

UNIVERSITY OF HRADEC KRÁLOVÉ  
FACULTY OF INFORMATICS AND MANAGEMENT  
DEPARTMENT OF INFORMATION TECHNOLOGIES

## MASTER'S THESIS

### Radio Fingerprint Acquisition Using Smartwatch

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Hradec Králové

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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.

## **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 Křiž, 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 pomocí 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 uživatelky 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.

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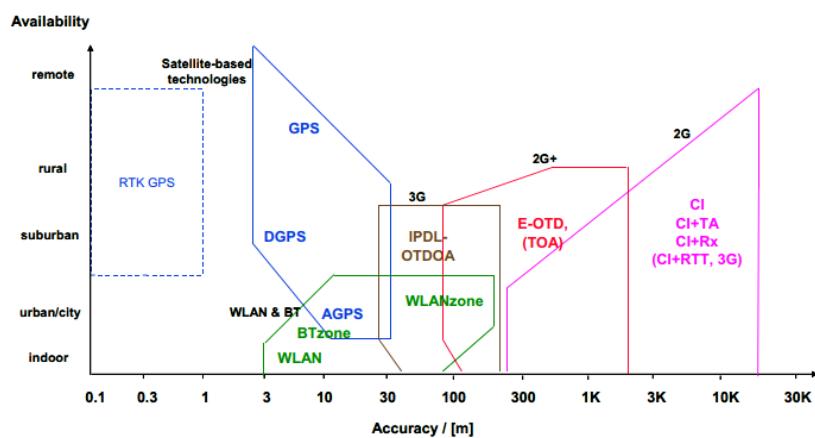
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# 1 Introduction

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 such as GPS, GLONASS or Galileo. All of these systems provide location using sufficient number (at least four) of satellites [1, 2]. GNSS solution requires clear line of sight 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, using wireless signal ranging approach with multiple kinds of data such as Time of Arrival (ToA). Second, using special equipment such as active bats (Ultrasonic). Final, 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 acquisition using smart-watch 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

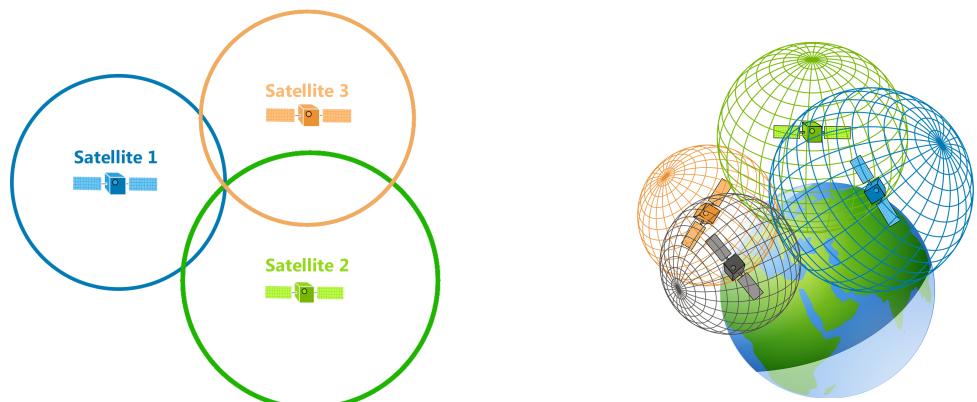
This chapter describes most common techniques and methods for localization. Most of these approaches have multiple implementations and can be also used in parallel. Finger-printing for example can be used to increase accuracy of other methods.

## 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 such as 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.

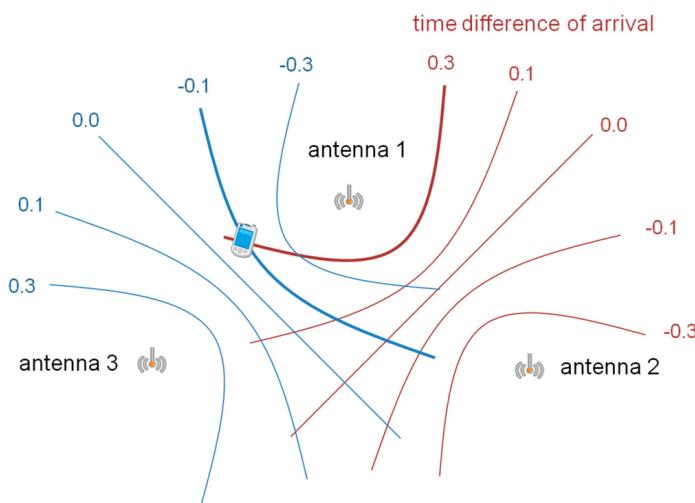


Figure 2.2: Multilateration (source: [11])

