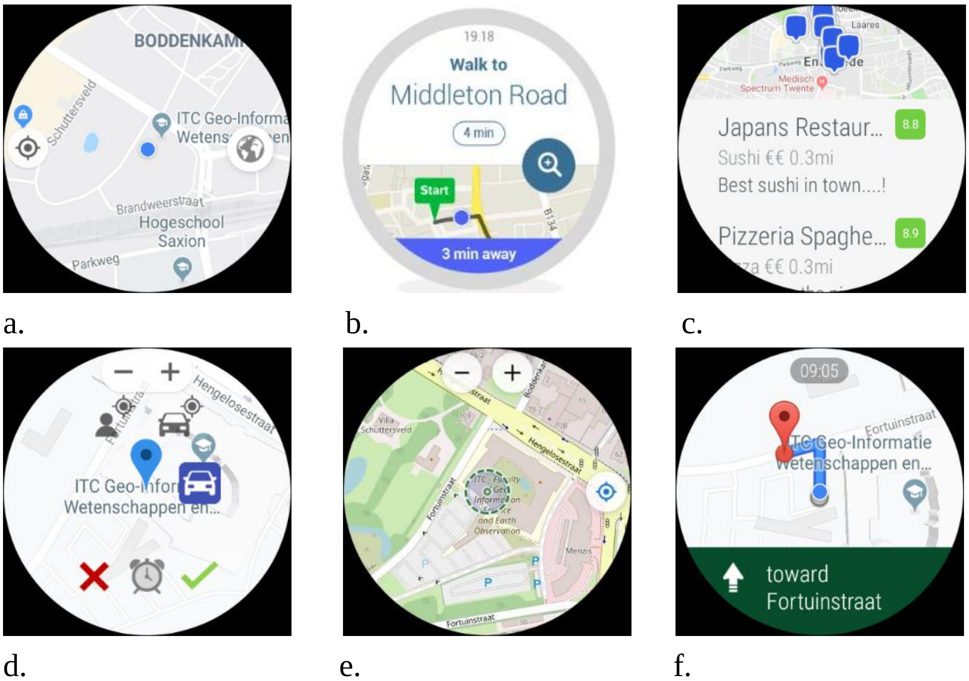


Figure 4-2 Smartwatch applications: a) My Location b) Citymapper c) Foursquare d) ParKing e) LocusMaps f) Google Maps.

My Location (URL13)
The My Location (see Figure 4-2a) application enables the users to identify their current location and the address of places. Users may pan and zoom and change the base map. The application utilizes Google Maps base maps (standard base map and satellite imagery).

Citymapper (URL14)
The Citymapper application (see Figure 4-2b) allows the user to find his/her route to home or work. The application utilizes multiple pages to display the directions. The application uses a Google basemap with custom icons to display the walking directions for the user.

Foursquare (URL15)
The Foursquare (see Figure 4-2c) application allows the user to find places of interest such as dining places and refine searches by selected criteria. The selected places are displayed on a list and visualized on a map. When pressed on the place icon, more detailed information is presented. The application supports voice search. The Foursquare application utilizes a Google Maps background.

ParKing (URL16)
The ParKing application (see Figure 4-2d) allows the users to virtually “park” their car by placing a car icon on the map. The displayed map is using a Google Maps background. The user can zoom, pan and self-locate on the map.

Locus Map (URL17)
The Locus Map application (see Figure 4-2e) allows the user to zoom and pan and navigate a route. The route has to be programmed on a smartphone first to be displayed on the smartwatch. When navigation is on, the screen is divided into two sections: navigation directions and the map itself. The map, unlike Google Maps, doesn’t support the pinch-to-zoom zooming technique. Locus Map uses Open Street Map basemap

with very detailed information. The smartwatch applications uses the same basemap as the smartphone application.

Google Maps (URL18)
The Google Maps application (see Figure 4-2f) allows the user to plan and navigate routes. The application has +/- buttons for zooming. The basemap displays information depending on the zoom level. Compared to the smartphones, the basemap for the smartwatches is more simplified due to screen size limitation, although has the same design (see Figure 4-3).
When in navigation mode, the screen is split in two parts: map and navigation directions. The top part displays the route and the bottom part displays textual instructions. When the user starts navigating, the map always shows the first segment of the route as a straight line heading to the top of the screen.

Figure 4-3 Google Maps basemap on smartphone and smartwatch for the same area.

The selected applications have different purposes: map exploration, public transit navigation, locating geographic objects, adding a place to the map, wayfinding and navigation. Moreover, the Locus Maps and Google Maps have different basemaps, which allows to compare the usability of the basemap designs.

The chosen applications allow to test the following aspects of the map:

- Identifying self-location, orientation
- Colors
- Design of point symbols
- Design of line symbols
- Legibility of the street names
- Data generalization
- Wayfinding and navigation

4.4. Test participants

Recruiting participants involved having potential participants to fill in an online questionnaire, (https://www.surveymonkey.com/r/K9YGLQZ) on SurveyMonkey (Appendix 1). Potential test persons, who were willing to participate in the user test, were asked to fill in information about their background (age, gender, education level, nationality, map reading experience and preferences and familiarity with the test area). In addition, they were asked about their experience with smartwatches and the usage of maps on smartwatches.

4.5. Recruitment process

In order to recruit participants for the user test, an email was sent to all staff and PhD students of 2 scientific departments of the Faculty of Geo-Information and Earth Observation (ITC) of the University of Twente and to the MSc students of the research theme Spatio-Temporal Analytics, Maps and Processing in that Faculty. A survey link was attached in the email to expedite the communication (see Appendix 2). This group of participants is biased in terms of pre-education and experience with maps, however this study can benefit from the relatively high levels of spatial abilities of the participants and the ability to articulate potential usability issues.

4.5.1. Participant selection

Fourteen people volunteered to be part of the study. Most volunteers worked or studied at ITC, except for two volunteers who were connected to other research groups. All respondents were considered, however only nine were selected with preference being given to respondents with smartwatch ownership. The preference was given to the smartwatch owners because of their prior experience with the smartwatches. Five participants could not join the usability study due to the scheduling/rescheduling problems.

4.5.2. Participant Demographics

After nine participants had been selected, each participant was allocated an ID from TP1 to TP9 (Table 4-1). The study group consisted of five males and four females from different countries. Six participants had a geospatial background and three not. Out of these nine participants, three participants owned a smartwatch and one used to own a smartwatch.

Most of test participants had experience using paper maps and all participants had experience using digital maps, however none of the participants used digital maps on smartwatches (See Table 4-2).

ID	Age	Gender	Country of Origin	Highest completed education level	Geo-related major	Smartwatch Ownership	How long have you lived in Enschede?	How well do you know the area?
TP1	36-40	Female	Indonesia	MSc	Yes	Yes	3-12 months	I am somewhat familiar with the area
TP2	26-30	Female	Mexico	MSc	Yes	No	I do not live in Enschede	I do not know the area
TP3	21-25	Male	Netherlands	MSc	No	Yes	More than 4 years	I know area very well
TP4	21-25	Male	India	B.Tech	Yes	Yes	3-12 months	I am familiar with the area
TP5	31-35	Male	México	MSc	No	No	3-12 months	I am somewhat familiar with the area
TP6	36-40	Male	Guatemala	MSc	Yes	No	More than 4 years	I know area very well
TP7	26-30	Male	Pakistan	BSc	Yes	No	3-12 months	I know area very well
TP8	41-45	Female	Romania	BSc	No	No	More than 4 years	I am familiar with the area
TP9	31-35	Female	Greece	PhD	Yes	No	1-2 years	I am familiar with the area

Table 4-1 Test participants' demographics.

ID	How often do you use paper maps?	How often do you use digital maps (such as map applications) on smartphones?	Please indicate your level of agreement with the statement "I am very good at reading maps"	Please indicate your level of agreement with the statement "My spatial abilities are very good"	Please indicate your level of agreement with the statement "I usually let someone else do route navigation"	Have you ever used a map on a smartwatch? Which application(s) did you use?
TP1	2-4 times per year	Weekly	Agree	Neither agree nor disagree	Disagree	Yes, Google Maps
TP2	5-10 times per year	Daily	Agree	Neither agree nor disagree	Disagree	No
TP3	2-4 times per year	Weekly	Agree	Agree	Disagree	No
TP4	Monthly	Daily	Agree	Agree	Disagree	No
TP5	Never	Weekly	Strongly agree	Strongly agree	Strongly disagree	No
TP6	2-4 times per year	Weekly	Strongly agree	Agree	Disagree	No
TP7	5-10 times per year	Weekly	Agree	Agree	Neither agree nor disagree	No
TP8	Monthly	Weekly	Neither agree nor disagree	Neither agree nor disagree	Disagree	No
TP9	2-4 times per year	Weekly	Strongly agree	Agree	Neither agree nor disagree	No

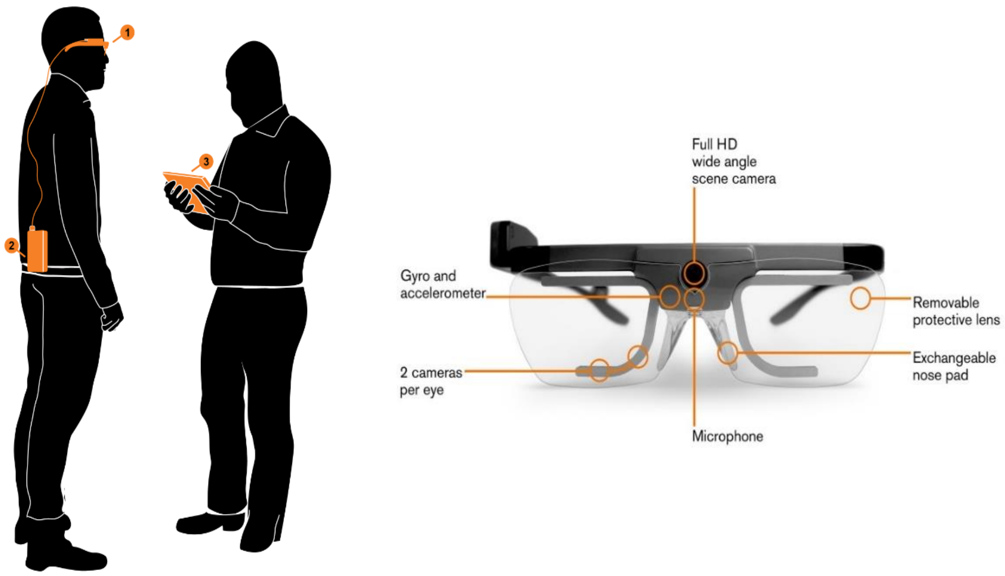
Table 4-2 . Test participants' experience with paper maps, digital maps on smartwatches and smartwatches.

4.6. Equipment

During this study, three types of equipment were used to collect the data: a mobile eye tracking system, a smartwatch and an audio recorder.

4.6.1. Mobile eye tracking

The Tobii Pro Glasses 2 were used to collect eye-tracking and think-aloud data during the whole exercise. Current mobile eye-tracking technologies allow to record the user's voice as well as video feeds of the environment. This technology allows to see exactly what a person is looking at in real time as they move freely in real-world settings (URL19). When the mobile-eye tracking device is mounted on the user, the researcher can also observe the test person's behavior from a first-person perspective.



a. b.

Figure 4-4 The Tobii Pro Glasses 2 system: a wearable eye tracker, a recording unit, a tablet (a), a wearable eye tracker (b)

The equipment was available at the Usability Lab of the Faculty of Geo-information and Earth Observation. The Tobii Pro Glasses 2 system (Figure 4-4a) consists of several components (URL20):

1. A wearable eye tracker (see Figure 4-4b)
2. A recording unit connected to the eye tracker via HDMI cable. The recording unit holds batteries and stores the recorded data in the SD memory card. The recording unit is controlled from a tablet running controller software.
3. A Windows 10 tablet running the controller software. The software allows for managing the test participants, controlling the recording unit and viewing both real-time and recorded eye tracking data. The software connects to the eye tracker through a wireless Ethernet connection.

The specifications for the Tobii Pro Glasses 2 (wearable eye tracker) are shown in Table 4-3.

Gaze sampling frequency	50 or 100 Hz
Calibration validation	Yes
Calibration procedure	One point
Parallax compensation	Automatic
Slippage compensation	Yes, 3D eye model
Tracking technique	Corneal reflection, binocular, dark pupil tracking
Pupil measurement	Yes, absolute measure
Number of eye cameras	4 eye cameras
Sensors	Gyroscope and accelerometer
Scene camera format and resolution	H.2641920 x 1080 pixels @25 fps
Scene camera field of view	90° 16:9
Scene camera recording angle/visual angle	82° horizontal 52° vertical
Sound recording/microphone	Yes
Frame dimensions	179 x 159 x 57 mm (7.0 x 6.3 x 2.2")
Weight	45 g (1.6 oz), incl. protective lens

Table 4-3 Tobii Pro Glasses 2 (wearable eye tracker) characteristics.

4.6.2. Smartwatch Mobvoi E2

After thorough research, the smartwatch TicWatch E2 (Figure 4-5) was selected to perform the user tests. Mobvoi's Ticwatch E2 is one of the best budget smartwatches on the market (URL21). The TicWatch E2 has features like built-in GPS, accelerometer, gyroscope and a voice assistant, which are normally reserved for more expensive watches (URL22)

Figure 4-5 Mobvoi TicWatch E2 (URL23)

Below are technical specifications for Mobvoi TicWatch E2 (Table 4-4).

Dimensions (mm)	46.9 x 52.2 x 12.9
Color	Black
Watch Case	Polycarbonate
Watch Strap	Silicone (interchangeable), 22mm
Operating System	Wear OS by Google™
Phone Compatibility	Android, iPhone
Voice Assistant	Google Assistant™
Platform	Qualcomm® Snapdragon Wear™
Display	1.39" (35mm) AMOLED (400 x 400 px)
Connectivity	Bluetooth v4.1, WiFi 802.11 b/g/n
GPS	GPS + GLONASS + Beidou
Sensors	Accelerometer, gyroscope, heart-rate sensor, low latency off-body sensor
NFC Payments	No
Battery Capacity	415mAh
Waterproof Rating	5 ATM (wim-ready, up to 50m)

Table 4-4 Mobvoi TicWatch E2 tecnical specifications.

4.6.3. Samsung smartphone

The smartphone used for the usability study was Samsung J2 Pro (Figure 4-6) with Android operating system. This phone was selected because of the adequate connectivity with the TicWatch E2 via Bluetooth connection. The test participants were not directly interacting with the smartphone.

Figure 4-6 Smartphone Samsung J2 Pro (URL24).

4.6.4. Audio recording

In addition to the recording unit in the eye-tracking device, a traditional voice recorder was used as a backup for collecting the think aloud data. An Olympia Memo 99 II (Figure 4-7) was used to capture these recordings. Prior to the execution of the test, the users were informed that they will be recorded, and they were asked whether they had any objection against that. None of the test persons had.

