

UNIVERSITY OF HRADEC KRÁLOVÉ
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DEPARTMENT OF INFORMATION TECHNOLOGIES

MASTER'S THESIS

Radio Fingerprint Acquisition Using Smartwatch

Author: Bc. David Sucharda

Study programme: Applied Informatics

Supervisor: Ing. Pavel Kříž, Ph.D.

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Prohlášení

Prohlašuji, že jsem diplomovou práci vypracoval samostatně a uvedl jsem všechny použité prameny a literaturu.

Declaration

I declare that I have elaborated this thesis independently and listed all the sources and literature.

Hradec Králové day 26th of April 2018

Bc. David Sucharda

Poděkování

Rád bych zde poděkoval Ing. Pavlu Kříži, Ph.D. za odborné vedení práce, podnětné rady a čas, který mi věnoval.

Thanks

I would like to thank to Ing. Pavel Kříž, Ph.D. for professional guidance, incentive advices, and the time he gave me.

Anotace

Název práce: Sběr rádiových fingerprintů pomocí chytrých hodinek

Diplomová práce se zabývá možnostmi sběru rádiových otisků (fingerprintů) za pomoci chytrých hodinek. Tyto otisky se používají k lokalizaci uvnitř budovy. Hlavním cílem této práce je prozkoumat možnosti sběru otisků a návrh aplikace která bude tento sběr umožňovat. V první části práce je potřeba zjistit, jestli je tento sběr na hodinkách vůbec možný. V další části je zpracování aplikace na mobil a hodinky. A jako poslední část této práce je sběr otisků a jejich analýza. Jeden z osobních cílů je zpracovat tuto aplikaci aby byla co nejvíce uživatelsky přívětivá.

Annotation

The Master's thesis deals with possibilities of collecting radio fingerprints with the help of smart watches. These prints are used in indoor localization. Main aim of this thesis is to explore possibilities of fingerprint collection and creation of application that will allow it. First part is to figure out if this collection is even possible using smart watch. Next part deals with creation of such application not only for watch but also for the phone. And at the end part there is testing of fingerprint collection and data analysis. One of the personal goal is to make this application as user friendly as possible.

Content

1	Introduction	1
1.1	Goals of this thesis	2
1.2	Reason for selection of this topic	2
2	Localization techniques	3
2.1	Triangulation	3
2.1.1	Lateration	3
2.1.2	Angulation	4
2.2	Fingerprinting	5
2.3	Proximity	6
2.4	Other techniques	7
3	Android	8
3.1	Android system structure	8
3.2	Wear technologies	9
3.2.1	Android Wear	10
	Standalone applications	11
	UI improvements	11
	Google Assistant	12
3.3	Other wear technologies	12
4	Analysis, design and implementation	13
4.1	Hardware	13
4.1.1	Smartphone	13
4.1.2	Smartwatch	13
4.1.3	BLE beacons	15
4.2	Software	15
4.2.1	AltBeacon Library	15

4.2.2	Database	15
	Couchbase database	16
	SQLite database	16
4.2.3	TileView	17
4.3	Application structure	17
4.3.1	Mobile application	17
	Activities	17
	Model	17
	Utilities	17
4.3.2	Wear application	17
5	Testing and data analysis	18
5.1	Data collection	18
5.2	Analysis	18
6	Conclusion	19
6.1	Application improvements	19
	Literature	20

List of figures

1.1	Comparison of Positioning Technologies (source: [4])	1
2.1	2D and 3D Trilateration (source: [10])	3
2.2	Multilateration (source: [11])	4
2.3	3D location using AoA from Quuppa Intelligent Locating System (source: [15])	5
2.4	Cell of Origin (source: [18])	6
3.1	Android stack (source: [24])	8
3.2	Smartwatch OS market share (source: [37])	10
3.3	Wear design examples (source: [41])	11
3.4	Wear watch faces (source: [38])	12

List of tables

4.1	Smartwatch comparison (sources: [52–56])	14
4.2	Couchbase vs SQLite (sources: [52–56])	17

1 Introduction

As the technology evolves it unlocks more and more possibilities. Just few years back there were no smart watches or phones but at this time they are important part of our lives. As they evolve there is the need for them to have more functions and features. One of them is to locate it's position on the map. This information is very useful since it can prevent people from getting lost, figuring out path to drive, used by military and countless more cases.