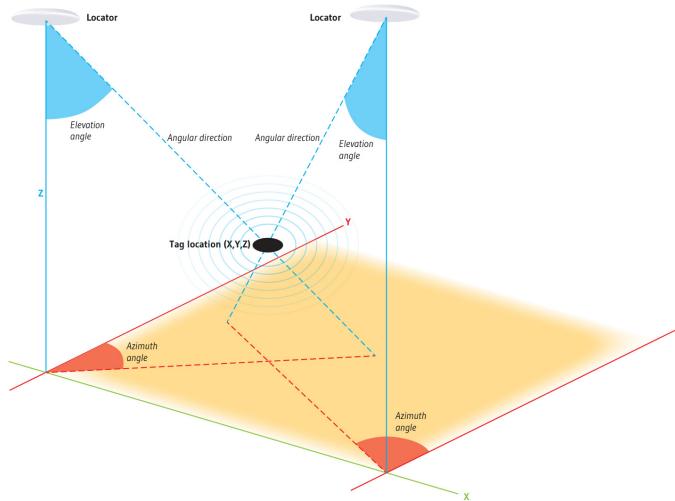
Note: At this time term Multilateration is not as strict as it used to be. It can now refer Lateration with more than three devices.

## 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 are multiple kinds of radio signal sources such as 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]

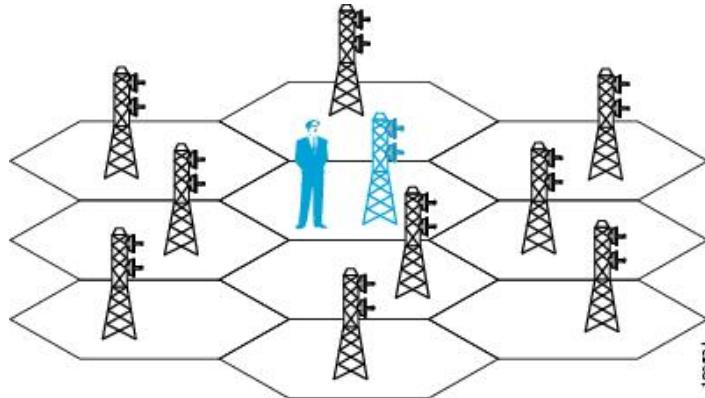
- probabilistic methods,
- k-Nearest Neighbors,

- 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 such as 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 Related Work

Since this is not a novel idea there are some completed solutions and paper written about Fingerprint collection using multiple devices. This chapter will describe few selected solution close to this one for comparison.

## 3.1 Improving Precision by Using Multiple Wearable Devices

Focused on improving indoor localization using BLE-based fingerprinting with multiple devices [23]. Using combination of smart phone and wear should in this case prevent signal obstruction from human body and at least one of the devices should receive beacon signal. Unfortunately due to low BLE sensibility of wear devices, authors decided to supplement them with smartphone, in this case with Nexus 5 running Android 4.4.

This paper proposes calculating medians using 800 millisecond tests where user can move at most one meter. For all medians at the same position is calculated average and variance, based on which a normal distribution is used to model the potential variation of RSSI. One thing to note is that fingerprint maps are built based on facing direction. There are five main scenarios tested

- P1: device held in hand where body does not obstruct its LOS path to all beacons,
- P2: device is put in breast pocket and LOS may be obstructed to some beacons,
- P3: user holds smartphone in hand and wears a smartwatch on one wrist,
- P4: one device is put in the breast pocket and the other is on one wrist,
- P5: one device is in the breast pocket, and two other devices, each on one wrist.

Firstly, four of these scenarios were tested in a 15x8 meters entrance hall with four deployed beacons in the corners and ten measurement positions. In this location using multiple devices can improve position precision and reduce error by 57%. Table 3.1 shows mean errors

for previously mentioned cases where using more devices improves localization. However there is one position where case P4 will result with higher error than P3 due to building structure and signal obstruction for nearest beacons.

Scenario	Mean error (m)
P1	2.36
P2	1.71
P3	0.96
P4	0.41

**Table 3.1:** Mean errors at first location (sources: [23])

Secondly, all of previously mentioned scenarios were tested in a conference room with unified ceiling and desks near the walls. This location is used to investigate the impact of beacon density to position precision. Three following combinations of beacons are used

- A: four beacons at the corners,
- B: combination A with one beacon at the center,
- C: combination B with four more beacons at the sides of the room.

Using directional maps at this location resulted in increase of maximum localization error, which was not expected. This error can increase even more when using higher count of beacons and occurs mostly when testing at the edges of the room. Mean error on the other hand shows an improvement, higher with more beacons used.

Scenario	Mean error (m)		
	A	B	C
P1	2.05	2.05	1.76
P2	1.84	1.49	0.90
P3	1.36	1.09	0.63
P4	1.24	0.78	0.23
P5	0.80	0.39	0.07

**Table 3.2:** Mean errors at second location (sources: [23])

In summary, position error can be improved by three aspects: using more devices, using directional map or increasing the number of beacons. There are two main conclusions of this paper. First, confirmed precision degradation when testing near the edge of the room with obstructed signal from nearest beacon. Second, human body does not greatly change radio signal and device can receive reflected signals with sufficient strength.