Figure 4-7 Olympia Memo 99 II audio recording unit (URL25).

4.7. Calibration

To collect accurate eye tracking data Tobii Glasses 2 were calibrated individually for each participant. During the calibration process the test participant was wearing the eye tracking glasses and focusing on the center of the calibration sticker. The calibration sticker was placed on the back of the tablet. The distance between the test participant and the calibration sticker was approximately one meter.

4.8. Tutorial and further preparations

Before the actual user study, the test participants were presented with a short tutorial on how to operate the smartwatch. Users were asked to read and perform the tasks on the tutorial sheet. The tutorial material is presented in Appendix 3.

4.9. Tasks

Users were presented with a list of tasks to perform with the Ticwatch E2 in the case study area. Some of the tasks required the user to write down specific answers on the task sheet, some required action such as wayfinding/navigation. The tasks were formulated such that the use of maps was triggered for different map purposes (overview vs finding answers to elementary spatial questions). Below are some examples of the tasks and geographic questions.

- Identify your current location by address– Where am I? – Self-position
- Find Oude Markt on the map – Where is that geographic object? – Locate an object
- Identify the address of the Grote Kerk – What is the address? – Identify object
- Find the closest parking - What is near a geographic object? – Positioning with respect to other objects
- Navigate to the closest parking location - How to get to a geographic object? – Navigation
- Find where are the lunch places are concentrated – What is the spatial distribution of the cafes? – Find spatial distribution
- Choose the lunch place at the Oude Markt (next to the Grote Kerk) with the highest rating. – At a given place, what is there? – Identify object based on criteria (spatial and non-spatial)

The complete set of tasks is presented in Appendix 4.

4.10. Post-test interview questions

To further investigate the user preferences and to gather more information regarding particular parts of the user test, a post-session semi-structured interview was performed. The participant was asked to answer ten questions, but they were also encouraged to add more comments related and unrelated to the standard questions. The list of questions is presented in Appendix 5.

4.11. Pilot tests

Two pilot tests were conducted to ensure the feasibility of the experiment. It helped to fine-tune the usability study before the full-scale implementation. Potential problems and issues with the current configuration were discovered and mitigated. In addition, the pilot tests allowed to determine the time required for completing the exercise.

During the first pilot test (see Figure 4-8), it was discovered that the recording done by the eye-tracking system did not always recognize the researcher's voice next to the voice of the participant. Hence, an additional voice recorder was added as a backup. Also, during the pilot test it was discovered that the user must hold the watch slightly higher up to ensure that the camera in the Tobii Pro Glasses 2 is capturing the watch.

Figure 4-8 Pilot test participant

Another main issue that was identified is the sensitivity of the power button on the eye-tracking system. A test person's sweater accidentally touched the button and the system became disconnected from the tablet, thus losing all the data collected previously. Therefore, it was decided to calibrate at least three times during the test and save often to ensure that the data is complete. Moreover, the structure of the user test tasks was slightly re-arranged and part of the test was performed indoors. Applications My Location, Foursquare, City Mapper were tested indoors in the usability lab because it was inconvenient for the test participant to fill out the answer form standing outdoors.

The final issue occurred when the user testing was performed on a sunny day. When in the direct sunlight, the eye-tracker did not recognize the pupils. As a solution, tinted glasses were used and participants were asked to put on a wide-brim hat.

Following the pilot tests, it was concluded that it would take the average user one and a half hour to complete the whole experiment. This information was used for planning the user testing and to inform the participants.

4.12. Conclusion

This chapter introduced the set-up of the experiment in detail. The usability study experiment consisted of nine participants, who were selected using an online survey. The six applications were used to test the use of maps on smartwatches. The first part of the experiment took part indoors, the second part was performed outdoors. During the usability study the users were asked to wear the smartwatch, the eye-tracking device and to think aloud. Following the experiment, the researcher conducted a semi-structured interview. The next chapter will report on the results of the execution of the experiment.

5. RESULTS

5.1. Introduction

The collected information from the user study will be presented in this chapter. The presentation of the resulting research material is split into two parts: video and audio material from the eye-tracking device during the task execution sessions (section 5.3.1) and audio material from the user study post-interviews (section 5.3.2).

5.2. Test execution

The test sessions took place between the 26th of July and the 13th of August 2019. In general, there were no major problems concerning the research methodology. However, there were some minor short-term technical problems with the electronic devices used, such as a lagging smartwatch and a disconnected eye-tracker. For this reason, a small part of TP8's recordings got lost.

The research data acquired from the usability testing contained three types of material: pre-test questionnaires (results already discussed in the previous chapter), video/audio recordings of the test sessions and post-study interviews. All the resulting files were carefully organized per test person. Each user test produced three video recordings from the mobile eye-tracking device and one audio file. Three video recordings were created for each participant because the test participants were calibrated three times in order to ensure that the data is preserved.

5.3. Resulting research materials

The resulting audio and video recordings have provided rich qualitative data. The acquired data from the thinking aloud during the usability test (approximately 90 minutes per test person) and interview (approximately 15 minutes per test person) were transcribed and coded. The thinking aloud of the test persons, as well as what the test persons were looking at during the test, were captured in the video and audio recordings. Tables with task completion times, think aloud protocols, important actions and errors were created for each test person to organize these rich research data. A sample of the transcription results for TP6 is shown in Appendix 6. Also, a verbatim transcription of the post-interview is provided in Appendix 7.

The initial transcription of the audio and video data was done using the AmberScript automatic speech to text tool (URL26). However, since the test participants were non-native English speakers and because of the loud background noise, the produced automatic transcription did not have a very good quality. Hence, the processed transcriptions were edited manually for each participant.

5.3.1. Task

For the usability testing experiment, the test persons had to complete a set of tasks with the mapping applications My Location, Foursquare, Citymapper, Google Maps, and ParKing. Table 5-1 shows the results of the experiments by task and by test person.

Application	No	Task description	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9
My Location	Task 1	Identify the name of the place of your current location on the map	ITC Faculty of GeoInformation Science	Van Galenstraat 10, 7511 JL Enschede, Netherlands	ITC Faculty of GeoInformation Science	ITC Faculty of GeoInformation Science	ITC Faculty of GeoInformation Science	ITC Faculty of GeoInformation Science	ITC Faculty of GeoInformation Science	ITC Faculty of GeoInformation Science	ITC Faculty of GeoInformation Science
	Task 3	Find Grote Kerk at Oude Markt on the map	Oude Markt 7511 GA Enschede, Netherlands	Oude Markt 7511 GA Enschede, Netherlands	Oude Markt 7511 GA Enschede, Netherlands	Oude Markt 7511 GA Enschede, Netherlands	Oude Markt 7511 GA Enschede, Netherlands	Oude Markt 7511 GA Enschede, Netherlands	Oude Markt 7511 GA Enschede, Netherlands	Oude Markt 7511 GA Enschede, Netherlands	Oude Markt 7511 GA Enschede, Netherlands
Foursquare	Task 1	Find the closest place where you can have dessert	Verso Cucina Italiana d'Intenzo	Van der Poel	Van der Poel	Van der Poel	Van der Poel	Van der Poel	Gelateria Talamini	Verso Cucina Italiana d'Intenzo	Van der Poel
	Task 2	Find the place where you can have breakfast next to the railway station	Bagel & Beans	Burger King	Bagel & Beans	Burger King	Burger King	Bagel & Beans	Burger King	Bagel & Beans	Burger King
	Task 3	Find where lunch places are concentrated	Oude Markt	Oude Markt	Oude Markt	Oude Markt	North side downtown	Oude Markt	Oude Markt	Oude Markt	Oude Markt
	Task 4	Choose lunch place next to the Grote Kerk (Oude Markt) with the highest rating	Proeflokaal België	Proeflokaal België	Proeflokaal België	Proeflokaal België	Proeflokaal België	Proeflokaal België	Proeflokaal België	Novi	Proeflokaal België
Citymapper	Task 1	What is the name of the street where the bus stop is located?	No	No	Boddenkamp	Noorderbaan	Noorderbaan	Boddenkamp	Noorderbaan	Boddenkamp	Noorderbaan
	Task 2	How many stops do you have to ride?	No	No	2 stops	2 stops	2 stops	2 stops	2 stops	2 stops	2 stops
Google Maps	Task 1	Find Blue Sakura	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Task 2	Check how long will it take you to arrive at the destination	12 min	12 min	12 mins	12 mins	12 mins	12 mins	12 mins	12 mins	12 mins
	Task 3	Follow the route	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Locus Maps	Task 1	Find the closest parking on the map on the smartwatch	Irenegarage Enschede	Irenegarage Enschede	St. Jacobuskerk parking lot	Irenegarage Enschede	St. Jacobuskerk parking lot	Irenegarage Enschede	Irenegarage Enschede	Wenninkgaarde parking lot	St. Jacobuskerk parking lot
	Task 2	Follow the route	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ParKing	Task 1	"Park" your car by placing the car icon on the map	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Task 2	Navigate to your car	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Google Maps	Task 1	Navigate to Mexican restaurant using smartwatch (with audio commands on)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 5-1 Results of the experiments by task and by test person (TP). Most answers to the questions were correct (indicated in green). Only some answers were incorrect (red).

5.3.1.1. My Location

Task 1 Self-positioning. The first task was to identify the TP's current location and write down the full name of it. All, except TP2, successfully identified their current location by seeing a blue dot on the map.

Task 2 Locate a geographic area. The next task was to find the Oude Markt. All test participants located the Oude Markt by using pinch gestures to zoom in and out and panning with one finger. TP4 complained that his fingers are too big and that it is difficult for him to zoom in and out.

Task 3 Locate a geographic object. The third task was to locate the Grote Kerk church on the map. TP7 had trouble locating the place, while other participants successfully did it. Four participants complained that the screen is small by stating "I can see already that my fingers are too big. I should have smaller fingers to do the pinch", "It's kind of small. It's doable.", "It is small", "If there are plus or minus buttons, it will be very useful for my fingers.".

5.3.1.2. Foursquare

Task 1 Position with respect to other geographic objects. The first task was to identify the closest place to have a dessert. TP6, TP9, TP3, TP4 & TP1 selected the location from the list provided, instead of consulting the map. TP7, TP5, TP8 & TP2 checked the map to see which location is closest. While all test participants used a scroll-down list to select place categories, TP3 used a voice command to search for the place and performed the fastest search with 1 minute and 18 seconds to complete the task.

Task 2 Locate a geographic object with one spatial constraint. The second task was to locate a breakfast place next to the railway station. All of the participants looked at the map and correctly identified the location. TP4 started using the double tap interaction to zoom in.

Task 3 Find spatial distribution. The third task was to see where the lunch places are concentrated. All of the participants consulted the map and correctly answered the question.

Task 4 Locate a geographic object with two constraints. The next task was to choose the lunch place next to the Grote Kerk. All of the test participants looked at the map to find the Grote Kerk first and then selected the lunch place with the highest ranking. The only participant who wrongfully identified the location is TP8.

5.3.1.3. Citymapper

Task 1 Identify a geographic location. The first task was to identify the street name where the bus stop was located. Four participants correctly identified the name of the street. Three participants identified the name of the bus stop as a street name and for two participants the application did not work due to the technical problem with the smartwatch.

Task 2 Public transport route-planning. The next task was to find the number of bus stops. All of the test participants were confused at first how to see the public transit directions. The test participants kept looking at the first page of the directions and panning the map instead of swiping to the right to see the rest of the directions. After the researcher's help, all participants found the directions. The researcher said that there were additional pages in this application. TP3 stated "So it wasn't very clear that I could also swipe to the right. Because now when you swipe, you can see the dots on the top. But they disappear, so when you don't swipe, they don't know it."

5.3.1.4. Google Maps

Task 1 Position with respect to other geographic objects. The first task was to identify the closest parking location. Most of the participants have chosen the St. Jacobuskerk parking lot or the Irenegarage parking lot except for TP 7. Test participants commented on how different Locus Maps was compared to Google Maps. TP 4 commented: "Locus Map use Open Street Map. Nice. The location has different symbols on this map. It has plus/minus."

Task 2 Navigation. The next task was to navigate to the parking lot. At first, test persons were confused by the interface of the application. But after getting used to it they successfully reached their destination. Four test persons out of nine were not following the navigation route shown on the maps, however they were using the map to navigate using shortcuts. The map showed the long route to get to the parking lot, however four test participants panned to destination place and walked using a shortcut. TP stated: "Because here there is a strange route, I could take a shortcut. It can be a little short. I'm almost sure that we can go with way."

5.3.1.5. ParKing

Task 1 Park your car. The first task was to park the car on the map. At first, most of the users were confused on how to place the car icon. However, they managed to perform the action.

Task 2 Navgation. The second task was to navigate to the parked car. Four participants were confused by the interface, pressing the wrong buttons to navigate to the car. The application was confusing to them.

5.3.1.6. Google maps with audio navigation.

Task 1. Navigation with audio commands. The task was to navigate to the location using audio commands. Overall, test persons liked the audio commands and said it was useful. However, TP3 and TP4 said that they would not use the audio navigation because it was too loud to use in public and that the audio commands come very suddenly, so that the user might not catch the directions. Even though the test participants had audio commands, they kept glancing at the map and directions to confirm their route.

5.3.2. Post-interview

After the test participants had completed the usability test session additional information was gathered through a semi-structured post-interview. In order to report the interview results, the answers of the test persons to the ten interview questions will be presented sequentially.

In question 1, the test persons were asked to identify the mapping application that they liked the most from the applications tested. TP1, TP2, TP3, TP4 and TP 8 (5 out of 9) liked the Google Maps application. TP 1, TP4 and TP8 said they liked it because they were familiar with the phone version of Google Maps. TP1 and TP2 preferred the Google Maps application because of the simplicity of the map and the ease of use. TP6 said that although the navigation experience was better for Google Maps, he liked the Locus Maps base map more. TP 7 and TP 9 liked the Foursquare application the most. TP 7 said that she easily managed to find suitable places using a map. TP9 said that out of all tested applications she would use the Foursquare application more frequently. TP5 liked the Locus Maps application because it showed clear directions and how he was moving in the map.

In question 2, the test persons were asked to compare two different base maps: the Google Maps base map and the OpenStreetMap basemap. TP 1 and TP2 made a distinction between the purposes of the maps, stating that they prefer OpenStreetMap for searching for data because the base map was very detailed. However, they prefer the Google Maps basemap for navigating. TP3 and TP6 stated that they prefer OpenStreetMap for the level of detail on the base map. TP 6 stated that he "use(s) the details to confirm some of the directions in the navigation". TP 4, TP5, TP7, TP8 and TP9 preferred the Google Maps basemap. TP 4, TP7 and TP8 said they preferred the Google Maps base map because of its familiarity and simplicity. TP9 stated that she liked it because it was "more useful, less distracting".

