TALLINN UNIVERSITY OF TECHNOLOGY

School of Information Technologies

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INDOOR POSITIONING APPLICATION CASE STUDY AT TALLINN UNIVERSITY OF TECHNOLOGY

Master's thesis

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TALLINNA TEHNIKAÜLIKOOL

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Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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Abstract

The thesis gives an overview of the indoor positioning technologies and highlights how to apply them in a commercial setting. Different technologies were studied and the most suitable ones in the context of Tallinn University of Technology campus were selected for development and testing. The kernel of these tests was indoor positioning application developed for the university visitors for sharing diverse information about the university and primarily location information.

The application can be downloaded from following address (Android):

https://play.google.com/store/apps/details?id=ee.ttu.augmenteeritudreaalsus

Privacy policy

http://dijkstra.cs.ttu.ee/~Sander.Saarsen/ttupartner/privacypolicy.html

This thesis is written in English and is 45 pages long, including 8 chapters, 13 figures and 4 tables.

Annotatsioon

Siseruumides postisoneerimise rakendus Tallinna Tehnikaülikooli näitel

Käesolev lõputöö annab ülevaate sisepositsioneerimistehnoloogiatest ja uurib kuidas neid kasutusele võtta suures organisatsioonis. Töös analüüsiti erinevaid tehnoloogiaid ja valiti välja sobivamad Tallinna Tehnikaülikoolis rakendamiseks ja testimiseks. Töö keskseks osaks on mobiilirakendus ülikooli külalistele, õpilastele ja töötajatele, mis aitab leida asukohti kampusel ja anna ligipääsu ülikooliga seotud informatsioonile.

Mobiilirakendus on kättesaadav järgnevalt aadressilt(Android):

https://play.google.com/store/apps/details?id=ee.ttu.augmenteeritudreaalsus

Privaatsuspoliitika:

http://dijkstra.cs.ttu.ee/~Sander.Saarsen/ttupartner/privacypolicy.html

Lõputöö on kirjutatud inglise keeles ning sisaldab teksti 45 leheküljel, 8 peatükki, 13 joonist, 4 tabelit.

List of abbreviations and terms

API	*Application Programming Interface*
BLE	*Bluetooth Low Energy*
CoO	*Cell of Origin*
GNSS	*Global Navigation Satellite Systems*
GPS	*Global Positioning Systems*
IPS	*Indoor Positioning System*
RFID	*Radio-Frequency Identification*
RTLS	*Real Time Location System*
SDK	*Software Development Kit*
UWB	*Ultra-Wideband*
WLAN	*Wireless Local Area Network*

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1 Introduction

Mobile devices and location-based applications (e.g., Google maps [1], Waze [2]) have become a part of people's everyday lives. These solutions are mostly based on Global Navigation Satellite Systems (GNSS), which can only be used outside, so indoor navigation has been a difficult task for a while. In recent years it has become a big area of interest for researchers and software developers alike since there are many large complex indoor areas where reliable navigation would have many applications. Today there are several working solutions for indoor positioning. Airports, shopping malls, hospitals and other institutions can make use of these possibilities and help people use their services.

Thesis will study different indoor positioning technologies and how to apply them in a big organization in our case Tallinn University of Technology and its campus. During the autumn semester of 2017, a proof of concept application was made in a university course ITX8540 that uses the Earth's magnetic field for indoor positioning and helps users to find various events and locations around the university campus. The prototype gave good results.

During writing the thesis the application redeveloped into a working wayfinding Android application for Tallinn University of Technology campus that works both indoors and outdoors. Also the application will make use of several universities micro-services and infrastructure that will be incorporated to applications architecture. The end user will have access to a diverse information about the university and can complete different tasks through the app. The application will use state of the art architecture and design principles which make it flexible and portable to be used by other organizations who have similar needs and interests.

Based on this work we can see better how viable is positioning based on the Earth's magnetic field, how to make use of it in a larger organization and how viable it is.