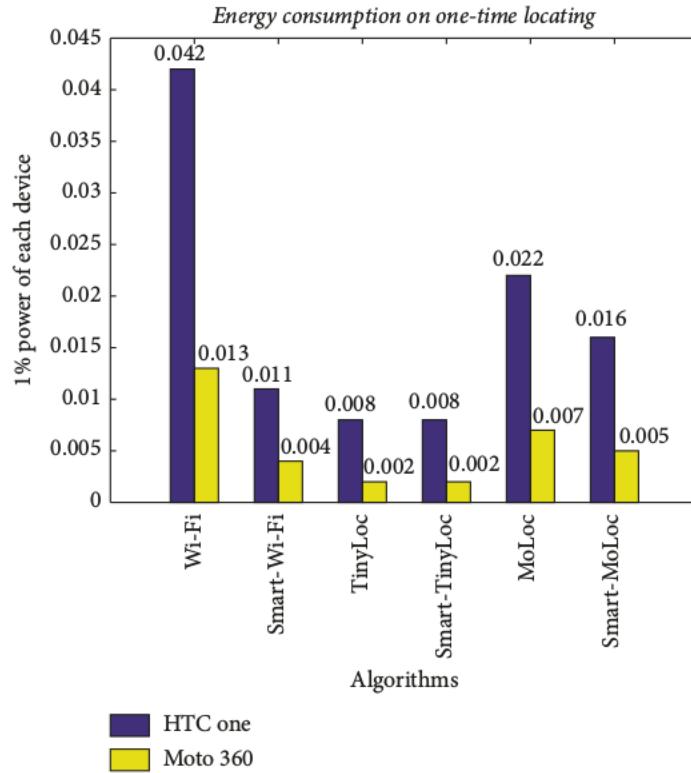
## 3.2 SmartFix

An Indoor Locating Optimization Algorithm for Energy-Constrained Wearable Devices called SmartFix [24]. The main goal of this paper is improve energy consumption efficiency for wearable-based indoor localization using WiFi fingerprints. Single real-time experiment of energy consumption was run and split into two main parts: computation of location and collection of fingerprints. According to this experiment, energy consumption caused by collection is occupies 99% of localization algorithm.

This paper proposes novel indoor localization strategy, SmartFix, that can cooperate with existing indoor localization technologies based on WiFi. It enhances accuracy of such algorithm with a little extra energy cost of calculation but a large save of signal collection energy cost. Aided with machine-learning algorithm, it obtains the relative features given the trajectories of users in certain areas and modify the localization results. SmartFix can save up to 70% of energy while achieving the same localization accuracy when compared to the original fingerprint method.

To test this new system it was implemented with prototypes of TinyLoc [25], MoLoc [26] and basic WiFi fingerprint method using k-neighbor algorithm. TinyLoc is more focused on energy efficiency than location accuracy. In contrast SmartFix analyses the history trajectory of people in given area to improve locating results. It refers to user motion features, SmartFix modifies locating results to achieve satisfying accuracy. MoLoc also leverages user motion by collecting trajectory patterns using device built-in sensors.

All previously mentioned prototypes were deployed with and without SmartFix to test its power consumptions. It only needs single real-time RSS signal in the locating phase to guarantee excellent energy saving performance. Figure 3.1 shows energy consumption of on-time locating on two specific devices: HTC one and Moto 360.



**Figure 3.1:** Energy consumption based on prototypes (source: [24])

This paper proposed and tested new localization technology, SmartFix, which main focus is to improve energy efficiency for wearable devices. According to experiment, the probability of error within 2 meter can be reached in 80% of cases. Meanwhile, energy consumption is 35% lower than that of MoLoc with the same accuracy, and SmartFix obtains best accuracy with minimal energy cost.

### 3.3 SmartWatch vs. SmartPhone

A comparative study about localization using smartwatch vs. smartphone [27]. It presents that positioning accuracy using WiFi based fingerprint implemented on a smartwatch is sufficient for at least room-size locations. Average minimum room size is  $10m^2$  or at least  $3 \times 3m$  with maximum of five WiFi APs broadcasting on different channels.

Field study was conducted in six specific locations such as farm, large room, house, two types of medium rooms and one small room. This study collected data using two Android based devices, MotoACTV was used as smartwatch and Samsung Galaxy S3 mini as smartphone. To make fingerprint data more reliable the study collects device orientation (horizontal, vertical) and samples were taken in all four cardinal directions (north, east, south, west).