Finding out such position is possible using Global Navigation Satellite System (GNSS). Multiple implementations of this system exist like GPS, GLONASS or Galileo. All of these systems provide location using sufficient number (at least four) of satellites [1, 2]. GNSS solution requires clear path between satellites and the receiving device because signal is not able to pass through buildings. That makes it the main reason why it cannot be used for indoor localization.

There are multiple approaches to find out location inside the building. They can be divided into three main types. First type is using wireless signal ranging approach with multiple kinds of data like Time of Arrival (ToA). Second approach is using special equipment like active bats (Ultrasonic). And final type based on Signal Strength Fingerprint Maps (SSFm), in which first part is to collect signal strengths from the environment and construct fingerprint maps. They are then used to match with current signal to obtain the location [3].

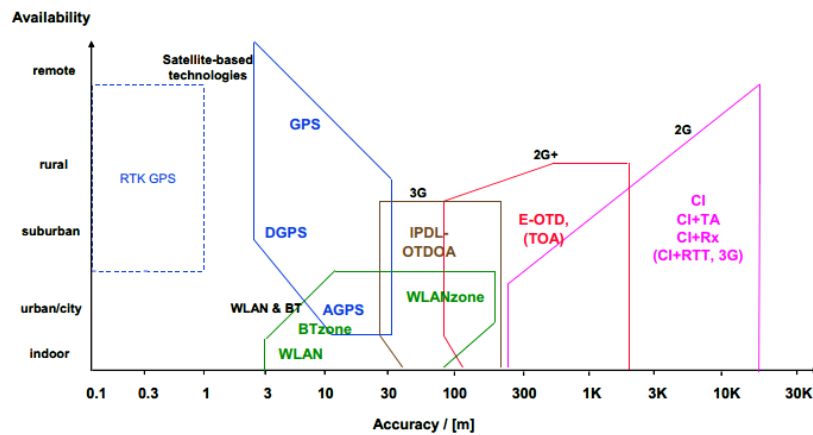


Figure 1.1: Comparison of Positioning Technologies (source: [4])

In addition to these types there are also multiple algorithms used in indoor localization. Some of them are location fingerprinting, triangulation, proximity and dead reckoning [5]. Description of few algorithms can be found in chapter 2.

This thesis is focused on method using radio signal strength (RSS) fingerprinting collecting data from bluetooth, wireless and cellular networks.

1.1 Goals of this thesis

Main goal of this thesis is to explore possibilities of fingerprint collection using smartwatch technology. The first question that needs to be answered is if this can be done. Is smartwatch capable of RSS data collection? And the answer to this question is yes since smartwatches have the similar specifications as low-end smartphones.

One of the goals for this thesis is to create an application for Android phone and wear device which handles fingerprint collection. Problem with smartwatches is their diversity in operational system because a lot of watch creators build their own custom systems which can complicate things. Luckily there is new system from Android called Wear 2.0 and it is basically port of Android system to wearable devices.

And final goal is to test created application and figure out if it's data are useful for indoor localization or not.

1.2 Reason for selection of this topic

The reason behind selection of this topic is rather simple. I was introduced to Android during my studies at the University but it was not any deep knowledge so I decided to go for a study abroad to deepen my knowledge. Part of that study was to work for a company where we developed rather technical heavy Android application. It's core part was using multiple APIs but it was focused only on a single device. So next thing I wanted try was working with multiple kinds of devices and since Android Wear 2.0 is rather new I wanted to test it out. So the main reason is to get more experienced with Android and as a developer.

2 Localization techniques

This chapter describes most common techniques and methods for localization. Most of these approaches have multiple implementations and can be also used in parallel. Fingerprinting for example can be used to increase accuracy of other methods.

2.1 Triangulation

Methods based on Triangulation use geometric properties of triangles to determine target position. This can further be divided into Lateration and Angulation [6]. There are multiple sources of data these methods can use like distance estimation between device and specific transmitters, measurements of the signal propagation-time (TOA: Time Of Arrival and TDOA: Time Difference of Arrival[7]) and the direction of received signal (AOA: Angle of Arrival[8]) [9].