In question 3, the test persons were asked about the vibrations on the smartwatch. TP 1, TP3, TP6, TP7 and TP8 found the vibrations very helpful. TP 6 stated that he thought it was useful because "otherwise I would have to be holding my arm and checking in very constantly. And that's tiring.". TP5 said that he found it useful because "if you are walking in the street you need to take care of your environment...It's important to know in which moment the change in the route is going to happen.". TP2, TP4 and TP 9 found the vibrations on the smartwatch not very helpful. TP2 found it annoying and stated that she "make a map in my head so I don't need the vibration".

In question 4, test persons were asked about the audio commands on the smartwatch. TP1, TP3, TP5, TP7, TP8 and TP9 had a positive response to audio navigation commands and TP2 and TP4 did not find it useful. TP6 and TP9 said that they use sound instructions to confirm the route. TP3 mentioned an erroneous pronunciation of the Dutch street names. Also, TP1 and TP3 stated that they would not use the audio commands in public.

In question 5, the test persons were asked about the automatic rotation of the map. The opinions of the test participants regarding the automatic rotation of the map were divided. TP1, TP3, TP4 and TP6 said that the automatic rotation of the map was useful for them. TP6 stated that "it's more intuitive for the users" TP5 and TP8 did not like the changing map and said they prefer to orient themselves knowing the north/south directions: "Point of reference for myself is knowing where is the north/south.". TP2 said that "I would not need rotation, but sometimes it is helpful.". TP7 said that the rotation of the map was confusing at first, but then he could manage. TP9 stated that she has not noticed the map rotation, because she was using the text directions to navigate.

In question 6, the test persons were asked about the zooming functionalities of the maps. When asked about the zooming function of the mapping applications, test persons talked about the small size of the screen. TP7 stated that "When you zoom in for details, the watch screen is not that big to accommodate a lot of details.". The majority of the test persons said they were struggling with zooming on a small screen. TP6 and TP 2 have suggested hardware improvements such as Apple watch crown. (URL2). TP5 and TP6 complained that their fingers are too big for the screen and the plus/minus buttons for zooming in and out were quite small. TP4 also complained that his fingers are too big to use the pinch to zoom gesture and said that the buttons for zooming were very helpful for him. TP2 and TP3 pointed out that zooming on the map on the smartwatch is not as smooth as in the phone. Only TP1 and TP9 said that zooming was okay, but they preferred to use their fingers to zoom in. TP8 said "you have to be on the spot to zoom, otherwise you usually drag the map to a different point, but in general, zooming in was practical.".

In question 7, the test persons were asked about the icons in the mapping applications. Again the majority of the test participants mentioned the small screen size of the device. TP6, TP9, TP7, TP8, and TP1 said that, in general, the icons were of the appropriate size and okay from a visual perspective. TP6 mentioned another issue regarding the name of the Dutch streets being long, hence not fitting on the screen at once. TP9 said that the parking icons had a very light blue color, hence they were difficult to find. TP4 and TP2 talked about the different base maps and the level of generalization of the base maps in OpenStreetMap and Google Maps. TP2 said she wishes the icons were more simplified. TP4 stated that the icons in the parking application were too big.

In question 8, the test persons were asked whether the map was helpful on a small screen. All of the test participants said that the map was useful. TP9 said that as long as she can manipulate the map to see the overall area, she did not have any problem with the size. TP3 said "Map in Google Maps was better". TP4 said, "Yeah, it will be helpful when you don't want to take out the phone to see the navigation.". TP2 also said the map was useful: "Yes, actually it was. I was a little bit skeptical how smartwatches might function because I've never used one in my life…It's pretty simple".

In question 9, the test participants were asked what they did not like of the applications used in the experiment.
Google Maps application: TP6 did not like that in Google Maps there was no heading arrow to show the direction and that there was no clear indication that he took the wrong route when hepurposefully took the wrong turn. TP7 and TP9 did not like that they could not manipulate the map on Google Maps while it was in navigation mode.
ParKing application: TP6 did not like that it was difficult to distinguish between a button and an information screen. He stated: "there in the parking app everything was flat, so everything looked like at the same level". TP5 also had a similar problem: "I couldn't identify the icon for navigation. I thought that was part of the image in general. I didn't think it was a button for navigation."
Locus Maps: TP1 and TP5 did not like that the base map was static and had a lot of details, of which TP5 said that it was sometimes useful. TP1 also said that she did not like it that the map did not turn when she made a turn. TP7 said that it was difficult to find a parking place on the map. TP4 did not like the accuracy of the route on Locus Maps.
Citymapper: TP3 did not like that it was not clear that one could swipe right or left to access additional pages to retrieve more information.
Overall interaction: TP8 did not like that in some applications there was no clear feedback: "So you push something or touch the screen but nothing happens and then you don't know whether it didn't register your touch or whether you have to wait because something is loading in the background."

In question 10, the test participants were asked for any suggestions. Although, when asked if the map was helpful, TP6 answered yes, later TP6 suggested to remove the map completely: "But if you're navigating the fact is that probably you are looking into the maps or you want to look into the map very often. Unless you remove the map completely out of it and by that I mean rely on vibration and sound so you don't need the map. You just need to know you're here. You turn right and left but that that probably would be a better experience if the accuracy reaches a better level. But then you need to remove the map. Because the map is just distracting and making the user tired.". TP5 suggested incorporating vibration commands for navigation. TP1, TP2 and TP4 suggested adding a search bar on the map. TP2 also suggested voice assistance instead of zooming in or zooming out manually. TP3 suggested improving the affordance of swiping more clear.

5.4. Conclusion

The resulting video and audio recordings led to very rich and detailed information of a qualitative nature. Each test participant created a rich information source of a qualitative nature, which was carefully transcribed and organized in tables. A sample of such tables and an interview are provided in Apendices. Analyzing this rich data may reveal a series of usability problems of maps on smartwatches.

6. ANALYSIS AND RECOMMENDATIONS

6.1. Introduction

This chapter will discuss the findings of the user research and provide recommendations for the use of maps on smartwatches and for the design of these maps. The first part of this chapter covers the analysis of the results which were presented in the previous Chapter 5. The next part discusses the map use on smartwatches and the usability issues that emerged from the analysis. Afterwards, the design aspects of the maps on smartwatches are examined in detail. Finally, general recommendations, as well as design recommendations, will be given.

6.2. Analysis

The transcription of the video and audio research material, as well as the action logging, constituted a source of very rich qualitative data. The first step in analyzing the video and audio research material was to identify the parts relevant to answering the research questions which are leading this thesis. The coding of the thinking aloud data first required a selection of the relevant segments. Then, the selected segments were assigned different codes that related to specific themes. The coding systems used in this task were not all defined ahead of time but also determined by the contents of the research material, because this study is exploratory in nature and is not completely based on a theoretical model.

The categorization of the codes is not organized by the tasks given, but rather by emerging themes. The coding scheme was developed by taking into account the research questions, but was largely based on the verbal protocols (when an issue is verbally expressed by the test person) as well as on the action logs (e.g. test participant is trying to zoom in on the map), and consists of sixteen categories, which are displayed in Table 6-1.

Category	Sample quote
Map use	*Maybe I look at the map because I want to be next to the church.*
Map description	*This is a very detailed map which in small places like the city center is very useful.*
Map layout	*I want to move the map because I want to… I need to locate the points, like for example the north point. In this case, I'm lost. Yes, I can't move this. That's a problem.*
Map generalization	*I think they could do some simplification depending on the level of detail or which level of zoom you are, they can have some simplification of the data because if you zoom out, the icons are very small, so you have to zoom in to look at them in real size.*
Map labels	*So when they have the navigation line it's always better not to obscure the name of the street, maybe you know more transparent color.*
Map symbols	*The symbols are so small. They are super small.*
Map orientation	*Actually, this is the first time I'm wondering is the north always pointing ahead of me? Can I rotate?*
Visual hierarchy	*So because basically one of the reasons may be that icons and the background were flat in terms of visual aspects.*
Color	*It took me so much time to find out, it was a very light blue color.*
Direction	*It would be very good if this shows which direction I'm seeing.*
Self-location	*Ok, now I see a blue dot with my location.*
Audio commands	*I'm not actually not used to listening to audio commands and moving.*
Vibration	*When we approaching the turning point it vibrates.*
Zooming	*Can I zoom in the map?*
Positional accuracy	*The G.P.S. precision is more, much better here now.*
Fat finger	*Well, but I can see already that my fingers are too big.*

Table 6-1 Codes used to describe the fragments of the recordings.

The second research question of this study sought to determine the usability of maps on smartwatches. Hence the categories of maps use, vibration and audio commands were used to answer this question. The third question was to provide the recommendations that can be provided for the communication of the spatio-temporal information on smartwatches, hence the map description, map generalization, map symbols, map labels, direction, visual hierarchy, color, and positional accuracy and fat finger problem categories were used to answer this question.

6.3. Map use on smartwatches

Tobii Pro Lab software was used to analyze the gaze of the participants. In order to map the collected eye-tracking data, a state of the art Real-World mapping function was used (URL27). This function allows mapping the produced eye gaze data onto a snapshot image automatically (see Figure 6-1).

Figure 6-1 Snapshot of map use on the Google Maps application

The Real-World mapping works best when the surrounding environment of the object is more static, which was not the case during the usability study. The heatmaps and visualizations could be created only on short time segments due to the changing environment and test participant's arm position; otherwise the outcome would be as shown in Figure 6-2. In the Figure 6-1, test participant was exploring the map standing in one position, hence not moving his arm as much and in Figure 6-2, the test participant was walking and glancing at the map on smartwatch.

Figure 6-2 Heatmap of the map use on the Locus Map application.

Therefore, the analysis of the eye-tracking data was done mostly manually by following the test participant's gaze in the Tobii Pro Lab software as shown in Figure 6-3 and linking it to the thinking aloud.

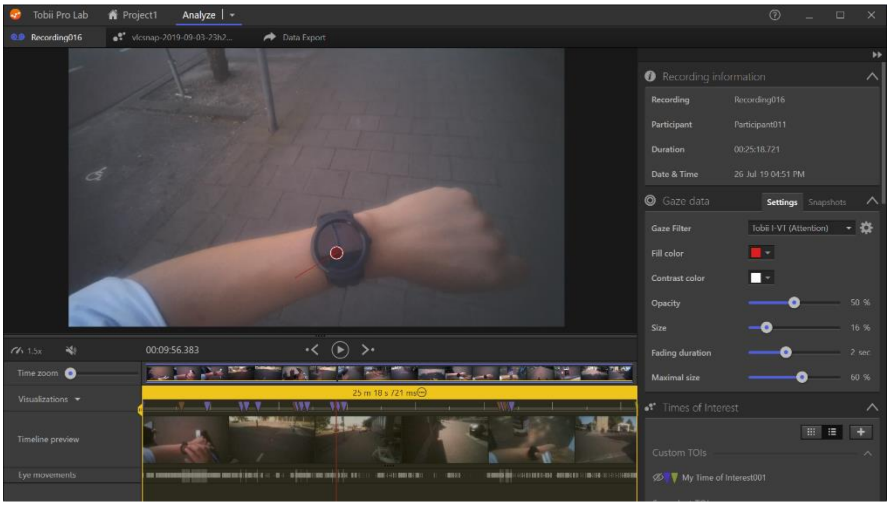


Figure 6-3 Eye-tracking recording of the navigation using the Google Maps application.

Analysis of the eye-tracking data has shown that when given a choice between using a map and selecting information from a list to locate the geographical location near their current location (Foursquare application, Task 1), five out of nine test participants have selected the closest place from the list. The list of locations provided the distances from the current location although the list was not sorted according to distance. Nevertheless, when the test participants were asked to locate a place next to a different location or provide information about the spatial distribution of the locations (Foursquare application, Task 2 and Task 3), all test participants have used the map. Moreover, for both Google Maps and Locus Map applications during the navigation mode, all test participants have utilized the map to confirm their route even the test participant who stated in the interview that she used the text directions to navigate. Surprisingly, the test participants looked at the textual directions more than at the map when navigating using the Google Maps. And when using the Locus Map application, test participants looked at the map more than the textual directions. A possible explanation for this may be that the map area on the Google Maps application could not be manipulated.

Two of the test participants have stated that they prefer the maps than the textual directions. In addition to that, during the interview all of the test participants have said that they found the maps on smartwatches helpful. It is important to bear in mind the possible acquiescence bias in these responses because the test participants could be trying to please the researcher. One of the test participants first said in the interview that he finds maps on smartwatches useful, but later in the interview he suggested to remove the map and to rely on the vibration and sound.

When using maps during the usability test exercises, many common usability issues have been uncovered, such as zooming functionality, fat finger issue, map rotation, direction and positional accuracy.

The first usability issue was the zooming functionality. Test participants were given three types of options for zooming. The first option (My Location application) was to use a map that had no buttons for zooming and all test participants used the pinch to zoom technique to zoom in and out. The second option (Foursqare and Google Maps) was to use the map that had both zooming buttons (see Figure 6-4b) and the affordance to pinch to zoom (see Figure 6-4 a). Four participants used the zooming buttons, and five continued to zoom in using the pinch to zoom technique. The third option (Locus Maps) was to use a map that only had plus and minus buttons for zooming and all test participants used these zooming buttons. Some users said they preferred to use pinch to zoom more, and some said they liked the buttons more. When given a choice four out of five test participants preferred to use pinch to zoom technique.

a. Pinch to zoom b. Plus/minus buttons

Figure 6-4 Test participants' zooming interaction

The second usability issue was the map rotation. Test participants were divided regarding the possible rotation of the map during the navigation. Test participants who were smartwatch owners stated that they would like a rotating map (Figure 6-5a). Some participants stated that it was confusing because they are orienting themselves by knowing the north/south direction (Figure 6-5b).

a. Map rotated to mimic the direction b. North is at the top of the map

Figure 6-5 Map rotation

The third usability issue was the direction. During the usability study, users stated that they wish they knew which direction they were supposed to walk and, moreover, most of the test participants started to turn to different directions to see if the map reacts somehow on Google Maps (Figure 6-6a). A compass-style graphic like in Locus Maps (Figure 6-6b), which shows in which direction the user is walking, would be helpful.

a. Map showing no direction

b. Map with a heading arrow to show person

Figure 6-6 Direction on the map

The fourth usability issue was the positional accuracy. Three users mentioned that the GPS positioning could be improved.

The fifth usability issue was the fat finger problem. Many users have complained about this. The footprint of the icon/button was not big enough for some users with large hands (Figure 6-7), so the user had to be very precise to press the icon/button.