1.1 Methodology

The thesis follows design science research methodology (DSRM). Scientific evaluation papers investigate existing problem situations or validate proposed solutions with scientific means, such as by experiment or case study [3]. Work is divided into six major parts:

- **Problem identification and motivation**
  Need for easier and faster wayfinding and source of information in large establishments.
- **Solution objectives**
  Mobile application with needed functionality.
- **Design and development**
  Android mobile application with incorporated organization micro-services and earth's magnetic field based positioning service together with Google’s map and backend solutions.
- **Demonstration**
  This part will be done in collaboration with universities marketing department. Different university events and test groups will be used to see the application in work and gather data based on usage.
- **Evaluation**

  Evaluation will be split into 2 parts. First of all, testing on users from university and getting feedback on the application to see whether it is fulfilling its purpose or not.
  Secondly, indoor navigation precision will be tested to see how reliable it is. Extreme precision isn’t needed for this project, so a few meter accuracy is enough. Measuring’s will be done with the help of Eliko’s KIO Ultra-Wideband positioning system.
- **Communication**
  This part will be fulfilled by the thesis itself, which is used to communicate the problem and solution.

1.2 Research questions

- How viable is indoor positioning and magnetic field positioning for use within a set of university buildings?
- What precision can be achieved with different technologies? Is the precision sufficient for indoor navigation in the campus buildings?

2 Background and Related Work

Indoor Positioning Solutions (IPS) are growing in popularity and organization have started to adapt various them. It is a growing market that is expected to reach 4.4 billion dollars by the end of 2019 [4]. Organizations from different sectors are showing interest to IPS as it opens up new opportunities for them. This fast growth has led to a lot of different solutions using various technologies and approaches.

Global Navigation Satellite System (GNSS) based solutions have been widely and successfully used for outdoor positioning, but GNSS isn't reliable for indoor positioning due to buildings causing signal loss and errors when positioning. This results in lower locating accuracy or even inaccessible locations depending on the architecture of given building. Because of this, alternative ways of positioning need to be used.

2.1 Indoor positioning technologies

There are a number of different technologies and approaches when it comes to IPS. In this thesis we will focus on solutions that are based on mobile devices. Today's smart phones have several different sensors like Wi-Fi, GPS, Bluetooth, gyroscope, compass, microphone – these can all be used for positioning.

Some of the solutions are more scientific and haven't been commercially used, but they are proven to work and could be theoretically used. Other solutions are more widely used and are more accessible. In this section we will be focusing on solutions that are mainly used in development at the current time and are easily accessible. The solutions can rely on different technologies and sensors or a mix of them, but for a clearer overview they have been divided into 3 groups.

Radio frequency signals

These solutions use various frequency signals to determine position. They usually work by having multiple appliances emitting signals (e.g. Wi-Fi, Bluetooth, Ultra-wideband) and then measuring strength, angle or travel time to devices in covered area. Then, based on this data, devices' approximate position can be calculated.

Signal based solutions have proven to work well, but are always reliant partly on hardware that generates the signals. This means extra investment and work for using this kind of technology. Also building architecture needs to be heavily taken into account when using signal based solutions. Different materials and electronic devices can cause problems or affect how you need to set up the system. Signal fading and interference need to be addressed when deploying signal based IPS [5]. Commercially, frequency based systems are the most popular and used type of solutions, where most used signal types are Wi-Fi and Bluetooth [4].

Bluetooth

Bluetooth based solutions usually use Bluetooth Low Energy (BLE) beacons for emitting signal. Bluetooth beacons are wireless, low cost and with low power consumption, usually powered by batteries making them more efficient than other radio frequency signal based solutions [6]. Low cost and size make them easy to set up and appealing for a lot of use cases. BLE beacons are placed in rooms and areas where indoor positioning coverage is needed. Bluetooth solutions have high accuracy (few meters), but require also high number of beacons, but due to their low cost and maintenance they are widely used. Among other solutions Apple has released a protocol for Bluetooth hardware devices that can be used for indoor positioning called iBeacon [7].

Wi-Fi

Wi-Fi based solutions are similar to Bluetooth ones, but instead of beacons, Wi-Fi routers and access points are used, this makes it an appealing approach since most buildings have at least partially the necessary infrastructure available. In a wireless local area network (WLAN) devices are receiving/emitting radio signal from/to routers, this communication between systems can further be used to determine location. Location is mainly determined through one of three main localizing methods: Cell of Origin(CoO), Triangulation or Fingerprinting [8]. Wi-Fi solutions use less hardware than Bluetooth solutions since the signal has higher range. Accuracy depends a lot on the building architecture and number of access points/routers, so it varies a lot more, but generally are less accurate than Bluetooth solutions. Lower accuracy comes from the fact that Wi-Fi signal is not as stable as other signal types used by indoor positioning systems. Signal quality is affected by distance and most buildings will have areas with weak or even dead signal [9], this depends on density of Wi-Fi routers and the building architecture.