2.1.1 Lateration

Lateration refers to the technique of determining position based on distance measurements that are calculated using specific devices that know their own position. Mainly used types of Lateration and are Trilateration and Multilateration.

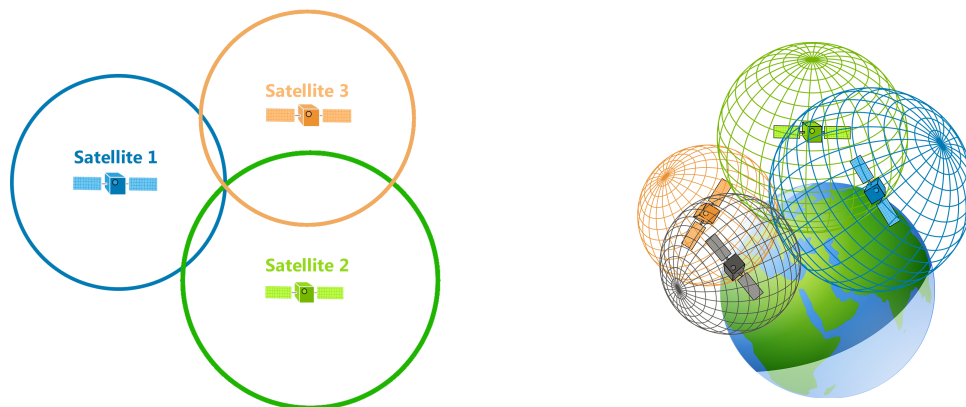


Figure 2.1: 2D and 3D Trilateration (source: [10])

Trilateration uses distance measurements from at least three devices in particular as "tri" in the name suggests [6]. Figure 2.1 illustrates usage of Trilateration in 2D and 3D environment. While working in 2D plane will result with only one specific location point. Moving to the 3D plane can create a problem because signal is send in a sphere which could result in more than one position. That is the reason why some systems use at least four signal sources, example of such system is GPS [2]. Advantage is easy implementation and simple calculations. One down side of this approach is that all devices must have synchronized clock [6].

Multilateration also known as hyperbolic positioning is using Time Difference of Arrival (TDoA) instead of Time Of Arrival (ToA) used in previous case. This approach involves the intersections of hyperbolas rather than circles as shown in Figure 2.2. Main advantage of this method is that only receiving devices must have synchronized clock instead of all [12]. Multilateration was developed for tracking aircraft position and it is widely used.

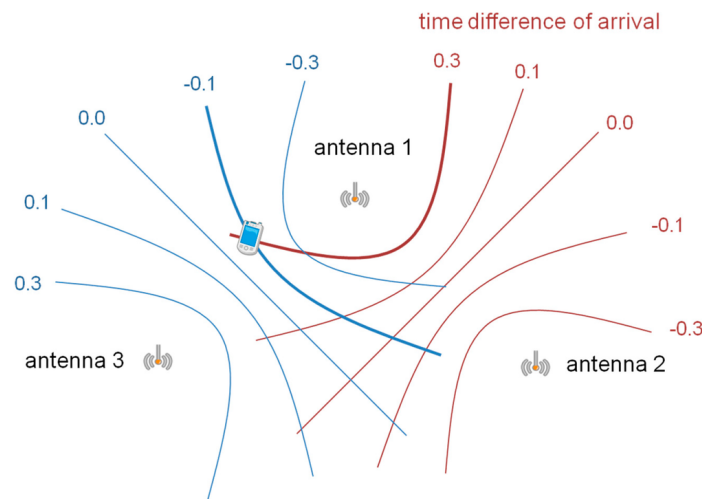


Figure 2.2: Multilateration (source: [11])

Note: At this time term Multilateration is not as strict as it used to be. It can now refer Lateration with more than three devices.

2.1.2 Angulation

This technique uses Angle of Arrival (AoA) of radio signals to determine location. It uses highly directional antennas or antenna arrays. Same as Lateration these antennas are placed in known location and basic AoA requires at least two of them to determine position on 2D plane but more of them can be used to improve accuracy [6]. That makes it an advantage over Trilateration. Second advantage of this approach is no need for synchronization between devices.