Test area	Floor size		Fingerprint size		Positioning accuracy SmartWatch (SmartPhone)		
	Dim.	Area	Dim.	Area	5AP	4AP	3AP
Farm	$30 \times 80m$	$2400m^2$	$10 \times 10m$	$100m^2$	82.5%(73.1%)	74.6%(69.8%)	56.2%(51.1%)
Large	$10 \times 20m$	$200m^2$	$2.5 \times 2.5m$	$6.25m^2$	41, 1%(40.3%)	36.9%(33.6%)	27.7%(28.1%)
House	$10 \times 16m$	$160m^2$	$2 \times 2m$ $> 2 \times 2m$	$4m^2$ $> 4m^2$	63.9%(68.5%) 83.5%(87.5%)	56.5%(66.6%) 79.3%(86.6%)	47.1%(63.8%) 73.2%(81.1%)
Medium	$6 \times 6m$	$36m^2$	$2 \times 2m$ $3 \times 3m$	$4m^2$ $9m^2$	67.1%(70.1%) 91.1%(96, 1%)	53.5%(67.9%) 86.3%(95.2%)	35.0%(61.2%) 75.7%(93.6%)
Small	$3.5 \times 3.5m$	$12.25m^2$	$1.75 \times 3.5m$	$6.13m^2$	98.1%(100%)	97.2%(99.5%)	91.3%(97.8%)

**Figure 3.2:** Summary table of results (source: [27])

Figure 4.2 shows summary results of experiments. Most important part of this data is comparison of positioning accuracy between smartwatch and smartphone. In all tests the difference in classification error between the smartphone and smartwatch was at most 5% if data from all five APs is used. On the other hand it can be 25% worse when using small amount of APs in large environments. The result of this study is a confirmation that localization using smartwatch is comparable to smartphone and sometimes even better for home environments. The usage of smartwatches is also preferable since it is tightly connected to a person.

# 4 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 [47].

## 4.1 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 4.1. 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 [29].

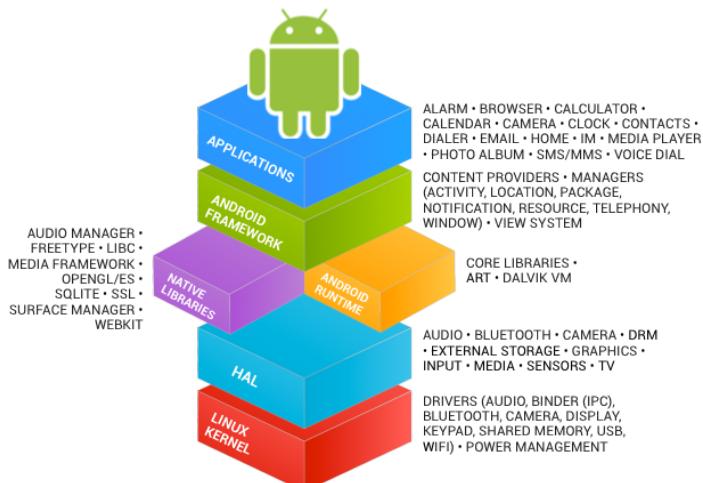


Figure 4.1: Android stack (source: [29])

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 [29, 30].

The highest part of the Android system stack are applications which extend device functionality and are written primarily in Java programming language [34]. These applications are packaged into .apk file, which is a zip archive, containing all application files like Java classes, layouts, images and more. The 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 [34, 36, 37].

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 [35]. Android has multiple ways to protect against such applications one of the most notable ones are Android Permission Framework and Google Play Protect [34].

## 4.2 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 [31].

Important thing to note is that there are multiple kinds of wear devices from smartwatches, wristbands, cameras or even glasses [32]. Based on a report from Gartner technology research, conducted in 2017, most used wear devices were Bluetooth headset, wristbands and smartwatch [33]. Thanks to their small size wear devices are ideal for hands-free communication and health monitoring.

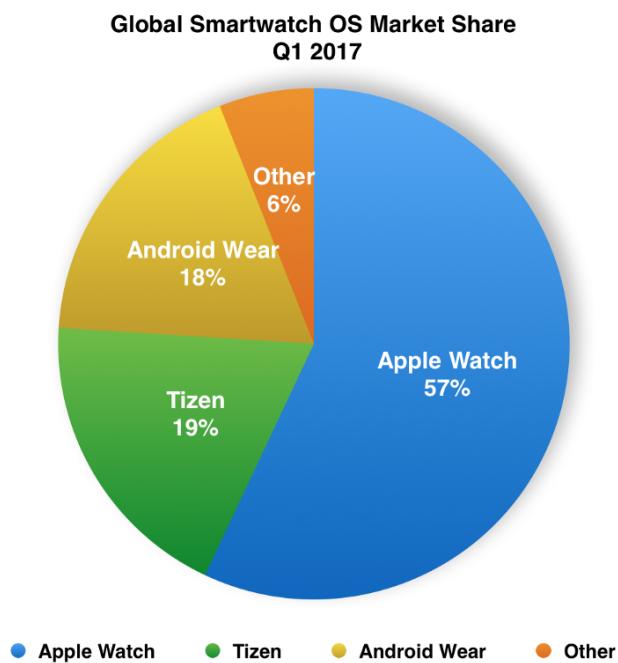
One problem with this diversity is hardware and software compatibility. Every device creator can create their own operating system for specific wear device and it can be difficult

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 points to note with watch devices. First, small battery capacity that can be almost ten times smaller then in typical smartphone. Second, point is display with around forty-times less pixels which completely changes properties. Final, scaled down CPU with high efficiency [31]. 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.