Ultra-Wideband

Ultra-Wideband (UWB) is a radio signal that works on a wide portion of frequency spectrum. This allows high amounts of data to be passed over the network. Similar to other approaches UWB also uses hardware for reference points to calculate device position off from. Due to its high-temporal resolution, multipath immunity, and simultaneous ranging and communication capability, Ultra-Wideband is a promising technology for indoor ranging and positioning applications [10]. Typical indoor localization scenario consists of a transmitter and receivers mounted on the ceiling and distributed around the region of interest to detect and localize the tags. Positioning calculation is usually done by using data travel time to location from beacons.

Geomagnetic fields

An IPS based on magnetic fields use a magnetometer to measure magnetic field variations, which will be used to determine the position of a person or object. The position estimation is commonly performed through methods such as fingerprinting [11]. Fingerprinting means that magnetic readings from the device are compared to pre-recorded mapping data. Mapping data consists of magnetic field strength vectors that are stored in fingerprint database. Final user position is determined based on algorithms that try to find the closest match based on live magnetic readings and info from database [12]. Main benefit of this solution is that it doesn’t rely on extra hardware, which makes it a lot easier to implement and also to test or try out. On the other hand, it does require magnetic field mapping of indoor areas. This method can achieve accuracy comparable to Bluetooth solutions or even higher depending on circumstances.

Physical markers

These kinds of solutions use real word markings or object that devices can later interact with to determine its indoor position. Examples would be RFID [10] tags that can be read by the phone or QR codes or other unique visuals that can be read through phones camera. Physical markers provide reliable way to determine position, but rely on user interactions, which make them less appealing for many use cases. Also the markers demand maintenance and upkeep, which can also be a problem in many cases. Accuracy is high, but doesn't allow reliable real time positioning.

Other

There are a lot of other possible additional positioning methods, like light [13] or sound [14] based solutions, but since they aren't commercially used, they won't be further discussed in this thesis. These solutions are proven and working, but were not accessible to the author at the time of writing the thesis.

2.1 Experimentally Evaluated Technologies

Three IPS-s were tested in the study:

- Wi-Fi – Was used in the first prototype, since the university campus had the required hardware available.
- Geomagnetic field based solutions – Alternative to Wi-Fi solution after finding out university Wi-Fi infrastructure was not sufficient for our use case. IndoorAtlas commercial platform is used as the main IPS for the project currently.
- Ultra-Wideband IPS - Eliko KIO RTLS was used to measure the accuracy of the application.

Most significant factors when considering different solutions were cost and accessibility. So the selection came down to Wi-Fi positioning for which Tallinn University of Technology partially has hardware support already in place and geomagnetic field positioning which doesn't require extra hardware.

Ruckus Wi-Fi routers

Ruckus R500 and R510 models are used in the Tallinn University of Technology's library and social sciences building. These routers come with an API SPoT that can be used to get locations and network information of devices using the WiFi network. SPoT Smart Positioning technology uses location fingerprinting and requires correct access point placement and calibration [15]. These routers together with SPoT were used in the first prototype of the campus application.

IndoorAtlas

IndoorAtlas is an IPS platform for Android and iOS. This is the only commercial magnetic field based IPS. It's mainly based on the magnetic field measuring's that are done before deploying the application, but uses also other mobile device sensors to improve accuracy (Wi-Fi, gyroscope and Bluetooth if needed). The platform doesn't use extra hardware and can be used without initial start-up costs. However, extra hardware could be used to increase the accuracy and reliability of the system. The solution requires magnetic field mapping which means recording magnetic field strength throughout buildings. These recordings are used later as a reference to determine location [16]. In university campus application IndoorAtlas was used as the primary IPS for positioning users.