There are few disadvantages of this approach since it needs complex hardware setup due to the use of antennas. Other problem is with multipath locations since it can cause signal reflection making it not useful for indoor localization. And final one to mention is the decrease of accuracy when mobile target moves further from the antennas [13, 14].

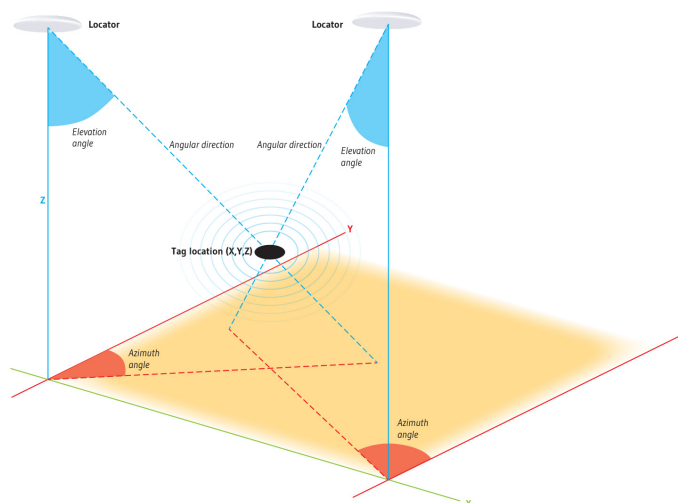


Figure 2.3: 3D location using AoA from Quuppa Intelligent Locating System (source: [15])

2.2 Fingerprinting

This method is a part of Signal Strength Fingerprint Maps (SSFm) type. Main point of this approach is using previously recorded data to figure out device location. Hence fingerprint term in the name. There is multiple kinds of radio signal sources like bluetooth, wireless or cellular devices that can be recorded.

Fingerprinting has two main phases where the first one is fingerprint maps construction also called offline phase. They are created by collecting Received Signal Strength (RSS) and optional extra features in known locations. All these values are saved in the database and it is called fingerprint map. The second phase is localization itself also known as online phase where the device measures RSS values and compares them with fingerprint maps to approximate position using suitable method [3, 16]. Most used algorithms or methods to approximate position are [9]

- probabilistic methods,
- k-Nearest Neighbors,
- neural networks,

- support vector machine,
- smallest M-vertex polygon.

There are multiple advantages of this approach and the most important is that it does not need any additional or specialized hardware. Next one is no need for time synchronization between the stations. Both of these advantages make it simple and cost effective method for localization. On the other hand building of the map is very time consuming and needs heavy calibration. It is also susceptible to changes in environment like people presence, object movement or relative humidity [9, 17].

2.3 Proximity

Proximity detection also known as connectivity based positioning calculates only approximate location. Position is determined by cell of origin (CoO) method with known position and limited range [6]. Specific device location is based on cell of the connected device ("associated access point" in Wi-Fi 802.11 systems) as shown in Figure 2.4 [18].

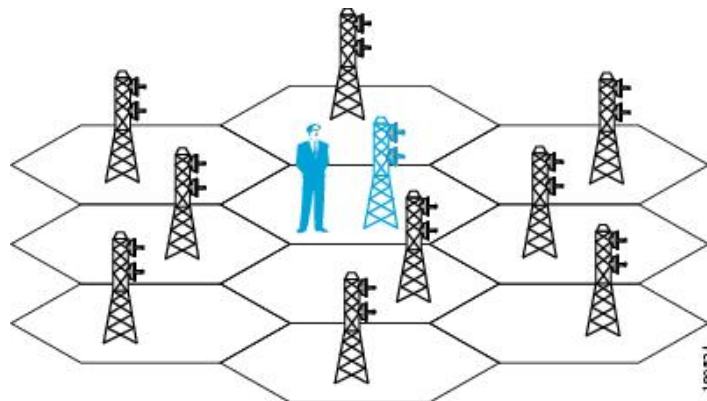


Figure 2.4: Cell of Origin (source: [18])

Primary advantage of this approach is very easy implementation and no need for complicated algorithms and thus making calculations fast. However, for various reasons devices can be associated to cells that are not in close physical proximity. Such errors can happen for example in multi-floor buildings where floor cells overlap. There are additional methods that can be used to improve localization such as using received signal strength indication (RSSI), manual method (human search) or connecting to device with highest signal strength [6, 18].