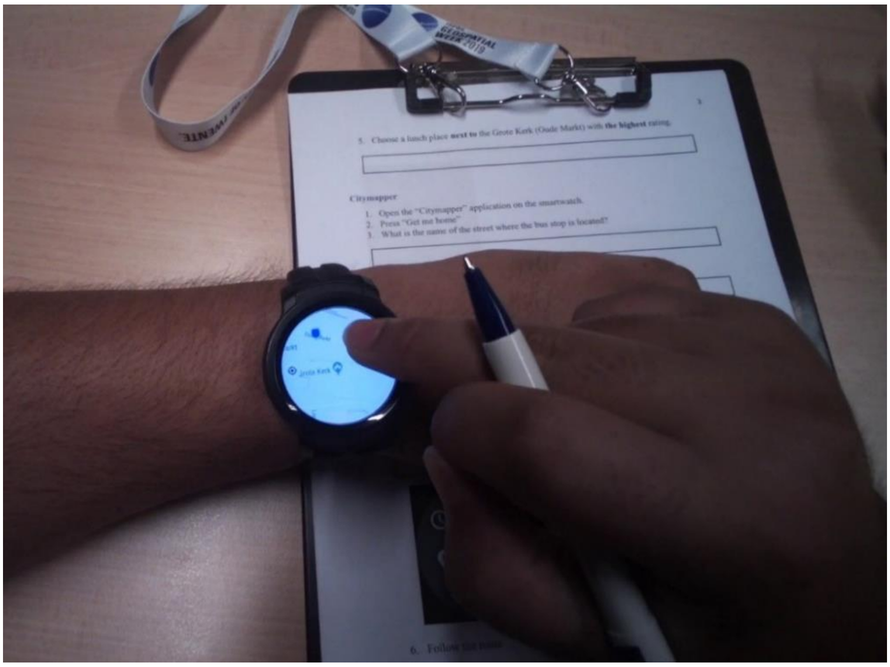


Figure 6-7 Test person pressing an icon on the map

6.4. Design

Influence of the design on the usability of the maps on smartwatches was explored by comparing the OpenStreetMap and Google Maps base maps. Five out of nine participants preferred the map on the Google Maps application due to its simplicity. A possible explanation for this might be the familiarity of the test participants with the Google Maps application on the smartphone. Two test participants made the distinction that they preferred OpenStreetMap (Figure 6-8b) for getting an overview and Google Maps

(Figure 6-8a) for navigation purposes. Moreover, two participants said that they preferred OpenStreetMap for the amount of information shown on the map.

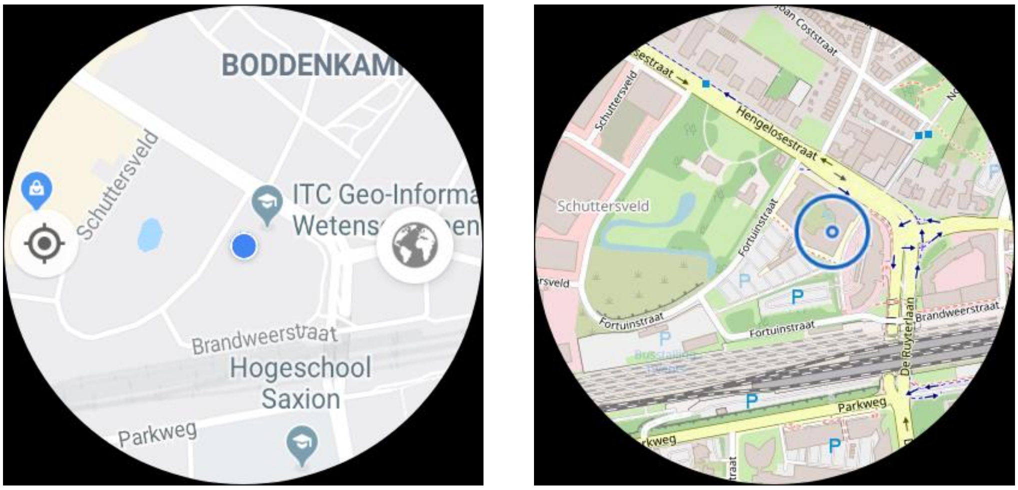
a. Google Maps b. OpenStreetMap

Figure 6-8 Base maps

Five main themes have emerged from the analysis of the research materials regarding the design of the maps on smartwatches: map generalization, map labels, color scheme, map layout, and map symbols.

6.4.1. Map generalization

Overall, the test participants stated that they preferred a more generalized base map for navigation. Also, they commented that they prefer adapted zooming, so that the map is showing more detailed information when they zoom in. Two test participants suggested that the base map for the overview should be more detailed and the base map for navigation more simplified and less distracting. Google Maps (Figure 6-9a) was more generalized than Open Street Map (Figure 6-9b).



a. Google Maps b. OpenStreetMap

Figure 6-9 Map generalization on Google Maps and OpenStreetMap

6.4.2. Map labels

Test participants have made several comments regarding the map labels, specifically the road names. In general, the road names had a legible and adequate size for both base maps. However, when the Google Maps' map was in the navigation mode (see Figure 6-10), the street names were covered with the route making it difficult to read the name of the street from the map for some participants.

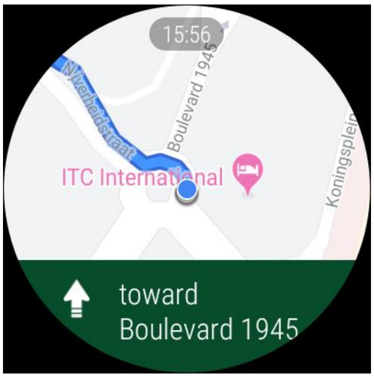


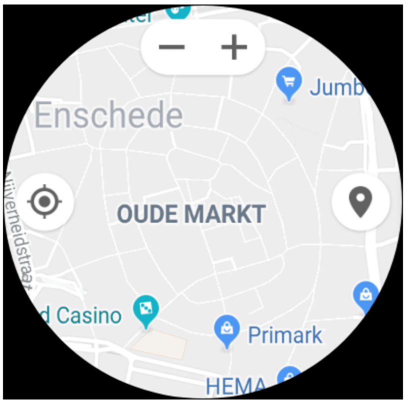
Figure 6-10 Street name label is covered by the blue route

6.4.3. Color scheme

The color scheme of both maps was found acceptable by the majority of the test participants. Two participants did not like the color scheme on the OpenStreetMap (see Figure 6-9b) because there were many colors. One test participant said that he prefers in general more contrast in the map.

6.4.4. Map layout

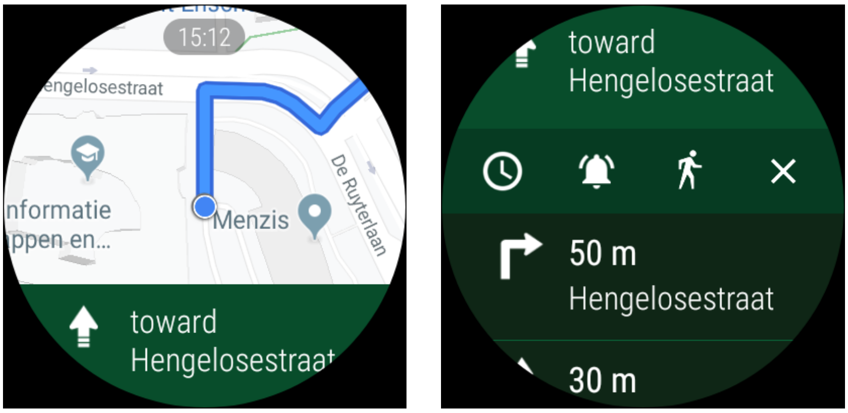
The map layout for general overview in Google Maps (Figure 6-11a) and OpenStreetMap (Figure 6-11b) is quite similar: the zoom buttons at the top and the self-location button on the right or left edge of the map.



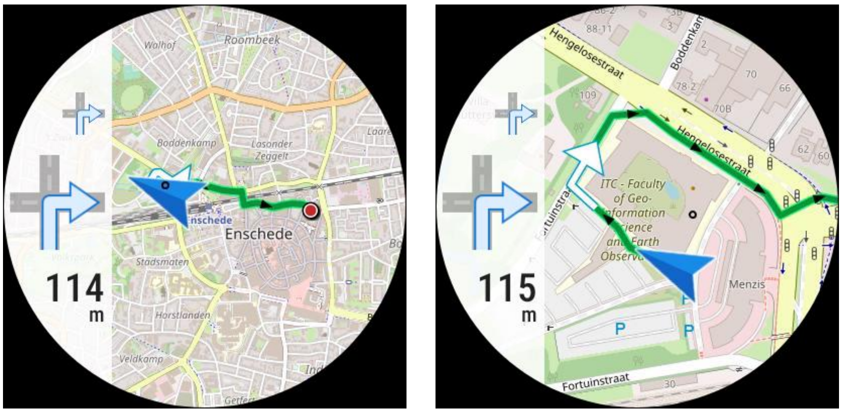
a. Google Maps b. Open Street Maps

Figure 6-11 General map layout

However, when it comes to the navigation mode, the maps differ quite a lot. Both maps have a compartmentalized map layout: one section of the screen for the mapped area itself and another section for the directions (see Figure 6-12).



a. Google Maps navigation directions. Once the user swipes up, additional details of the route are shown.



b. Locus Maps (OpenStreet-Map base map)

Figure 6-12 Compartmentalized map layouts

Once in navigation mode, on a Google Maps application, the map section is locked, and the user can not manipulate it in any way. Two test participants complained that they want to zoom out to see the whole route and orient themselves. Moreover, three more test participants repeatedly tried to manipulate the map section of the screen. In the Locus Map application, the map section was not locked; hence the user could pan and zoom the map. It is interesting to note that these map layouts have influenced the test participants' gaze during the usability study session. When using Google Maps, test participants tended to look at the directions more and confirming their directions with the map, as shown in Figure 6-13 (a). When the Locus Maps application was used, test participants focused both on the map and the directions, as shown in Figure 6-13 (b). Also, the test participants actively manipulated the map when navigating at the beginning of their navigation or at the decision points.

a. Google Maps navigation mode   b. Locus Map navigation mode

Figure 6-13 Heat maps showing of the participant's gaze while navigating

Another reported suggestion was to add a search capability to the map. Test participants stated that it is challenging to find a location by panning the map and that a search bar with voice/text input could be useful.

Another recurring theme in the map layout category was the layout in the Citymapper application. Most of the test participants were unaware of the possibility of swiping the screen to the side to retrieve further details. As one of the test participants pointed out there were no visual affordances (see Figure 6-14) that indicated that the page could be swiped to the side in the beginning. However, when the user had already swiped, the dots at the top of the screen emerged and then it became clear that more information was available.

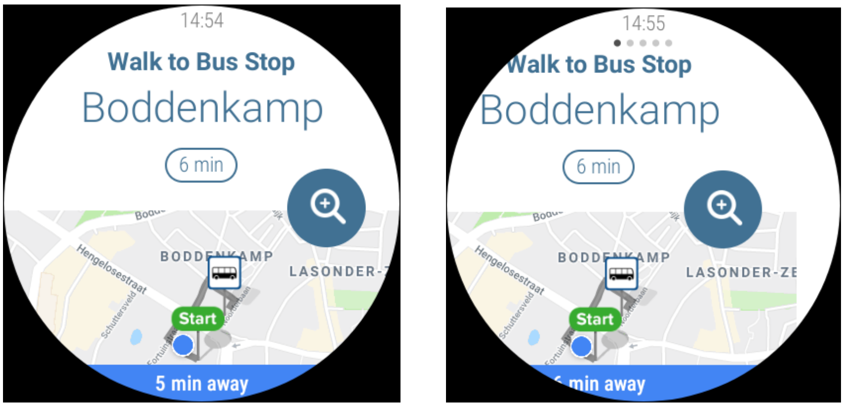


Figure 6-14 Citymapper application. Dots on the top part of the screen provide affordance that indicate that the page can be swiped.

6.4.5. Map symbols

There were some negative comments regarding the icons on the OpenStreetMap base map. Test participants indicated that they were rather small, and sometimes the color was too light for them to locate a place quickly. On the contrary, for the ParKing application, the users suggested to make the icons smaller. Moreover, test participants complained that the icons in the ParKing application did not have a visual affordance for clicking, buttons looked like part of the interface (Figure 6-15).

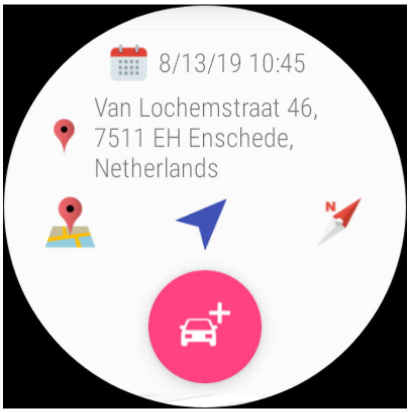


Figure 6-15 ParKing application main screen. Top three buttons lack visual affordance for clicking.

Six out of nine test participants were confused with the icons in the ParKing application. A few test participants have relocated their car icon when pressing the green confirmation button (see Figure 6-16), because the button did not have a proper background and it was shaped like a checkmark, hence forcing the users to move their finger with precision to hit the target. Moreover, many test participants were confused by the alarm symbol next to the confirm button.

Figure 6-16 Parking application map. Test participants erroneously misplaced the car icon below the confirmation button.

6.5. Recommendations

The analysis of the eye-tracking data, think-aloud protocols, and post-test interviews led to the conclusion that maps are useful to convey spatio-temporal information on smartwatches. The information gathered from the task execution as well as the interviews was used to derive recommendations for the use and design of maps on smartwatches.

General recommendations for the use of maps on smartwatches are related to the geographic questions the map should answer.

- For gathering spatio-temporal information regarding geographic objects in the user's proximity, a map is not necessary, and information could be provided in textual form.
- For gathering spatio-temporal information regarding the spatial distribution of geographic objects, the spatial relation between different objects, and overview of the region, maps are needed.
- For wayfinding and navigation, the map is needed for route confirmation.

In order to improve the user experience, the following design guidelines for future mapping applications on smartwatches are proposed:

1. Make rotations of the map smooth, allow the user to disable it, if possible.
2. Allow the user to manipulate the map when in navigation mode.
3. Include compass-type graphics, so that users know which direction they are facing.
4. Use both zooming buttons and a pinch to zoom tool.
5. Include a search bar on the map with text and audio input.
6. Keep visual hierarchy in the map layout.
7. Make map icons more simplified and bigger.
8. Make icons "clickable" – use shading to emphasize that the icons could be clicked.
9. Include vibration commands.
10. Create visual affordances to recognize the availability of additional information.
11. Use the same swiping motion for opening and closing the page.
12. Do not cover up the street names with the route.
13. Use a more generalized map in the navigation mode and provide more information when the user is browsing the map.
14. Use simple colors on the base map with sufficient contrast.
15. Make sure the positional accuracy is high.

6.6. Conclusion

This chapter presented the analysis of the results as well as the recommendations on the use and design of maps on smartwatches. The usability of the maps on smartwatches was examined by analyzing the think-aloud protocols, action logs, interview protocols, and eye-tracking gaze data. After careful inspection of the research material, it can be concluded that maps, in general, are indeed useful on smartwatches. In order to improve the user experience, design and interface recommendations were given.