#### 4.2.1 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 [38]. Due to scaled down processing power of watches Android Wear wirelessly offloads data to the smartphone for heavy computing tasks, e.g., voice recognition [39].



**Figure 4.2:** Smartwatch OS market share (source: [42])

Android Wear is one of the most popular smartwatch systems but comes with its 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 such as system compatibility, custom hardware or phone type but it is more common than it should be [40]. 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 [41].

Even with all these problems it is popular system and in early 2017 it got its 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 [43–45].

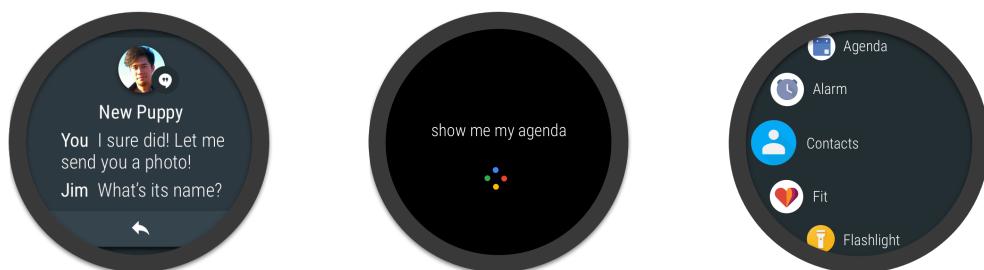
#### 4.2.1.1 Standalone applications

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 [43, 44].

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 [44]. 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 [43].

#### 4.2.1.2 UI improvements

Part of new Android Wear version is implementation of Android's Material design guidelines [46]. It has much more "mature" look and darker design for reducing battery drain [44]. It is completely focused on Wear devices and supports both round and square screens with new re-design of application launcher [43].



**Figure 4.3:** Wear design examples (source: [46])

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 [43]. This ensures quick access to the data user deems important [45]. All this data displays also match design of currently selected watch face and after clicking it will direct right into the application [44].



**Figure 4.4:** Wear watch faces (source: [43])

#### 4.2.1.3 Google Assistant

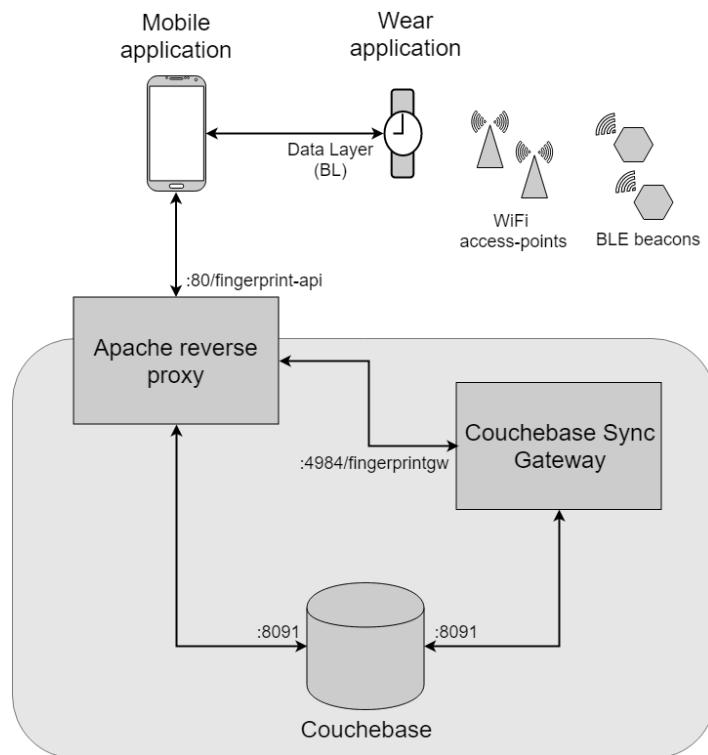
Google Assistant is basically voice controlled smart assistant same as for example Amazon's Alexa, Apple's Siri or Microsoft's Cortana. There are multiple tech sites that run benchmarks of these systems [48–51] and they do not seem to be that different so there is no need to buy one over the other. These 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 [47]. With the update of Wear 2.0 this feature is now available on smartwatches [43, 44].

### 4.3 Other wear technologies

Tizen, Pebble, Apple, ...

# 5 Application design and implementation

This chapter describes all important information about created application. First is hardware and software used for developing and testing of the application. Second is structure and description of core parts used in the application.



**Figure 5.1:** Application architecture (based on [9])

Figure 5.1 shows basic devices and technologies used in this application. There are three main part of this implementation, mobile, wear and server application. Mobile and wear parts implement scanning for radio signals and are written in Java language for Android system. Server is also programmed in Java to keep implementations close to each other and make future adjustments easier. Main goal of the server is to store scanned data.

## 5.1 Hardware

There are multiple hardware devices used in this application. All of them can be seen on Figure 5.1, where first and the most obvious are smartphone and smartwatch. These devices scan radio signals from WiFi access-points and BLE beacons that are placed in the indoor environment. And a final hardware part is a server holding scanned data from all devices.