2.4 Other techniques

Scene analysis is a pattern recognition method that uses features of a scene observed from a particular vantage point to draw conclusions about the location of the observer or of objects in the scene also [19]. This approach has been used in many applications, such as image and speech recognition, as well as location [20]. The advantage is that the location of objects can be inferred using passive observation and features. The disadvantage is that the observer needs to have access to the features of environment against which it will compare its observed scenes [19].

Dead Reckoning refers to a position solution that is obtained by measuring or deducing displacements from a known starting point in accordance with motion of the user [21]. Basically calculate new position based on starting point, travel distance and angle of movement. Because new position calculations are dependent on previous ones there is the need for high accuracy of data since it makes errors cumulative [22].

3 Android

This chapter will provide information about Android and Wear 2.0 technology. Why it was developed and what are the differences between previous version and other wear technologies.

Android is a Linux based operating system for mobile and wear devices developed by Google. The main selling point of this system is that it's open-source project, meaning everyone can access the code and modify it as they wish. Android was mainly developed for mobile phones but in time moved beyond and at this time is implemented into all kinds of wear devices, tablets, televisions and even refrigerators or cameras [42].

3.1 Android system structure

Android is created as a stack, meaning there are functional modules stack on top of each other from Linux core over native libraries to applications as shown in Figure 3.1. Android maintains complete software stacks to enable device creators to run and modify Android for their specific hardware. To support these modifications and testing every release has multiple "code lines" to separate stable versions from experimental work [24].

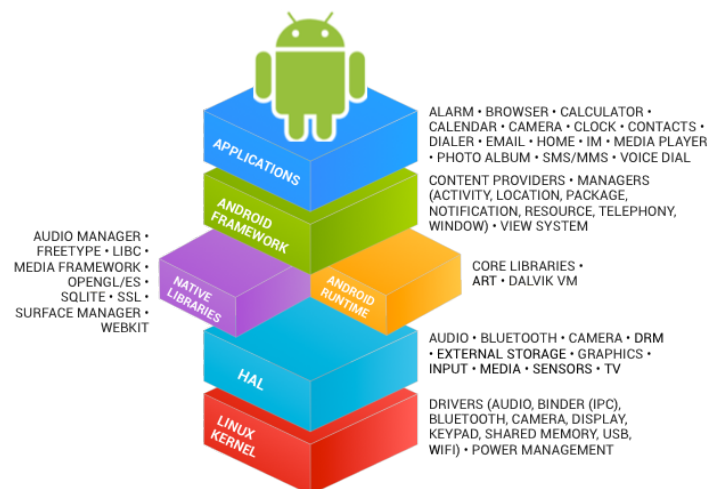


Figure 3.1: Android stack (source: [24])

There are multiple versions of Android system at this time and every single one has its own version, code name and API level. Version codes are number identifications of a specific system version. Highest levels of these numbers are grouped into code names that are ordered alphabetically. As an example versions 8.0.0 and 8.1.0 have the same code name called Oreo. Finally API level is number identification for compatibility of specific application and it will be compared to API level of device Android system [24, 25].

The highest part of the Android system stack are applications which extend device functionality and are written primarily in Java programming language [29]. These applications are packaged into .apk file, which is a zip archive, containing all application files like Java classes, layouts, images and more. Most important file is `AndroidManifest.xml` that contains all meta-data about the application, such as permissions, package name, used components, versions and so forth. These applications can be shared, for a nominal fee, via official market called Google Play. At the end of 2017 there were over three and a half million applications available in Google Play Store [29, 31, 32].

Android is a platform designed to be open source and free which makes it easy to create malicious applications. These applications can bypass existing security and steal sensitive data, use telephony services or even gain control over the device [30]. Android has multiple ways to protect against such applications one of the most notable ones are Android Permission Framework and Google Play Protect [29].