7. CONCLUSIONS

7.1. Overview

Smartwatches are one of the latest trends in Information and Communications Technology for mobile devices, and their popularity is growing. Through the smartwatches, spatio-temporal information can be communicated to the users. One of the main limitations when thinking of maps on smartwatches is the small size of the screen. The amount of spatio-temporal information that can be obtained is limited due to the small size of the display on smartwatches. The idea of the usability of the maps on smartwatches was investigated by performing a usability study centered around the Tobii Pro Glasses 2 mobile eye-tracking system. Other research techniques applied were a pre-test questionnaire, the thinking aloud method, video observations, and post-interviews.

Chapter 2 starts with a definition of a smartwatch, briefly talks about the history of smartwatches and describes some key smartwatch characteristics. Then an inventory of current smartwatch applications communicating spatio-temporal information is presented, later focusing more specifically on the applications that utilize maps to communicate spatial and spatio-temporal information. Further, the usability aspects of maps on smartwatches are described, and techniques for solving the problem of displaying maps on small screens are explored. Lastly, related user studies that have been performed with maps on smartwatches are discussed.

In Chapter 3 the design adopted for this master thesis is described, focusing specifically on the research methodology selected. Due to the lack of previous research on the use and design of maps on smartwatches, it was decided to make use of qualitative research methods. The chosen research methods such as eye-tracking, observation, thinking-aloud and semi-structured interviewing are described.

In Chapter 4 the set-up of the experiment is described in detail. The usability study experiment consisted of nine participants who were selected using an online survey. Six smartwatch applications were used to test the use of maps on smartwatches. The experiment took part both indoors and outdoors. During the usability study the users were asked to wear the smartwatch, the eye-tracking device and to think-aloud. Following the experiment, a semi-structured interview was conducted to obtain additional qualitative data.

The collected information from the user study was presented in Chapter 5. The presentation of the resulting research material is split into two parts: video and audio material from the eye-tracking device during the task execution of the user study sessions and audio material from the user study post-interviews.

Chapter 6 embodies the results and recommendations of the use and design of maps on smartwatches. The usability of the maps on smartwatches was examined by analyzing the think-aloud protocols, action logs, interview protocols, and eye-tracking gaze data. The relevant selected segments from the collected data were assigned different codes that related to specific themes. Common usability issues have been uncovered, such as those related to the zooming functionality, fat finger issue, map rotation, direction, and positional accuracy. Moreover, five main themes have emerged from the analysis of the research materials regarding the design of maps on smartwatches such as map generalization, map labels, color scheme, map layout, and map symbols.

7.2. Answering the research questions

The answers addressing the research questions set in Section 2.2 in Chapter 1 are summarized as follows:

1. What is the state-of-affairs with respect to the provision of spatio-temporal information through smartwatches?

a. What spatio-temporal information is currently communicated through smartwatches and for which purposes?

An inventory of the smartwatch applications communicating spatio-temporal information has been made. The applications were divided by use purpose: biking, running, travel, hiking, skiing, golfing, taxi/driving, weather, general navigation, and social navigation. Spatio-temporal information such as duration, average pace, average speed, elevation gain, distance travelled, directions, weather notifications, self-location, location of geographic objects (and their changes), and the locations of friends are communicated through smartwatches.

b. How is spatio-temporal information currently communicated through smartwatches?

Spatio-temporal information on smartwatches is communicated in four ways: through text only, using text and symbols, using both maps and text, and using the map as a primary tool.

c. Which maps are being used for the communication of spatio-temporal information through smartwatches? What are their characteristics?

A variety of maps is being used to communicate spatio-temporal information through smartwatches. Some smartwatch applications use a compartmentalized map layout, where part of the screen real estate is occupied by the map and another part is occupied by text and symbols to provide additional information. For a number of these applications the background map has a less saturated basemap and the textual elements are displayed in high contrast colors. Other smartwatch applications use maps as the main communication tool. Some of these maps have zooming buttons at the top of the screen and self-location on the edge of the screen, some do not provide zooming buttons, but instead afford pinch-to-zoom techniques. The basemap for these applications has different levels of generalizations as well as different color schemes. In general, there are no thematic maps, but more general maps like Google Maps and Open Street Map. Google Maps basemap was simplified for the small screen of the smartwatches, as well as the WorkOutDoors maps. WorkOutDoors also utilizes a vector basemap.

d. What are the purposes of maps on smartwatches?

The main purposes of maps on smartwatches are to aid the discovery of a location, continuously track the location of a user, and to help people in wayfinding and navigation.

e. Who is the target audience?

The composition of the target audience is evolving. According to the Ericsson ConsumerLab report (Ericsson ConsumerLab, n.d.), the majority of the new users of wearables are adults in the 25-34 age bracket. However, in the experienced (experience with smartwatch) users category the age groups are more evenly spread out. Moreover, a higher percentage of the smartwatch users are males.

f. What are the potential strengths and weaknesses of maps on smartwatches.

One of the potential strengths of maps on smartwatches is the ability to quickly communicate (location-based) spatio-temporal information to the user, the hands-free interaction allows users to continue with their current activities.

One of the potential weaknesses is the small display size. The small screen size limits the amount of information that can be accessed by the user looking at the map, as well as the overview that can be obtained.

2. What is the usability of current maps on smartwatches?

When using maps during the usability test exercises, many common usability issues have been uncovered, such as those related to the zooming functionality, fat finger issue, map rotation, direction, and positional accuracy.

3. Which recommendations can be provided for the communication of spatio-temporal information through smartwatches?

a. In which cases and for which purposes are maps useful to convey spatio-temporal information?

General recommendations for the use of maps on smartwatches are related to the geographic questions the map should answer. For gathering spatio-temporal information regarding the spatial distribution of geographic objects, the spatial relation between different objects, and overview of the region, maps are needed. Also, for wayfinding and navigation, the map is needed for route confirmation.

b. In which cases and for which purposes is it better to use other ways of communication (eg. text, audio or haptics)?

The audio commands and vibrations were found most useful for the navigation tasks as complementary techniques. For gathering spatio-temporal information regarding geographic objects in the user's proximity, a map is not always necessary, and, in some cases, information could be provided in textual form.

c. How should a map be designed for an effective, efficient and satisfactory communication of spatio-temporal information?

In order to provide effective, efficient and satisfactory communication of spatio-temporal information, the following map design characteristics are needed (Table 7-1).

Map Composition & Layout
Maximize the screen real-estate used for the map view for the purpose of overview and use a compartmentalized layout for navigation.
Scale & Generalization
Use a more generalized basemap in the navigation mode and provide more information when the user is browsing the map.
Projection
Make rotations of the map smooth and allow the user to disable it, if possible.
Symbolization
Make map icons more simplified and bigger.
Use self-explanatory icons for POIs.
Keep visual hierarchy in the map layout.
Use simple colors on the basemap with sufficient contrast.
Do not cover up the street names with the route symbolization.
Include vector and imagery basemap options.
Typography
Keep text upright as a user rotates the map.
Map Elements
Include a compass-type graphic, so that users know which direction they are facing.
Include a search bar on the map with text and audio input.

Table 7-1 Design recommendations for maps on smartwatches

d. *How should an application be designed for an effective, efficient and satisfactory communication of spatio-temporal information?*

In order to provide effective, efficient and satisfactory communication of spatio-temporal information, an application should have the following characteristics (Table 7-2).

Interaction
Allow the user to manipulate the map when in navigation mode.
Make icons "clickable" – use shading to emphasize that the icons could be clicked – provide visual affordance.
Create visual affordances to recognize the availability of additional information.
Use the same swiping motion for opening and closing the page.
Use both zooming buttons and a pinch to zoom tool.
Use sound and vibration.

Table 7-2 Recommendations for map interactions

7.3. Suggestions for further research

The limitations of this research and resulting suggestions for future research are discussed below.

- During the realization of this research due to the exploratory nature of the research questions, this research was largely based on qualitative research methods. Hence, one of the suggestions for future research is to have a larger number of test participants to yield statistically significant results and perform research using quantitative methods.
- Another limitation of this study is the "selection bias." The test participants used in this study had mostly a geographic background and moreover not all the test participants owned a smartwatch. Therefore another suggestion is to involve smartwatch owners with diverse backgrounds.
- Moreover, all test participants, except for one, were familiar with the research area. Thus, selecting participants who are new to the area might retrieve more reliable results.
- For this research, only one smartwatch with a WearOS operating system was used. A suggestion for further research is to test multiple smartwatches with different operating systems.
- Due to the time limitation, only six applications were tested in this user study. Furthermore, more smartwatch applications could be tested on different operating systems.

LIST OF REFERENCES

Arefin Shimon, S. S., Lutton, C., Xu, Z., Morrison-Smith, S., Boucher, C., & Ruiz, J. (2016). Exploring Non-touchscreen Gestures for Smartwatches. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, 3822–3833. https://doi.org/10.1145/2858036.2858385

Baudisch, P., & Chu, G. (2009). Back-of-device interaction allows creating very small touch devices. *Proceedings of the 27th International Conference on Human Factors in Computing Systems - CHI 09*, 1923. https://doi.org/10.1145/1518701.1518995

BMS Lab. (n.d.). Tobii Pro Glasses 2 | BMS LAB High-Tech meets Social Sciences. Retrieved April 17, 2019, from https://bmslab.utwente.nl/knowledgebase/tobii-pro-glasses-2/

Brata, K. C., Pinandito, A., Ananta, M. T., & Priandani, N. D. (2018). Design of public transportation navigation system on android wear device. *Proceedings - 2017 International Conference on Sustainable Information Engineering and Technology, SIET 2017*, *2018-Janua*, 385–391. https://doi.org/10.1109/SIET.2017.8304169

Budiu, R. (2017). Quantitative vs. Qualitative Usability Testing. Retrieved June 17, 2019, from https://www.nngroup.com/articles/quant-vs-qual/

Burigat, S., Chittaro, L., & Gabrielli, S. (2008). Navigation techniques for small-screen devices: An evaluation on maps and web pages. *International Journal of Human-Computer Studies*, *66*(2), 78–97. https://doi.org/10.1016/j.ijhcs.2007.08.006

Cecchinato, M. E., Cox, A. L., & Bird, J. (2017). Always On(line)? *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 3557–3568. https://doi.org/10.1145/3025453.3025538

Chauhan, J., Seneviratne, S., Kaafar, M. A., Mahanti, A., & Seneviratne, A. (2016). *Characterization of Early Smartwatch Apps*. (May 2011).

Chun, J., Dey, A., Lee, K., & Kim, S. J. (2018). A qualitative study of smartwatch usage and its usability. *Human Factors and Ergonomics In Manufacturing*, *28*(4), 186–199. https://doi.org/10.1002/hfm.20733

Davie, N., & Hilber, T. (2016). *Smartwatches As a Learning Tool: a Survey of Student Attitudes*. (April).

Dillemuth, J. A. (2009). Navigation Tasks with Small-Display Maps: The Sum of the Parts Does Not Equal the Whole. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *44*(3), 187–200. https://doi.org/10.3138/carto.44.3.187

Ericsson ConsumerLab. (n.d.). ConsumerLab report on Wearable Technology and IoT – Ericsson - Ericsson. Retrieved from https://www.ericsson.com/en/trends-and-insights/consumerlab/consumer-insights/reports/wearable-technology-and-the-internet-of-things

Flick, U. (2010). An Introduction To Qualitative research Fourth Edition. *SAGE Publications*, 506. https://doi.org/978-1-84787-323-1

Gorman, G. E., Clayton, P. (Peter R., Shep, S. J., & Clayton, A. (2005). *Qualitative research for the information professional : a practical handbook*. Facet.

Hasan, K., Ahlström, D., & Irani, P. (2015). SAMMI: A Spatially-Aware Multi-Mobile Interface for Analytic Map Navigation Tasks. *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI '15*, (i), 36–45. https://doi.org/10.1145/2785830.2785850

Huang, H., Gartner, G., Krisp, J. M., Raubal, M., & Van de Weghe, N. (2018). Location based services: ongoing evolution and research agenda. *Journal of Location Based Services*, *12*(2), 63–93. https://doi.org/10.1080/17489725.2018.1508763

IDC, & Statista. (June 19, 2019). Smartwatch shipments worldwide from 2018 to 2023 (in millions) [Graph]. In Statista. Retrieved September 13, 2019, from https://www.statista.com/statistics/878144/worldwide-smart-wristwear-shipments-forecast/

Kalantari, M. (2017). Consumers adoption of wearable technologies: literature review, synthesis, and future research agenda. *International Journal of Technology Marketing*, *12*(1), 1. https://doi.org/10.1504/ijtmkt.2017.10008634

Kerber, F., Kiefer, T., & Löchtefeld, M. (2016). Investigating Interaction Techniques for State-of-the-Art Smartwatches. *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '16*, 2540–2547. https://doi.org/10.1145/2851581.2892302

Kjeldskov, J., & Stage, J. (2004). *New techniques for usability evaluation of mobile systems*. *60*, 599–620. https://doi.org/10.1016/j.ijhcs.2003.11.001

Lamkin, P. (n.d.). 101 Million Smartwatch Shipments by 2020 with Apple and Google Leading The Way. Retrieved September 13, 2019, from https://www.forbes.com/sites/paullamkin/2015/05/11/101-million-smartwatch-shipments-by-2020-with-apple-and-google-leading-the-way/#2bc1b27742ae

Lee, J., Kim, D., Ryoo, H. Y., & Shin, B. S. (2016). Sustainable wearables: Wearable technology for enhancing the quality of human life. *Sustainability (Switzerland)*, *8*(5). https://doi.org/10.3390/su8050466

Liu, X., Chen, T., Qian, F., Guo, Z., Lin, F. X., Wang, X., & Chen, K. (2017). *Characterizing Smartwatch Usage in the Wild*. 385–398. https://doi.org/10.1145/3081333.3081351

Maier, J., & Wörndl, W. (2015). *Smartwatch Interaction – More than just Notifications*. 299–303.