### 5.1.1 Smartphone and Smartwatch

Both smart devices must support scanning of Bluetooth Low Energy beacons that can be done with Bluetooth 4.0 and higher. Secondary requirements are Wi-Fi, GSM and LTE modules to support more data types than just BLE beacons.

#### 5.1.1.1 Phone

Main part of the application is 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 [53]. This phone has Bluetooth 4.1 with LE support so main requirement for the hardware is met, with all the secondary requirements also met with Wi-Fi 802.11 a/b/g/n, GSM, and LTE support like most modern smartphones would [52].

One interesting thing about Xiaomi smartphones is their locked bootloader. It prevents users from any manual updates but most importantly from factory reset. To unlock it owner has to create an account in Xiaomi website and put a request to unlock bootloader. This request is usually processed within two weeks period and there is no actual guarantee of it being approved. After evaluation process is complete user is notified via sms about the result of such request.

#### 5.1.1.2 Smartwatch

First goal of this thesis was to select smartwatches running on Android Wear 2.0 technology. This iteration is quite new currently, which makes it harder to select proper wear device since there are not so many options. During selection process there were around twenty of watches with this system and only five of them were selected to closer inspection based on few articles [54–56].

Only one smartwatch could be selected out of five displayed in Table 5.1. Firstly, wear device had to support BLE and Wi-Fi which all have. Secondly, it must have been sold in

Watch	BLE / Wi-Fi	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 5.1:** Smartwatch comparison (sources: [57–61])

Czech Republic (CR) since it makes shipping and warranty easier. Only three of five devices were sold in Czech Republic at that time so others were taken out of the consideration. Final decision was made based on extensive research of customer reviews in shopping sites such as Amazon, CZC, Heureka, Alza, wear official websites [57–61] and other tech sites [54–56]. Finally, selected device was 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, update wear system which took about one to two hours. Second task was to setup the watch and copy Google account, this is where some problem were discovered. Copying of accounts from Redmi Note 4 to the watch never completed. To fix this problem another smartphone (Huawei Y5 II) was used to copy the account, it was already mentioned that only single device can be connected to smartwatch and connecting to a new one requires factory reset removing all the data. It was needed to pair wear with phone without factory reset which was handled via Android Debug Bridge following this [62] article.

Since Google wants to focus also on iOS devices technology Android Wear 2.0 was rebranded to Wear Os by Google to remove confusion in the future [63]. This updated was forced on wear devices, updating it to the newest Android version which forced some changes in the development of this solution. First, implementation bug in scanning library was introduced and had to be fixed. Second and bigger problem was inability to deploy new version of the application from Android Studio to the watch. This, for some reason, effects the main computer used to develop this application and it was fixed by using another computer.

## 5.1.2 Radio signal devices

As hardware devices are used BLE beacons, WiFi access-points and Cellular towers. Only first two types of these devices can be placed inside a building and are most commonly used in indoor localization. Signal from cellular towers is only a complimentary data that does not have to be used and cannot be influenced since they are placed by telecommunication companies.

### 5.1.2.1 BLE beacons

Beacons are small devices that can be easily placed in almost any environment. Only thing they do is send an information packets using Bluetooth and nothing else. They are commonly used in museums, airports and as of late in indoor localization [65]. Beacons have their own battery powering them which can last around a year or two without charging because of the new Bluetooth Low Energy (BLE) standard. This technology drastically reduces power consumption and introduces new configuration options regarding the advertising interval and the transmitter output power [64]. More in depth description of this technology and devices was written by Pavel Kriz et al. [9].

There are multiple beacon manufacturers with their own quality, signal strength, battery life and other hardware differences. Changes can also be found in software (packet) specifications for beacons, meaning data they send have different format but it does not mean other systems cannot see them. Usually some software changes have to be made to detect such beacons but they are documented and not hard to make. Beacons are also usually platform independent, making them work with multiple platforms such as Android or iOS [64, 65]. Beacons used in this thesis are from a company called Estimote and they are most commonly used.



**Figure 5.2:** Parts of Estimote beacon (source: [66])

Another important thing to note, Beacons are not connected to the Internet and do not collect any data from devices around them. Meaning all the data have to be processed in another device, most commonly a smartphone, and it also makes Beacon safe to use because there is no need to worry about sensitive data theft [65].

### 5.1.2.2 WiFi access-points

WiFi signals are commonly used in indoor localization due to their presence almost anywhere. In this case several WiFi transmitters of the eduroam network made by Cisco were used. They are permanently deployed on every floor of a test building and cannot be influenced or changed.

## 5.2 Server

Implemented application do not necessarily need a server for its core functionality but it is common and faster to run an analysis of the data and other heavy computational work on a different, faster device. Functionality of the server is to serve as a backup of the data and also as a synchronization point to enable other devices to download fingerprints and upload new ones.