3.2 Wear technologies

Interactive wearable, as an example smartwatches, is a new part of mobile computers. Wear devices are categorically different from phones or tablets in terms of usage, design and user interfaces (UI). According to the app design guidelines by major vendors, users interact with wearable devices frequently throughout daily use. Each interaction is short, often less than 10 seconds, and is dedicated to simple tasks [26].

Important thing to note is that there are multiple kinds of wear devices from smart watches, wristbands, cameras or even glasses [27]. Based on report from Gartner technology research, conducted in 2017, most used wear devices were Bluetooth headset, wristbands and smart-watch [28]. Thanks to their small size wear devices are ideal to use for hands-free communication and health monitoring.

One problem with this diversity is hardware and software compatibility. Every device creator can create their own operating system for specific wear device and it can be difficult

to develop custom applications for it. To avoid such problems this thesis is focused only on smartwatch with Android Wear operating system.

There are three main point to note with watch devices. First of all is small battery capacity that can be almost ten times smaller then in typical smartphone. The second point is display with around forty-times less pixels which completely changes properties. And final part is scaled down CPU with high efficiency [26]. Last two points are main parts of lowering power consumption of smartwatches but even with these cuts high-end watch devices can have really small battery life only in matter of few days or just hours.

3.2.1 Android Wear

Android Wear is a version of Android OS tailored to small-screen wearable devices. There are not too many changes from system for smartphone but one of the main differences can be seen in UI since system had to be adjusted for watch size [33]. Due to scaled down processing power of watches Android Wear wirelessly offloads data to the smartphone for heavy computing tasks, e.g., voice recognition [34].

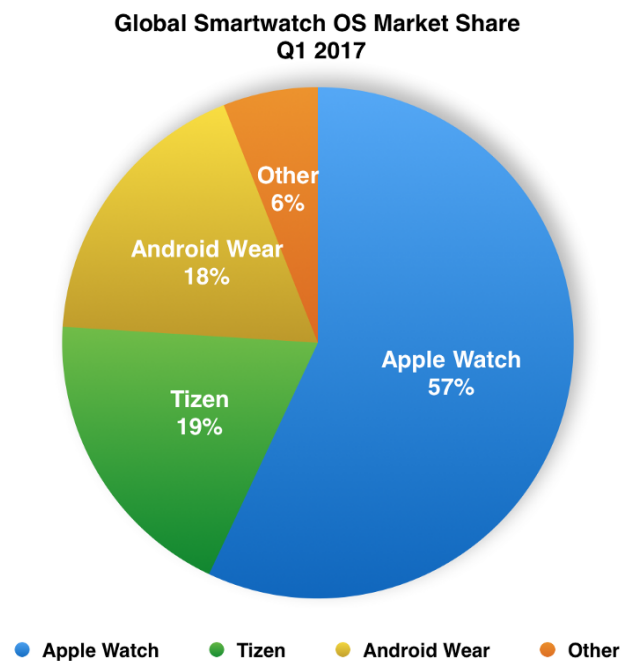


Figure 3.2: Smartwatch OS market share (source: [37])

Android Wear is one of the most popular smartwatch systems but comes with it is own set of problems. Most notable and annoying one is being unable to pair wear with specific mobile device. It can be caused by combination of things like system compatibility, custom

hardware or phone type but it is more common then it should be [35]. Having phone connected to Android Wear can also cause phone to drain battery way faster. One thing to note is that smartwatch can be connected to only single device and connecting to another requires factory reset. Few other problems can be update issues, notifications not coming through to the watch, not being able to connect to Wi-Fi and system crashes [36].

Even with all these problems it is popular system and in early 2017 it got it's biggest update yet. New version 2.0 brought numerous improvements and features and few of the most notable ones will be described in this section [38–40].

Standalone applications

This feature is crucial change and it means that watch applications do not need mobile phone to function. Before this version it was needed to have connected phone with Android Wear support to use applications. Being forced to have Android phone proved as an obstacle for users without one since they could not use any applications on the watch [38, 39].

Since application can now work without phone there should be a way to install them directly. Thankfully part of this update is also standalone Google Play Store where users can browse apps that are designed specifically for the watch [39]. Part of this feature is also enabling watch to use wireless and cellular networks on their own since most standalone applications require this feature. And final part of this update was improving and securing communication with phone. This is now done via Wearable Data Layer API that is used in almost all Google applications and it is also pretty easy to use as a developer [38].