McMillan, D., Brown, B., Lampinen, A., McGregor, M., Hoggan, E., & Pizza, S. (2017). Situating Wearables: Smartwatch Use in Context. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 3582–3594. https://doi.org/10.1145/3025453.3025993

Montuwy, A., Cahour, B., & Dommes, A. (2019). Using Sensory Wearable Devices to Navigate the City: Effectiveness and User Experience in Older Pedestrians. *Multimodal Technologies and Interaction*, *3*(1), 17. https://doi.org/10.3390/mti3010017

Muehlenhaus, I. (2013). *Web Cartography*. https://doi.org/10.1201/b16229

Perebner, M., Huang, H., & Gartner, G. (2019). Applying user-centred design for smartwatch-based pedestrian navigation system. *Journal of Location Based Services*, (May), 1–25. https://doi.org/10.1080/17489725.2019.1610582

Rawassizadeh, R., Price, B. A., & Petre, M. (2015). Wearables. *Communications of the ACM*, *58*(1), 45–47. https://doi.org/10.1145/2629633

Ricker, B., & Roth, R. (2018). Mobile Maps and Responsive Design. *Geographic Information Science & Technology Body of Knowledge*, *2018*(Q2). https://doi.org/10.22224/gistbok/2018.2.5

Rovelo, G., Abad, F., & Camahort, E. (2015). *Studying the User Experience with a Multimodal Pedestrian Navigation Assistant*. (November), 438–445. https://doi.org/10.5220/0005297504380445

Schall, A., & Romano Bergstrom, J. (2014). The Future of Eye Tracking and User Experience. In *Eye Tracking in User Experience Design* (pp. 351–360). https://doi.org/10.1016/B978-0-12-408138-3.00014-5

Slaughter, N. (n.d.). Designing maps for mobile devices - Points of interest. Retrieved September 13, 2019, from https://blog.mapbox.com/designing-maps-for-mobile-devices-32d2e49d2096

Strategy Analytics. (n.d.). Strategy Analytics: Global Smartwatch Shipments Jump to 12 Million Units in Q2 2019 | Strategy Analytics Online Newsroom. Retrieved September 13, 2019, from https://news.strategyanalytics.com/press-release/devices/strategy-analytics-global-smartwatch-shipments-jump-12-million-units-q2-2019

Suchan, T. A., Brewer, C. A., Suchan, T. A., Brewer, C. A., Methods, Q., & Brewer, C. A. (2010). *Qualitative Methods for Research on Mapmaking and Map Use Qualitative Methods for Research on Mapmaking and Map Use *. 0124*(September 1997), 145–154. https://doi.org/10.1111/0033-0124.00212

van Elzakker, C. P. J. M. van. (2004). The use of maps in the exploration of geographic data. In *Netherlands Geographical Studies;326*. Retrieved from https://dspace.library.uu.nl/handle/1874/1235

van Elzakker, C., Delikostidis, I., & van Oosterom, P. (2008). Field-Based Usability Evaluation Methodology for Mobile Geo-Applications. *The Cartographic Journal*, *45*(2), 139–149. https://doi.org/10.1179/174327708x305139

van Elzakker, C. P. J. M., & Delikostidis, I. (2010). Use, user, and usability research for mobile geo-applications for personal orientation and navigation. *IEEE International Professional Communication Conference*, 121–130. https://doi.org/10.1109/IPCC.2010.5529824

van Elzakker, C. P. J. M., & Ooms, K. (2017). Understanding map uses and users. In *The Routledge Handbook of Mapping and Cartography* (Vol. 0, pp. 55–67). https://doi.org/10.4324/9781315736822-5

van Elzakker, C. P. J. M., & Wealands, K. (2007). Use and Users of Multimedia Cartography. In *Multimedia Cartography* (pp. 487–504). https://doi.org/10.1007/978-3-540-36651-5_34

Visuri, A., Sarsenbayeva, Z., van Berkel, N., Goncalves, J., Rawassizadeh, R., Kostakos, V., & Ferreira, D. (2017). *Quantifying Sources and Types of Smartwatch Usage Sessions*. 3569–3581. https://doi.org/10.1145/3025453.3025817

Wang, J., Antonenko, P., Celepkolu, M., Jimenez, Y., Fieldman, E., & Fieldman, A. (2019). Exploring Relationships Between Eye Tracking and Traditional Usability Testing Data. *International Journal of Human-Computer Interaction*, *35*(6), 483–494. https://doi.org/10.1080/10447318.2018.1464776

Wanjari, N. D., & Patil, S. C. (2017). Wearable devices. *2016 IEEE International Conference on Advances in Electronics, Communication and Computer Technology, ICAECCT 2016*, 287–290. https://doi.org/10.1109/ICAECCT.2016.7942600

Wenig, D., Steenbergen, A., Schöning, J., Hecht, B., & Malaka, R. (2016). ScrollingHome: Bringing image-based indoor navigation to smartwatches. *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services, MobileHCI 2016*, 400–406. https://doi.org/10.1145/2935334.2935373

Wenig, Dirk, Schöning, J., Hecht, B., & Malaka, R. (2015). *Stripe Maps : Improving Map - based Pedestrian Navigation for Smartwatches*.

Wenig, N., Wenig, D., Ernst, S., Malaka, R., Hecht, B., & Schöning, J. (2017). Pharos: improving navigation instructions on smartwatches by including global landmarks. *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services*, Article 7. https://doi.org/10.1145/3098279.3098529

Wu, Y., Cheng, J., & Kang, X. (2016). *Design, User Experience, and Usability: Technological Contexts* (A. Marcus, Ed.). https://doi.org/10.1007/978-3-319-40406-6

URLS

URL1: Smartwatch Definition https://techterms.com/definition/smartwatch (Accessed on April 14, 2019)

URL2: How to use your Apple Watch without your iPhone nearby https://support.apple.com/en-us/HT205547 (Accessed on September 7, 2019)

URL3: Garmin vs Fitbit – which fitness tracker is best for you? http://bestgpstech.com/reviews/garmin-vs-fitbit-which-fitness-tracker-is-best (Accessed on September 7, 2019)

URL4: Smartwatch vs. Fitness Tracker – Which Is Best For You? https://www.pcmag.com/roundup/297910/the-best-fitness-trackers (Accessed on September 7, 2019)

URL5: Best smartwatch 2019: September update on the top tech watches https://www.wareable.com/smartwatches/best-smartwatch-buyers-guide-2019-7283 (Accessed on September 7, 2019)

URL6: Apple Watch 4 vs Samsung Galaxy Watch https://www.thefonestuff.com/blog/apple-watch-4-vs-samsung-galaxy-watch/ (Accessed on September 7, 2019)

URL7: Google just changed the name of Android Wear to Wear OS https://www.theverge.com/2018/3/15/17124448/google-wear-os-announced-android-wear-rebranding-smartwatch (Accessed on September 7, 2019)

URL8: App Store https://www.apple.com/ios/app-store/ (Accessed on September 7, 2019)

URL9: Google Play https://play.google.com/store (Accessed on September 7, 2019)

URL10: Galaxy Store https://www.samsung.com/global/galaxy/apps/galaxy-store/ (Accessed on September 7, 2019)

URL11: How do Tobii Eye Trackers work? https://www.tobiipro.com/learn-and-support/learn/eye-tracking-essentials/how-do-tobii-eye-trackers-work/ (Accessed on May 20, 2019).

URL12: City of Enschede website https://cityofenschede.com/aboutenschede/the-city/facts-figures/ (Accessed on May 1, 2019)

URL13: My Location smartwatch application https://play.google.com/store/apps/details?id=com.location.test&hl=en&pageId=none (Accessed on May 1, 2019)

URL14: Citymapper smartwatch application https://play.google.com/store/apps/details?id=com.citymapper.app.release&hl=en (Accessed on May 1, 2019)

URL15: Foursquare smartwatch application https://play.google.com/store/apps/details?id=com.joelapenna.foursquared&hl=en (Accessed on May 1, 2019)

URL16: ParKing smartwatch application https://play.google.com/store/apps/details?id=il.talent.parking&hl=en (Accessed on May 1, 2019)

URL17: Locus Map https://play.google.com/store/apps/details?id=menion.android.locus&hl=en (Accessed on May 1, 2019)
URL18: Google Maps https://play.google.com/store/apps/details?id=com.google.android.apps.maps&hl=en (Accessed on May 1, 2019)
URL19: Tobii Pro Glasses 2 https://www.tobiipro.com/product-listing/tobii-pro-glasses-2/ (Accessed on May 1, 2019)
URL20: Tobii Pro Glasses 2 User's Manual https://www.tobiipro.com/siteassets/tobii-pro/user-manuals/tobii-pro-glasses-2-user-manual.pdf/?v=1.1.3 (Accessed on May 1, 2019)
URL 21: Best cheap smartwatches 2019: Ticwatch, Samsung, Amazfit and more. https://www.wareable.com/smartwatches/best-budget-smartwatches-pebble-sony-samsung-and-more (Accessed on August 14, 2019)
URL22: Best Cheap Android Smartwatches in 2019 https://www.androidcentral.com/best-cheap-android-wear-smartwatches (Accessed on August 14, 2019)
URL23: TicWatch E2 https://www.mobvoi.com/us/pages/tcwatche2 (Accessed on August 14, 2019)
URL24: Samsung J2 Pro https://www.samsung.com/ph/smartphones/galaxy-j2-pro/SM-J250GZKDXTC/ (Accessed on August 14, 2019)
URL25: Olympia MEMO 99 II https://www.olympia-vertrieb.de/en/products/office/dictation-machines/digital-recording/digital-dictation-machine-olympia-memo-99-ii.html (Accessed on August 14, 2019)
URL26: AmberScript https://app.amberscript.com/ (Accessed on August 1, 2019)
URL27: Real-world Mapping—Tobii Pro from https://www.tobiipro.com/learn-and-support/learn/steps-in-an-eye-tracking-study/data/real-world-mapping/ (Accessed on September 1, 2019)

APPENDIX 1

Online questionnaire

Dear Sir / Madam,

I am Maira Utebaliyeva, an Erasmus Mundus Master of Science Programme student, currently studying in the Faculty ITC of the University of Twente. In my Master research, I am researching the usability of maps on smartwatches. As part of my research, I would like to conduct a user study for understanding the usability of maps on smartwatches.

I would very much appreciate it if you would be willing to participate in my test. Besides helping me, it will be an opportunity to learn a little bit more about the use of maps on smartwatches. In case you are willing to participate, I would like to ask you to complete a survey.

I would like to use this survey to select participants through collecting some of your background information and your smartwatch use experience (or not) to determine your suitability to participate in this study. If you will be selected as a participant, you will be invited to use several applications on a smartwatch (Mobvoi Ticwatch E2) while wearing eye tracking glasses (Tobii Pro Glasses 2) during the study in part of the Enschede city center area. The field session will take one and a half hour.

This survey will take around 5-7 minutes to complete. At the beginning of this survey, your name and email are required to be further contacted to participate in the field test. All collected information will be strictly kept confidential.

After completing the survey, you will soon be contacted about your possible participation in the test. Your availability because of summer holidays will be taken into account.

Thank you for participating in this survey.

*** 1. What is your name and email address?**

Name [ ]

Email [ ]

2. What is your gender?

○ Male

○ Female

*** 3. What is your age?**

- 20 and below
- 21-25
- 26-30
- 31-35
- 36-40
- 41-45
- 46-50
- 51 and above

*** 4. What is your country of origin?**

*** 5. If you are corrected to normal vision, do you wear contact lenses or frame glasses daily?**

- I have normal vision
- Corrected vision, I wear contact lens
- Corrected vision, I wear frame glasses
- I don't have normal vision, but I haven't been corrected to normal vision.

*** 6. What is your highest completed education level?**

- BSc
- MSc
- PhD
- Other (please specify)

*** 7. What is the subject of your field of study?**

8. Do you own a smartphone? If yes, what is the operating system?

- Yes, iOS
- Yes, Android
- Yes, Other
- No, I do not own a smartphone

9. Do you own a smartwatch? What is the operating system?

- ○ Yes, WearOS/Android Wear
- ○ Yes, WatchOS
- ○ Yes, FitbitOS
- ○ Yes, Tizen
- ○ No, I do not own a smartwatch

*** 10. How often do you use paper maps?**

- ○ Daily
- ○ Weekly
- ○ Monthly
- ○ 5-10 times per year
- ○ 2-4 times per year
- ○ Once or less than once per year
- ○ Never

11. How often do you use digital maps (such as map applications) on smartphones?

- ○ Daily
- ○ Weekly
- ○ Monthly
- ○ 5-10 times per year
- ○ 2-4 times per year
- ○ Once or less than once per year
- ○ Never

*** 12. How often do you use digital maps on smartwatches?**

- ○ Daily
- ○ Weekly
- ○ Monthly
- ○ 5-10 times per year
- ○ 2-4 times per year
- ○ Once or less than once per year
- ○ Never

*** 13. Have you ever used a map on a smartwatch? Which application(s) did you use?**

- ○ No, I have never used a map on a smartwatch
- ○ Yes (Please specify)

*** 14. Please indicate your level of agreement with the statement "I am very good at reading maps"**

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

*** 15. Please indicate your level of agreement with the statement "My spatial abilities are very good"**

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

*** 16. Please indicate your level of agreement with the statement "I usually let someone else do route navigation"**

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

*** 17. How long have you lived in Enschede?**

- Less than 3 months
- 3-12 months
- 1-2 years
- 2-4 years
- More than 4 years
- I do not live in Enschede

*** 18. How well do you know about this area?**

- ○ I know area very well
- ○ I am familiar with the area
- ○ I am somewhat familiar with the area
- ○ I do not know the area

19. Will you please indicate during which week(s) you are NOT available to participate in this test?

- ☐ Week 30 (22 - 26 July 2019)
- ☐ Week 31 (29 July - 2 August 2019)
- ☐ Week 32 (5 - 9 August 2019)
- ☐ Week 33 (12 - 16 August 2019)
- ☐ Week 34 (19 - 23 August 2019)

APPENDIX 2

Invitation email

Dear Sir / Madam,

I am Maira Utebaliyeva, an Erasmus Mundus Master of Science Programme student, currently studying in the Faculty ITC of the University of Twente. In my Master research, I am researching the usability of maps on smartwatches. As part of my research, I would like to conduct a user study for understanding the usability of maps on smartwatches.

I would very much appreciate it if you would be willing to participate in my test. Besides helping me, it will be an opportunity to learn a little bit more about the use of maps on smartwatches. In case you are willing to participate, I would like to ask you to complete a survey. Please follow the link to complete the survey:

https://www.surveymonkey.com/r/K9YGLQZ

I would like to use this survey to select participants through collecting some of your background information and your smartwatch use experience (or not) to determine your suitability to participate in this study. If you will be selected as a participant, you will be invited to use several applications on a smartwatch (Mobvoi Ticwatch E2) while wearing eye tracking glasses (Tobii Pro Glasses 2) during the study in part of the Enschede city center area. The field session will take around one and a half hour.

Sincerely,

Maira Utebaliyeva

APPENDIX 3

Tutorial

Smartwatch: Mobvoi Ticwatch E2

The watch supports single side-button press and the screen can recognize gestures, such as tap and slide.