The server infrastructure was built in previous years [9] but it was improved for this solution. It uses NoSQL database to save fingerprints. This type of database does not have fixed scheme, making it easy to save all kinds of data. There are many NoSQL databases, around 250 at this time, to choose from. Selected database is called Couchbase, it saves data in JSON files with its own query language similar to SQL. Part of this database can also replicate data between other devices which could be used in the application part. In the end it was deemed too slow and data heavy for usage in the application, creating the need for creation of a middleman API between Android application and Couchbase database.

As Figure 5.1 shows server has three main parts to work with. First, already mentioned is Couchbase database to keep scanned data. Second, sync gateway that can synchronize data between devices, not used in this implementation. Both of these part were already implemented in previous years [9]. Final part is web application working as a REST API to send data between the server and mobile application.

This API is written in Java based framework called Spring to keep the code similar to Android. It was documented using Swagger and it handles two main HTTP routes: `fingerprints` and `fingerprints-meta`. Before any tasks are issued, mobile application checks data on

the server using `fingerprints-meta` route which returns count of new fingerprints and last time specific device saved fingerprints on the server. With this information the application knows how many fingerprints to upload and download, in this specific order, to ensure data is stored first. To prevent device memory exhaustion and connection timeout both of these tasks have specific limits, download can process 100 of fingerprints while upload only 20. Server can also generate data files for analysis, split by technology, time, origin device and other filters. To simplify this generation it is similar loading all fingerprints, meaning it does not create file but prints the data directly into the connection stream.

One last thing to note in Figure 5.1 is the connection with sync gateway. Even though it is not used in this implementation for synchronization it is used to save fingerprints into the database. When data is saved into Couchbase directly sync gateway will not display them, that is why the upload must go through the gateway. This is to ensure all previous and next solution can use this feature without loosing any important data.

## 5.3 Application Software

Software part for smartphone and smartwatch uses Android system which was already described in Chapter 3. This section will provide basic information about libraries, technologies and systems used in such applications.

### 5.3.1 AltBeacon Library

Since Android core does not allow scanning for BLE beacons this feature must be implemented in a library extending system features. There are multiple solutions that can be used to scan for beacons such as Estimote SDK [67] which was already used in previous thesis [68]. To change things up BLE beacons are found via AltBeacon Library [69].

Since there was no open and inter-operable specification for proximity beacons, Radius Networks has created the AltBeacon specification as a proposal to solve this issue. It is an open and free specification for BLE beacons with focus to create an open, competitive market for implementation of these devices [70]. Basic configuration of this library can scan for beacons based on this standard and it also supports Eddystone beacons which is Google's open source format. To support already mentioned Estimote beacons this library configuration must be altered to support their detection. Luckily this function can be easily modified to support different kinds of beacons by just one following line of code [69, 71].

```
beaconManager.getBeaconParsers().add(
```

```
new BeaconParser().setBeaconLayout("m:2-3=0215,i:4-19,  
i:20-21,i:22-23,p:24-24"));
```

#### Code example 5.1: Code to enable all beacon types

This library uses publish-subscribe design pattern, meaning one scan data is send to multiple clients if they listen for them. Using this approach has an advantage of eliminating the need to run a scan per client. Update to Android 8 introduced a bug in this feature making it unable to confirm the registration of client so the scanner has to be reworked thus postponing the data collection and analysis.

### 5.3.2 Database

This solution makes use of two different types of databases to store all the Fingerprint data for calculations. First, is SQLite database implemented in Android mobile application to save Fingerprints from smartphone and smartwatch. This database is default implementation and most commonly used in Android applications. Second database type is Couchbase implemented on the server `beacons.uhk.cz` to keep all Fingerprint data in one place and this enable synchronization and data analysis.

#### 5.3.2.1 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, meaning all data is saved into tables with specified rows and columns [77]. These tables usually have set amount of rows with specific names that protect from adding wrong data, for 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.

Structured data is one of the advantages of this database type and it makes calculation faster but usually uses more storage space. Other advantage is that 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 is hard to setup and does not allow other data then is defined in the tables [76]. Altering schemes in the future can be really complex since there is the need to parse all previous data to the new tables which does not need to have the same scheme as previous ones.

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 [77].

- 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, ...).

### 5.3.2.2 Couchbase database

Since SQL based databases can be complex to implement, scale and consuming more data storage space there was a drive to create so called NoSQL databases. Their most important feature is not having a schema, that makes them easy to scale, and easy to replicate between multiple devices. There are around 225 NoSQL databases at this time and Couchbase is one of them [73].

Couchbase is distributed, document-based database with its own querying language called N1QL. It is a database focused on simple server configuration and easy use for clients and with built in caching layer and distribution system it does not require any changes in the application. There can be either one server instance of Couchbase or multiple of them can be connected and create a database cluster that holds all the data in multiple location (nodes) [74].

Since SQL is used for decades and it became standard for working with data in databases this approach was extended for usage with JSON and called N1QL. It has all features of the SQL with only difference of being focused on JSON files that has no structure and it is used in Couchbase [75].

There is a version of Couchbase for mobile called Lite that provides APIs to work with the documents and synchronize with the server instance. Problem of this solution is that Lite version does not implement N1QL and maps data as document views that have to be indexed and usually use more data, at least on Android.