UI improvements

Part of new Android Wear version is implementation of Android's Material design guidelines [41]. It has much more "mature" look and darker design for reducing battery drain [39]. It is completely focused on Wear devices and supports both round and square screens with new re-design of application launcher [38].

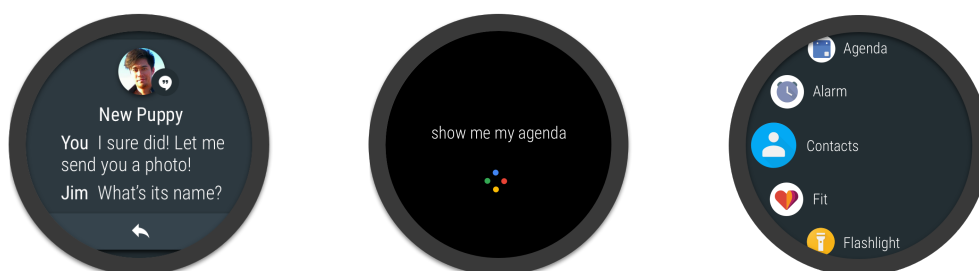


Figure 3.3: Wear design examples (source: [41])

Android is also trying to catch up with Apple's watchOS and make default watch display, also called watch faces, much more useful. Users can add different widgets of any containing data of any application to the watch faces [38]. This ensures quick access to the data user deems important [40]. All this data displays also match design of currently selected watch face and after clicking it will direct right into the application [39].



Figure 3.4: Wear watch faces (source: [38])

Google Assistant

Google Assistant is basically voice controlled smart assistant same as for example Amazon's Alexa, Apple's Siri or Microsoft's Cortana. There are multiple tech sites that run benchmarks of these systems [43–46] and they do not seem to be that different so there is no need to buy one over the other. These systems can pull information that you need or want and they track where you work, sports you like, your schedule, stuff that might interest you and much more [42]. With the update of Wear 2.0 this feature is now available on smartwatches [38, 39].

3.3 Other wear technologies

Tizen, Pebble, Apple, ...

4 Analysis, design and implementation

This chapter describes all important information about created application. One of the main parts are hardware and software used for developing and testing of the application. Other part is structure and description of core parts used in the application.

4.1 Hardware

There are three main Hardware components used and those are smartphone, smartwatch and BLE beacons. Main requirements for both hardwares is support for scanning Bluetooth Low Energy beacons that is supported from Bluetooth 4.0. As a secondary requirements are Wi-Fi, GSM and LTE modules to be able to scan more types of devices than just BLE beacons.

4.1.1 Smartphone

Main part of the application will be developed and tested on Redmi Note 4 from Chinese company Xiaomi. It is running customized version of Android 6.0 called MIUI. Even though system was customized in core it is still Android so there are no problems in that regard [48]. This phone has Bluetooth 4.1 with LE support so main requirement for the hardware is met. This device also met all the secondary requirements with Wi-Fi 802.11 a/b/g/n, GSM, and LTE support like most modern smartphones would [47].

4.1.2 Smartwatch

As already mentioned this thesis is using smartwatch with support of Android Wear 2.0 which makes it harder to select proper wear device since there not so many options at this time. There was around twenty of watches with 2.0 system and only five of them were selected to closer inspection based on few articles [49–51].

Watch	BLE / Wi-fi support	Sold in Czech Republic	Problems
LG W280 Sport	Yes / Yes	No	Battery life is one day or less. Too big in size.
LG W270 Titanium Style	Yes / Yes	Yes	Battery life is one day or less.
Huawei Watch 2	Yes / Yes	Yes	First update can take a long time. Slight Bluetooth pairing issues.
Polar M600	Yes / Yes	Yes	Polar support complains. Phone synchronization issues. GPS location malfunctions.
ASUS ZenWatch 3	Yes / Yes	No	Strap breaks fast. AW 2.0 update can break the watch. ASUS support complains.