Press Power button:
Press once to open the application list or go back to the dial display
Press and hold to open Google Assistant

Slide rightward:
Go back to previous display/ exit the application

Slide leftward:
See additional information (if exists)

Slide up:
View the notifications

Slide down:
View the shortcut menu
Hidden notifications

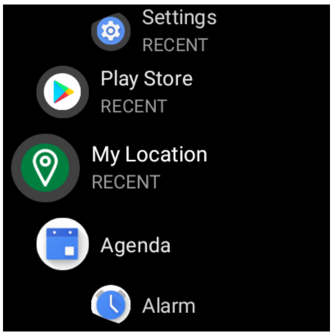
APPENDIX 4

Map tasks

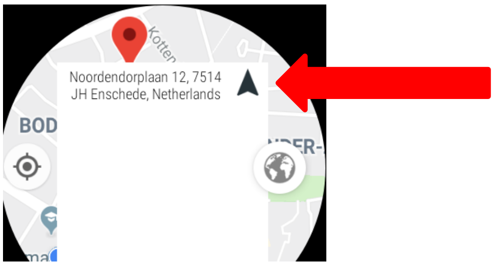
Please follow these instructions carefully and write down your answers in the boxes. The screenshots provided are not solutions to the tasks, they are merely assisting with the task description.

My Location

1. Open "My Location" application.



2. Identify your current location on the map
3. Identify the name of the place of your current location on the map (**Long tap on the map**)

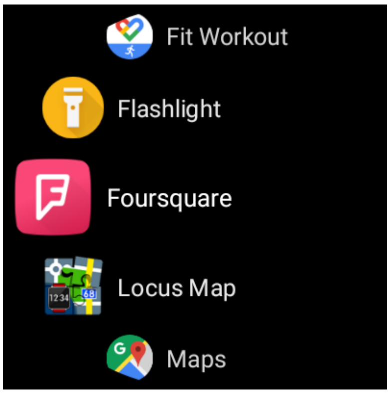


4. Explore the map and pan to Oude Markt on the map on a smartwatch

5. Find Grote Kerk at Oude Markt on the map
6. Identify the address of the Grote Kerk (**long tap on the map**)

Foursquare

1. Open the "Foursquare" application on the smartwatch



* If you wish to exit the map, long press and hold the map until the following screen appears and press quit.

2. Find **the closest** place where you can have dessert

3. Find the place where you can have breakfast **next to** the railway station

4. Find where lunch places are **concentrated**

5. Choose a lunch place **next to** the Grote Kerk (Oude Markt) with **the highest** rating.

Citymapper

1. Open the “Citymapper” application on the smartwatch.
2. Press “Get me home”
3. What is the name of the street where the bus stop is located?

4. How many stops do you have to ride?

Short break. The researcher will save the recorded data.

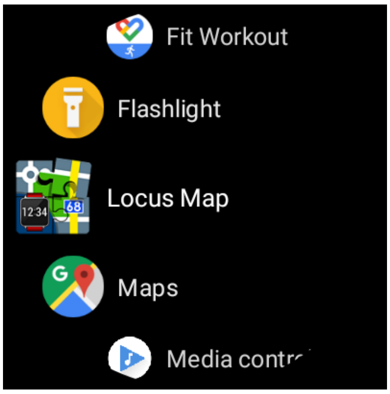
Google Maps

1. Open “Google Maps” application on the smartwatch
2. Pan to the Oude Markt
3. Find “Blue Sakura” restaurant
4. Press navigate to it
5. Check **how long** will it take you to arrive at the destination (swipe up)

6. Follow the route

LocusMaps

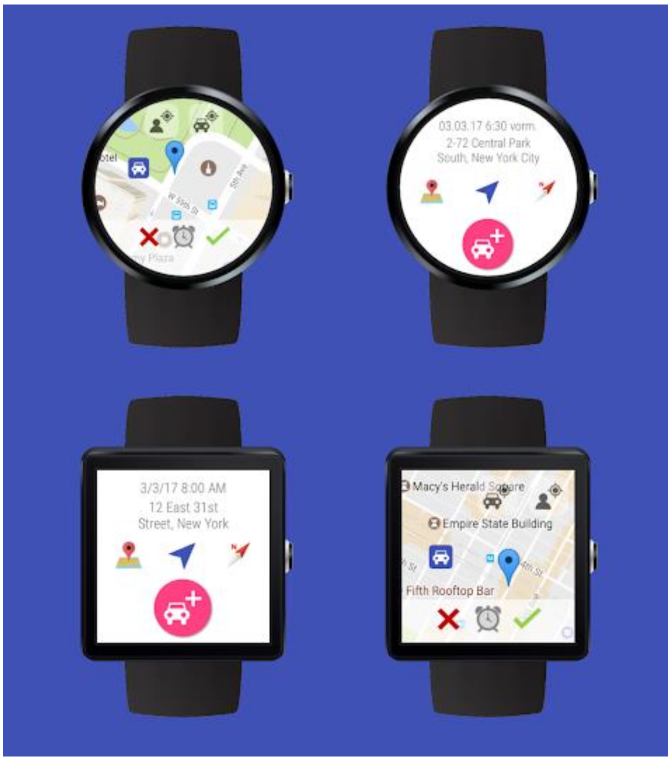
1. Open the “LocusMaps” application on the **smartwatch**.



2. Explore the map
3. Find **the closest** parking on the map on the smartwatch
4. Show the parking location to the researcher (to program the route)
5. Following the navigation on the smartwatch

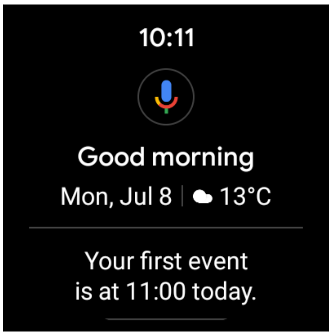
ParKing

1. Open ParKing application on smartwatch
2. “Park” your car by placing the car icon on the map



Google Assistant

1. Slide the screen to the right to get to Google Assistant



2. Say “Find Mexican restaurants nearby”

3. Press Navigate to it (Navigation starts with **Google Maps**)

Google Maps

1. Change navigation to **walking**

2. Navigate to Mexican restaurant using the smartwatch (**with audio commands on**)

ParKing

1. Navigate your car (application switch to **Google Maps**)

Google Maps

2. Navigate to your car

APPENDIX 5

Semi-structured interview questions

1. Which mapping application did you like the most? Why?
2. Compare LocusMaps and Google maps (different basemaps) Which one do you prefer?
3. What did you think of vibrations?
4. What did you think of the audio commands?
5. Are you pleased with the automatic rotation of the map?
6. What did you think of zooming functions?
7. What did you think about the icons?
8. Is map helpful on such a small screen?
9. What didn't you like on the applications tested?
10. Do you have any suggestions regarding the use of maps on smartwatches?

APPENDIX 6

Application	Task	Type	TP6
My Location	Identify the name of the place of your current location on the map	Time of the completion	1:30 - 3:00
		Completed task	Yes
		User actions	User takes a watch and opens the application. He **immediately recognizes his current location** by seeing a blue dot. User **zooms in using two fingers**. User reads the name of the place from the base map. Then he taps on the map and the popup with the name of the place appears.
		Where the user is looking	User is looking at the map
		User Comments	I go to My Location... I'm tapping on it and accessing the map. Ok, now I see a blue dot with my location. Identify the name of the current location. Well, the name is the ITC Information Faculty… not all the name appears. Okay, long tap on the map. Ah, okay. Now I see, there is a pop-up, the name of the faculty. ITC Faculty Geoinformation Sciences.
	Explore the map and pan to Oude Markt on the map on a smartwatch	Time of the completion	03:00-03:55
		Completed task	Yes
		User actions	User is looking to see how to close the previous window. Then panning with screen using one finger and using two fingers doing pinch and zoom.
		Where the user is looking	Map
		User Comments	Now it would be good to know, how do I close this window. Just tap once, then I'm zooming out and swiping to the Oude Markt. I can see… Enschede Oude Markt. Yes, Enschede Oude Markt here. Yes, ok, I can see the the area of the Oude Markt. Oh, oh, I went too far. Okay. Yes.
	Find Grote Kerk at Oude Markt on the map	Time of the completion	03:55-04:22
		Completed task	Yes
		User actions	User uses two fingers to zoom in and one finger for panning the map
		Where the user is looking	Map
		User Comments	Okay, so I know it should be close to the La Cubanita restaurant. Well, but I can see already **that my fingers are too big**. I should have smaller fingers to do the pinch. Yes, so I found the church, the Grote Kerk.
	Identify the address of the Grote Kerk	Time of the completion	04:22-04:51
		Completed task	Yes
		User actions	The user performs as expected. Long taps on the map to retrieve the address.

		Where the user is looking	Map, popup window.
		User Comments	So, long tap on the icon. Fetching the address, so I have the address.
Foursquare	Find the closest place where you can have dessert	Time of the completion	6:15-8:43
		Completed task	Yes
		Behavior	User opened an application and started immediately scrolling down to see the list of options. The user tapped on the "dessert" options. He scrolled down and tapped on names of the places for the description. He chose the closest place based on the **distance shown in the list,** although he was expected to use a map to choose the closest place.
		Where the user is looking	The main menu, then the list of places, then the descriptions of the places
		User Comments	Foursquare… What can I see what are you in the mood for? Coffee, lunch, breakfast. A list of options. Find a closest place where you can have dessert. Let's see. I'm tapping the dessert and it's loading. I see a small map and a list of places with the rating. I see Van der Poel Bakkerij, Gelato, cafe... The closest ones ... is one of the stores Van der Poel. I'm tapping on it and yes, I see a description, and I see the information regarding to the opening hours, and it's ranked #2 in the ice-cream shops in Enschede.
	Find the place where you can have breakfast next to the railway station	Time of the completion	08:43-10:34
		Completed task	Yes (Burger King/Bagels and Beans)
		User actions	User tapped the "breakfast" choice in the list of options, then tapping on the map to see the spatial relation. He pans to the train station, then taps on the icon to expand the description of the place. Then he zooms out to pick another one, the one outside the train station - Bagel and Beans. User behaved as expected.
		Where the user is looking	The user first looks at the list of options, then looks at the map
		User Comments	I believe I go back and go back and there is breakfast in the list, yes. Yes, I'm loading breakfast and I should know that it's next to the railway station. So I will do that by accessing the map, tapping on the map. Now zooming in a little bit. Actually I can have breakfast in the train station. Should I do next to or in the? So, okay, I can have breakfast there. So of course, there is a Burger King and they have breakfast. Now I have a conflict with the next to, because this is not next to.. okay, I will be very picky with the location "next to the station", the one next to the station and that's Bagels and Beans.
	Find where lunch places	Time of the completion	11:34-11:52
		Completed task	Yes

	are concentrated	User actions	The user taps on the main menu with the list of options, then clicks on the lunch option. After clicking the lunch option, the user taps **on the map** to see where the lunch places are concentrated.
		Where the user is looking	Main menu, list of places, map
		User Comments	Okay, I see. It becomes more complicated. Going back to the map. Going back to the list of places. Going back to the main list of options from Foursquare. Now I shall find things for lunch. And now I have to know where they are concentrated. I tap on the map. There is no surprise, they are concentrated around the.. not really the Oude Markt. Yes, actually, so I believe if we look at the Enschede city center. So the place is Oude Markt. Okay.
	Choose a lunch place next to the Grote Kerk (Oude Markt) with the highest rating.	Time of the completion	12:00-14:55
		Completed task	Yes
		User actions	User starts looking at the list of the lunch places, then after remembering that he should select a place next to the Grote Kerk, **opens the map**, zooms in to the Grote Kerk. After finding the Grote Kerk, he taps on each icon and opens a popup to see the rating of the place. Then selects the correct location with the highest rating.
		Where the user is looking	First the list of the lunch places, then the map itself.
		User Comments	So I'm going back. Going back is a bit difficult. So have to tap and hold… Lunch with the highest reating. I'm already in the list of the places with the highest rating. Okay, I'm already of the places for lunch. I think I just have to go down to list. 8.3, 8.6. Next to the Grote Kerk, then I go back to the main map, so where is the Grote Kerk. Next to it, it seems like there closest to it, there are four. It would be good to know, which ones have the highest rating. So I have to tap on each one.
Citymapper	What is the name of the street where the bus stop is located?	Time of the completion	15:16-16:20
		Completed task	No, Boddekamp - the bus stop, not the street name
		User actions	The user pressed "Get me home", then pressed "GO". To find out the street name he tapped on the screen and tried to pinch the map with two fingers, although there was a plus button to make the map bigger.
		Where the user is looking	Map
		User Comments	Tapping on Get me home. So this is Boddekamp. Apparently I'll go home this way.
	How many stops do you have to ride?	Time of the completion	16:21-19:00
		Completed task	Yes, 2 stops
		User actions	User took longer to find the public transportation directions (it was not clear that user could slide the screens, no indication of this affordance was given explicitly)
		Where the user is looking	The main screen, the walking directions screen, the map, the further instructions screens

		User Comments	I believe if ... I'm pressing on the zoom button. Nothing happens. Something happened. The map appears. There is a path to the bus stop, it says five minutes away. Then I press on the x, then I go to the first screen. I go back to the map. There is a label in the map that says start, but it's not starting. Again, close the map and pressing Boddekamp... Ok, I see, Yes, um... okay, now the app crashed. I'm going to app again, but it is saved where I left, so I'm swiping left... So how may stops? ... so it's two stops
Google Maps	Pan to the Oude Markt, Find Blue Sakura	Time of the completion	00:36-2:25
		Completed task	User opened the Google Maps application. Panning to the Oude Markt. Zooming out first with two fingers to get an overall view of the area. Then zooms in to the Oude Markt. Uses +/- buttons to zoom in to find the Blue Sakura restaurant.
		User actions	User is looking at the map, panning with one finger, the screen goes in the dark mode when the user is taking his time to read the instructions. User shakes the watch to make the map appear. Panning to the Oude Markt, then zooming in using two fingers.
		Where the user is looking	Map
		User Comments	I'm accessing Google Maps now. And the task says that I have to pan to Oude Markt. Okay, **turns in to some dark mode.** Okay, I see. Panning to Oude Markt. I would have to zoom out, because I don't know where I am. Yes, I found Oude Markt. Find Blue Sakura restaurant. I have to zoom in. I still think that **my fingers are too big**… The buttons, ah yes, definitely, Blue Sakura. Where was Blue Sakura? Too close now, okay, yes, La Cubanita. Ok, I have Blue Sakura on the spot.
	Check how long will it take you to arrive at the destination (swipe up)	Time of the completion	03:27-03:38
		Completed task	Yes
		User actions	User swipes up and presses the clock icon to find out how much it takes to arrive at the destination
		Where the user is looking	The map, then the bottom page with the directional information
		User Comments	It will take .. Click on the clock, time icon and it says 12 minutes
	Follow the route	Time of the completion	04:05-25:18
		Completed task	Yes
		User actions	The user is confused in the beginning because he does not know which direction to go. There is no indication on the Google Maps navigation about the user's orientation. The user starts following the directions on the screen. After arriving at the intersection of the Korte Haaksbergerstraat and the Brammelerstraat, user decided to test if the map will update accordingly if he "got lost" and turned to the wrong direction. The user discovered that the application has not notified him of his mistake and merely rerouted by