### 5.3.2.3 Comparison

Both of these database solutions were tested on Android and SQL proved as a better solution. Not only it takes less storage space it is also able to load data faster. As Table 5.2 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 5.2:** Couchbase vs SQLite (sources: [57–61])

As shown SQL comes up better but it does not support any data synchronization so there must be custom solution created. If Couchbase Lite would have faster query time it would be preferable solution but it is not at this time.

### 5.3.3 TileView

There are multiple ways to display map image in Android but the main ones have problems while displaying a big image because they will run out of memory. So it is usually better to try custom library or widget created specifically for displaying big image. There is multiple 2D and 3D libraries to display such an image but most of them display image as a whole meaning one big image file.

There is another way introduced by Google Maps where map is displayed using small images so called tiles. Image is cut into small pieces which is better for device memory management than one big image. Depending on how big the cuts are it can also display multiple zoom levels keeping the map quality high with high and low levels.

## 5.4 Application structure

This section describes structure of the applications and since there are two parts of this application (mobile and wear) both of them will be described.

### 5.4.1 Mobile application

Mobile application is the bigger and more complex part that handles scanning, map display and synchronization with the server.

### 5.4.1.1 Activities

Activities are visible screens of the application. They serve as the entry point for a user's interaction with an application, and are also central to how a user navigates within an application (as with the Back button) or between apps (as with the Recents button) [30].

Main activity for this application is called `ScanActivity`. It displays map with proper building, floor and found Fingerprint in that specific location. It enables users to scan for new beacons and thus create new Fingerprints. Map and controls are implemented using `TileView` widget that was described in previous section.

### 5.4.1.2 Model

Model package contains most important classes of the application and it's split into four parts called: adapters, configuration, database and tasks.

#### Adapters

Adapters information.

#### Configuration

Configuration classes contain settings of the application. It uses Android's shared preferences that are key-value (xml) files to save small amount of application data. Each Shared-Preferences file is managed by the framework and can be private or shared. One thing to note is that these files are not encrypted so it is not good to save user sensitive data in them.

#### Database

Database package contains all classes needed for communication between application and SQL database. First part of this package are Fingerprints classes that correspond with tables and columns of the database. Second part are so called database helpers that handle communication between the application and SQLite database such as tables creation, selects, inserts, updates and deletions.

#### Tasks

Tasks contain the most complex classes of this application and that is the Fingerprint scanner that has multiple sub-classes to parse all the necessary data from the scan. Tasks also contain connection with the server for data synchronization and Fingerprint transfers.

### 5.4.1.3 Utilities

Utilities contain classes not fit to any other category or classified as support ones which usually means classes for animations or warning messages but since this application communicates with the wear device this package also contains classes that handle such communication.

### 5.4.2 Wear application

Wear application is simplified version of its smartphone counterpart. It handles only scanning, display of scanning progress and sending the data to the phone.

# **6 Testing and data analysis**

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

## **6.1 Data collection**

## **6.2 Analysis**

# **7 Conclusion**

## **7.1 Application improvements**

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# Attachments

1. CD with application
  - a) Application data
2. Public Github repository with application and thesis text.

<https://github.com/Del-S/WearNavigation>

Univerzita Hradec Králové  
Fakulta informatiky a managementu  
Akademický rok: 2017/2018

Studijní program: Aplikovaná informatika  
Forma: Prezenční  
Obor/komb.: Aplikovaná informatika (ai2-p)

**Podklad pro zadání DIPLOMOVÉ práce studenta**

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**TÉMA ČESKY:**

Sběr rádiových fingerprintů pomocí chytrých hodinek

**TÉMA ANGLICKY:**

Radio Fingerprint Acquisition Using a SmartWatch

**VEDOUCÍ PRÁCE:**

Ing. Pavel Kříž, Ph.D. - KIKM

**ZÁSADY PRO VYPRACOVÁNÍ:**

Cíl: Navrhnout a implementovat aplikaci pro mobilní telefon a chytré hodinky na platformě Android Wear 2.0, pomocí které bude možné změřit rádiové fingerprinty souběžně pomocí mobilního telefonu a hodinek. Vyhodnotit a porovnat přesnost indoor lokalizace s použitím existujících algoritmů využívajících rádiové fingerprinty.

Osnova:

1. Úvod
2. Indoor lokalizace s pomocí rádiových fingerprintů
3. Platforma Android Wear 2.0
4. Analýza a návrh
5. Implementace
6. Testování, zhodnocení výsledků
7. Závěr

**SEZNAM DOPORUČENÉ LITERATURY:**

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<https://www.microsoft.com/en-us/research/project/radar/>  
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<http://www.sciencedirect.com/science/article/pii/S1877050912005170>  
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<http://www.mdpi.com/1424-8220/17/6/1339>  
<http://www.mdpi.com/1424-8220/17/8/1789>

Podpis studenta: ..... 

Datum: 18. 11. 12

Podpis vedoucího práce: ..... 

Datum: 15. 11. 17