Table 4.1: Smartwatch comparison (sources: [52–56])

There were funds only for one watch device out of five which is displayed in Table 4.1 with selection parameters. First requirement for the wear device is support of BLE and Wi-Fi which all have. Second information considered was being able to buy it in Czech Republic (CR) since it is easier for prices, shipping and reclamations. Only three of five devices were sold in CR at that time so others are out of the question. Final decision was made based on extensive research of customer reviews in shopping sites (Amazon, CZC, Heureka, Alza), wear official websites [52–56] and other tech sites [49–51]. And selected device is Huawei Watch 2 since there were not too many problems in reviews and other requirements were met.

Initial setup of the wear device was composed of two main parts. First one was update wear system that took about one to two hours. Second task was copy Google account into the wear device where problem was discovered. Copying of accounts from Redmi Note 4 to the watch hanged and never completed. To fix this problem another smartphone was used to copy the account but as it was already mentioned only single device can be connected to smartwatch and connecting a new one requires factory reset that would remove all the data. So there was the need to pair wear with phone without factory reset which was handled via debugging following this [57] article.

4.1.3 BLE beacons

Some info about beacons.

4.2 Software

Smart phone and wear use Android system which was already described in Chapter 3. This section will provide basic information about libraries, technologies and systems used in the application or supporting it.

4.2.1 AltBeacon Library

There are multiple solutions that can be used to scan for BLE beacons as for example Estimote SDK [58] which was already used in previous thesis [59]. To change things up BLE beacons are found via AltBeacon Library [60].

Since there is no open and interoperable specification for proximity beacons, Radius Networks has authored the AltBeacon specification as a proposal for how to solve this problem. It is a open and free specification for Bluetooth Low Energy beacons with focus to create an open, competitive market for proximity beacon implementations [61].

This library enables Android devices to scan for iBeacons based on previously mentioned AltBeacon standard but it can be customized to support different kinds of beacons. It also supports Eddystone which is Google's open source beacon format and calculation of range between the devices which will help with localization [60, 62].

4.2.2 Database

Database is needed to keep all the Fingerprint data for calculations and there are two types of databases used for this application. First one is SQLite database that is used in Android application to save Fingerprints. This database is default and most used solution in Android applications and there is no need to use other ones. Another type of database used is Couchbase which is implemented on `beacons.uhk.cz` server to keep all Fingerprint data on one place for multiple applications.

Couchbase database

SQLite database

SQL (Structured Query Language) is a standard language for storing, manipulating and retrieving data in databases. It is a type of Relational Database that means all data is saved into tables with rows and columns [63]. These tables usually have set amount of rows with specific names that protect from adding wrong data as an example you cannot add data `Person(name, surname, eye color)` into table `Person(name, surname)` because there is no column named `eye color` in the table.

Advantages of these databases are structured data which makes calculation faster but uses more storage space. Data can be only saved once since they can be connected to each other. It supports complex queries for creating, reading, updating and removing data (CRUD) and better security with user and table management. Some disadvantages of this system can be with complexity and inflexibility of database scheme because it can be hard to setup and it does not allow other data than is defined in the tables [64].

Since SQL with all the features can consume a lot of hardware resources for a smartphone that is not as fast as a server Android decided to implement SQLite. SQLite has the following noticeable features: self-contained, serverless, zero-configuration, transactional [65].

- Serverless = does not need second process for the server.
- Self-Contained = requires minimal support from operating system.
- Zero-configuration = no need for installation or any configuration.
- Transactional = data are protected against failed changes (application crashes, power failure, ...).

This solution was tested against Couchbase database for Android and it proved as better solution. Not only it takes less storage space it is also able to load data faster. As Table 4.2 shows SQL lite takes less data space and is almost three times faster in loading all the documents.

Database type	Data size	Loading speed (315 documents)
SQLite	15MB	23 second
Couchbase without views	31MB	65 seconds
Couchbase with views	91MB	65 seconds

Table 4.2: Couchbase vs SQLite (sources: [52–56])

4.2.3 TileView

4.3 Application structure

4.3.1 Mobile application

Activities

Model

Utilities

4.3.2 Wear application

5 Testing and data analysis

This chapter goal is to show application testing, data collection and analysis.

5.1 Data collection

5.2 Analysis

6 Conclusion

6.1 Application improvements

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