			enlongating the route. After walking all the way till the end of the wrong street, the user turned around and followed the navigation on the watch.
		Where the user is looking	User looks at the map to confirm a turn
		User Comments	And now I follow the route. It **would be very good if this shows which direction** I'm seeing. Anyhow, this says Hengelosestraat, let's follow Hengelosestraat. Ok, I see that the **GPS is not so accurate**. 300 meter to Molenstraat.. 280 meters.. 220 meters to Molenstraat... I want to know what is this.. okay, but.. I'm not sure, okay, **I was expecting** that it, I was thinking that **the name of street** is the point where I shall stop or do something and not **the current street I'm walking on**. **Okay, the vibration helps. I'm close...**I wonder what will happen if I get lost. No, I mean if I take the wrong way. I'm curious what it will do. **When we approaching the turning point it vibrates**. Okay, I will go the wrong direction. The watch still says 10 meters straight. But I will go to the right and see what happens. Now it vibrated, so it was 25 meters from the wrong direction. I don't have sound feedback, so it says .. The only thing that I see is go to the Brammelerstraat. There should be **a street plate**. The intriguing part is that, the map is not rerouting. It still tells me go straight in the direction I'm heading, which is the wrong direction. And it says Brammelerstraat. I'm on the Brammelerstraat apparently. But in the map there is not visual correction that I'm going in the wrong direction. And this is Google Maps. If I remember correctly, in the phone it is obvious when there has to be a turn, because you are going in the wrong direction. And also there is automatic recalculation, like for example here I will expect, the map shows me that I have to turn, make a u-turn to do that. So now there is another vibration signal. Okay, I see what the map is doing. What the map is doing that it is making my path longer but closer to my position, but it is not telling me to turn around. Yes, it does not say turn around, it just says straight. I will walk till the end of the street and then I will turn to the right direction. Because what I want to see, is if it will tell me take left or right because you are going in the wrong direction. Okay, yes, there is another vibration, but still what I see, but the app just extended the line towards where I am, but it is not telling me that I am in the wrong direction. Okay, so I will turn around to the right direction. Oh, no. Now it says go straight... the name of the street changed and now it says, but **you cannot read the full name of the street**. Now it says Hoedemakerplein, but maybe it is this or that. But anyhow, it doesn't say where I should go, but it says where I am. Anyhow, I will turn to the right direction and start walking toward the center of the city... Okay, now it says in 60 meters turn right to the Marktstraat. No, I think it's messed up. The **instruction for navigation are messed up**. Right now, I'm at the intersection between Korte Haaksbergerstraat and Brammelerstraat. Okay, and now it says 0 zero meters turn to the Marktstraat, but according to the icon in directions, I understand that I should turn right. But right is Korte Haaksbergerstraat. Okay, there is a sign that says that Oude Markt is this way. **I really think it's messed up**, because I

			got lost on purpose. Now it says Oude Markt. **Okay, now I understand.** Now it says in 120 meters turn left, so I will walk straight... I was wondering if I could see the time, while using the map. Now there is a vibration signal and it says in 40 meters turn left. Now there is a strange icon. Now it says 100 Oude Markt 23. I don't know what it is. Did I reach the end of the navigation. I mean I can see the place. Ok, it probably means walk 100 meters straight. Okay, I can see the place, so let's walk there... Ok, 30 meters. 20 meters. So it vibrates, so I believe this means we are here. And the app closed automatically and came to the watch face.
LocusMaps	Find the closest parking on the map on the smartwatch	Time of the completion	00:21-5:01
		Completed task	Yes
		User actions	The user trying to pinch to zoom, but LocusMaps doesn't allow to pinch to zoom action. User uses the +/- buttons to zoom in and out. User uses his index finger to pan around his current location to find the closest parking. User is trying to rotate the map to see if he can change the orientation of the map.
		Where the user is looking	The user is looking at the map
		User Comments	Now the LocusMaps. And the app is starting. This is **OpenStreetMap**.. The thing that **I like about OSM is the level of detail.** I can see that the gestures don't work, but there are **some zoom buttons.** The only gesture that works is panning. It's very very accurate. Ah okay, it's says the **direction** I'm looking at. It's a wrong direction, but okay, it's telling me... **I was missing that in the Google Maps, the direction where I was heading**. **This is a very detailed map which in small places like city center is very useful**... Parking, I wonder which **symbol** they are using. Hopefully a **"P", a blue "P"**. Yes, I found one, two **"P"**s... There are two parking places on the what I believe is the north. Actually, this is the first time I'm wondering is **the north always pointing ahead of me**? Can I **rotate**? Oh, I can't **rotate**... I'm scrolling around, looking for the parking places. I see two parking places... I don't know which one is really closest, but it doesn't matter, they are just separated by a few meters. I found the closest one, the one next to the Irenepromenade next to Jumbo... I chose that one just because we don't have to cross the main street. I picked that one because I know this Jumbo at the city center, and I think that's closer.. But I **can not really measure,** so I don't know which one is actually the close one...
	Follow the navigation on the smartwatch	Time of the completion	05:20-11:13
		Completed task	Yes
		User actions	User follows the navigation on the map, at first the arrows are confusing for him, but later he understands their purpose and follows the navigation

		User Comments	Yes I see. Yes I see. I see the route okay. Yes. Okay. This is uh well it doesn't say much but there are **some icons**. And yeah I don't know what these icons mean. I mean there are **two arrows and crossings**, **one small on the top that says turn left one big one in the middle** that says turn right. So the question is should I turn left or right. Okay follow and then I follow the navigation on the smartwatch. Well first. Well there is a **heading arrow** and it says that I'm looking yes that way. Okay. So first let's try to align with this. But yes I as expected it doesn't work. I will move a little bit just to see if this works.... Now it's updated by I don't know. Yeah. This one I will say this a little bit **difficult to navigate** through but I'm assuming that this street is the street that I have to go to the one in front of me. So I will try to move that way. Let's see. Yeah. Okay. Yes. Now I see that I'm heading in the **right direction**. Forty meters. I believe this is 40 meters. Oh okay. Now I understand the meaning of the **arrows**. So the big icon of **the big arrow means the next step**. And the **small arrow means that they step after**. So this is I should turn right and then left. Yep. I guess the time out is for the brightness just a little bit complicated. Okay. Yes. Now I have to 28 meters turn left. OK. Twenty eight meters. 28 28 13 7. Okay. Was okay. Yeah I guess that's here. Yeah. Uh okay. I think that one of the things is that I haven't turned and the watch is showing me the next step and that is confusing because now **the direction changed**. Now it says hundred and sixty two meters to the right which I cannot go right. Okay. So ... I believe is it was this street first. And uh yeah. And I cannot see you I cannot go. I think that the in the the. Yes. I cannot see that. I think there is no way to see that. Yeah. The thing is that I **cannot see where the previous steps were**. I mean the previous turns. So I cannot. I think it will become difficult if **you don't know what I did before**. Okay. Yeah. Also the **accuracy**. I mean it is a hundred and thirty six meters but the street is almost over. Oh maybe I have to go straight. Okay. Yes I have to go through. And something that is **lacking in this app is that it doesn't mention the names of the streets** and it is probably yeah. **The name of the streets appear only in the map but they are covered by the green line that you show in the path. So it's not really readable.** **It's not nice.** Okay so ninety two meter meters straight. Huh. And this app **doesn't show the time.** Well that now I know we're in navigation mode but I don't know. I just think that maybe it's just me that I have a habit of **wanting to know what the time is every 10 minutes.**
ParKing	"Park" your car by placing	Time of the completion	11:44-14:19
		Completed task	Yes, but struggling to complete

	the car icon on the map	User actions	The user gets confused with the application icons and functionality. The user is looking at the main interface and looks confused by the buttons. After pressing the wrong buttons he finally opens the map and puts the car icon on the map.
		Where the user is looking	The main menu, the map
		User Comments	Parking. I see a first screen and it just says ... the address, this address?... Okay. So I will tap on the car icon. Okay. So the idea is that I go there... I don't understand. Okay. So it's not the car icon which I have to move but I'm huh... Okay. So I need to park my car, right. So I choose any any place. Okay. Let's choose. I don't know. I don't know. Well, interestingly enough there are no parking signs on this map. I tap on the green. What did I do? Because I tapped on it. It doesn't work. Ok, parking saved successfully.
	Navigate your car (route planning)	Time of the completion	24:54-26:16
		Completed task	Yes
		User actions	User is confused by the interface
		Where the user is looking	Main menu
		User Comments	Parking. Yes. And. Yeah. I wonder where is my list of.. how do I? What is this button here? The blue? No? Ah, yes, I tap on blue navigation arrow and then it is yes. And then it shows me to choose an app. So I choose Google Maps.
Google Maps with audio navigation	Navigate to Mexican restaurant using the smartwatch	Time of the completion	17:19 - 24:23
		Completed task	Yes
		User actions	User followed the route with audio commands as expected he was looking at the map even though he had audio directions
		Where the user is looking	Map directions

		User Comments	Okay now it says change navigation to walking. How do I change that? It says walking, no. No, it says with car... Oh okay. I see. Van Lochemstraat. Is this the Lochemstraat? I mean **the map** says it is. I am trusting the map ... because I cannot see the name of the street anyway. Yeah apparently I **move in the right direction**. Turn right on the Noorderhagen. Yes this is Noorderhagen. Turn right. Here. Three hundred meters. It is two hundred and sixty meters. ... Hundred and Seventy meters. Okay almost there, hundred and ten meters. 50 meters okay. Right on the Marktstraat. Yeah. Well here is the restaurant 10 meters just 10 meters slight left. Okay. I go slight left. Okay, I see that is mentioned.. She wants me to go this way. Okay, yes you are right. Okay I see it is mentioned in. Okay. So she wants me to go this way. Okay. Yes you're right. Yes. Okay.

APPENDIX 7

Sample Interview protocol (TP6)

Question 1.

I think that navigation experience per se was better with Google Maps. But then Locus Maps had OpenStreetMap, which is more detailed. Like in my case I'm a person who is more inclined to maps. I like the more detailed one because it will compensate a little bit with the general navigation with the precision and location and so on. So, the ones that I like the most I think that for the navigation perspective was Google Maps.

Question 2

Yes, definitely. Because otherwise I would have to be holding my arm and checking in very constantly. And that's tiring. So yeah I think that, well, in this first because this is my first trial of course I wanted to look into it very often. But I think that an experienced user with this device once it gets used to how it works, it will basically ignore the screen until watch vibrates and then okay, here you need to take attention to the screen and so on.

Question 3

Definitely changed the experience. Because the graphic part in the watch is limited. And. And. Basically it's very graphic but doesn't say what action to take. I mean it doesn't explain. Sometimes it's not self-explanatory. So having a sound, instructions through the sound, by confirming what you should do it is helpful because maybe you could say that okay, yes I think we could do the task without them, but it helps to confirm what you're doing.

Question 4

In the Google Maps what happened is that there is a dot marking the location and most when you are in navigation mode, but there is no indication of the heading. So which direction I am heading, right? And. We could see that when I basically on purpose took the wrong direction.

In the Locus Map, there was the heading, but it was not precise, so that's misleading. Yeah. That's misleading. In Google Maps it would be good to have a direction, the heading arrow. And in Locus Maps, it would be useful to be more precise. I think it's a matter of the device. For example I can imagine that if it is a maybe better device it will have besides let's say besides a compass, a computerized compass, which is precisely do these heading and not rely on the service provided by the maps. This is what I would be.

Question 5.

OK so to begin with I didn't notice that the Google Maps he was turning. I just assumed it was for example, it was always in front of me. So for example the direction I could take it was always in front of me. And probably that makes more sense because when you're when you're walking you are seeing the word in that direction. So probably it's better, because now that you mention it, yes, in the Locus Map I thought yeah I mean you have. I remember myself looking into it and trying to picture the position on the ground. So I will think that the user will have it easier if it turns because it is more intuitive for the users to say oh yes I'm in this direction the map is also pointing in that direction whatever it is north and west and so on.

Question 6

Yeah the zooming functions were okay. I just think that my fingers are too big for the screen and the buttons are quite small, so I made some mistakes because the buttons are so small. Maybe I have some ideas on how to improve that. I mean. Do you have a... I could tell you right. If for example I just imagine now. Imagine you have a dial here that actually rotates or in the case of the Apple Watch that you move it and then it does something but that it will have to be kind of not software improvements or visual improvements, but mechanic improvements.

Question 7.

Icons on the map, no, not for my anatomy. They were difficult to press, but from the visual perspective they were okay. I could see them clearly. And within the map, in the map everything was okay for me.

I think one issue is the name of places of the street. In this case, in the Netherlands, you may have these long names that doesn't fit on the screen. I mean if you made them to fit it would be too small to read.

I prefer the OpenStreetMap. If I have to navigate… So, this is my intuition. In Google Maps they simplify things to not overwhelm people with the amount of information so you don't have all these … details. However, the way I use it is that I use the details to confirm some of the directions in the navigation.

So if I have that level of detail I can say yeah I can confirm visually. Yes. The navigation system right. And on right there is this … building and I can see yes it is there. But that's I think this a personal preference. Yes. I prefer those details to be there if they are available, I prefer those details.

Question 8

Helpful. Yes, it was. I mean it was possible to find the places and it was possible to navigate. So yes, it was helpful.

Question 9

On the application side. And. The **Google Maps** I. I didn't like the fact that I didn't have a heading and the fact that when I took the wrong direction on purpose there was no at least without an audible aid, there was no way to see that I was going on the wrong direction because the corrected route was just showing me and it was just extending the actual route to where I was right. So there was no way to say that I was in the wrong direction and there was no way that that particular part.

In the **Locus Maps**, what I didn't like the fact that I couldn't use the gestures to zoom in and zoom out.

With the **ParKing** I think it was very confusing to know which was a button on the screen, on the front screen. Which one actually was a button and which one was let's say information things that will not change. So because basically one of the reasons may be that icons and the background were flat in the terms of visual aspects. So there was no shading or whatever you said, oh this is a button and this is just information. Yeah, that, I think. That will help.

And actually that's what it helps in the other apps. Because they divide the screen or they make it in a circle. But there in the parking app everything was flat. So everything looked like at the same level and it was like okay, this is something I could press or not, that was confusing.

Question 10

About the navigation method or the size of the, the information provided in terms of maps, I think it's useful.

If I talk about particularly this device, One of the things that I think would be a problem is the holding the hands here. All the time. Right. That is really tiring because he is not a natural position of the arm. But I mean in a traditional watch it works because you don't check the time for a very long time I mean you just take a short glimpse to it and that's it.

But if you're navigating the fact is that probably you are looking into the maps or you want to look into the map very often. Unless you remove the map completely out of it and by that I mean rely on vibration and sound so you don't need the map. You just need to know you're here. You turn right and left but that probably would be a better experience if the accuracy reaches a better level. But then you need to remove the map. Because the map is just distracting and making the user tired. Like I have to look on the map. No, you don't need the map. And sometimes you don't need a map. Although, that might sound contradictory to your research about maps, maybe sometimes you don't need a map.