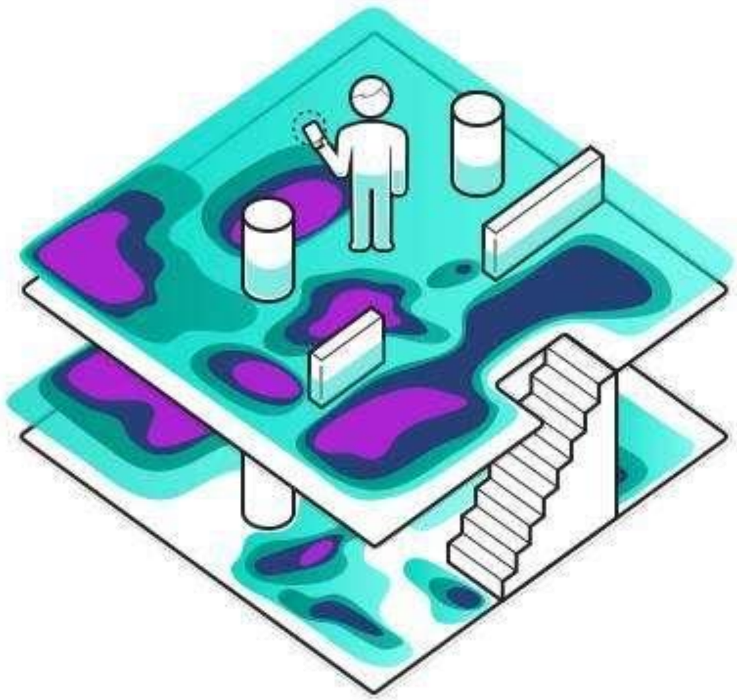

Figure 1 Magnetic field map illustration

Eliko KIO RTLS

Eliko KIO real-time location system (RTLS) uses Ultra-Wideband (UWB) technology for positioning. It works similarly to Wi-Fi and Bluetooth based systems, but uses Ultra-Wideband signals that position objects through walls and obstacles. KIO uses anchors for positioning, similar to Bluetooth beacons. Anchors provide up to 5cm accuracy, which is very high compared to other similar solutions. [17]

The system uses anchors for positioning and tag on objects that need to be tracked. Location is estimated based on the time-of-flight of UWB radio signal. So the signal travel time is measured to at least 4 anchors, based on the measurements final position can be calculated.

Output data gives x-y-z coordinates not latitude-longitude. The system is scalable with extra anchors; buildings can use tens or even hundreds of positioning anchors, depending on the building architecture and size. Materials used and floor layouts affect the anchor count.

Eliko KIO RTLS was used in the project for measuring the precision of the final application.

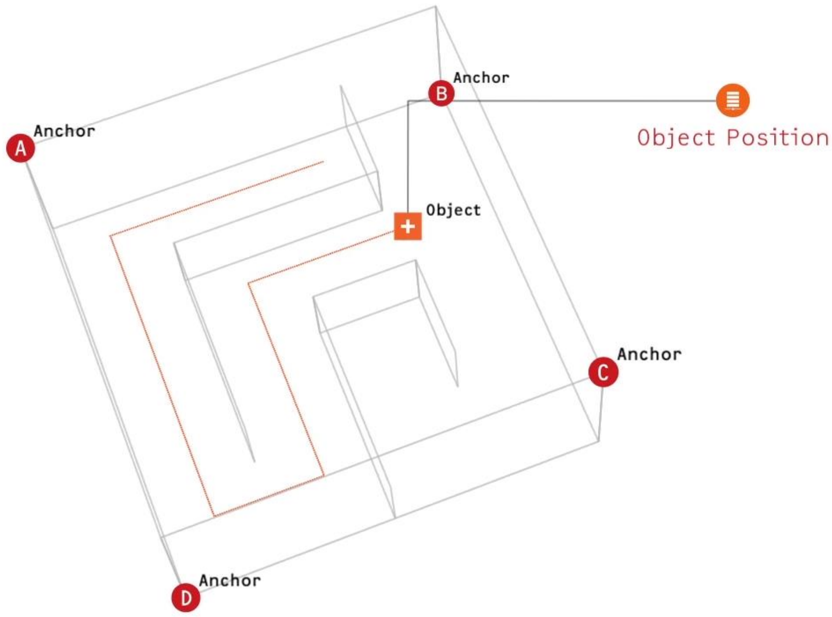

Figure 2 Eliko KIO positioning system setup illustration

3 Requirements for the TTU-Partner Indoor Positioning Application

The application consists of several key parts. The centre part is the app that runs on user's mobile device, this can also be referred to as the client. The client has several services and APIs it communicates with – Google Maps and Directions API, Facebook API, Firebase backend services, IndoorAtlas positioning services and organization APIs or services, in our case the organization is Tallinn University of Technology.

3.1 Functional requirements

Functional requirements for the application:

- Floor plans can be accessed for all university buildings and floors (limited to public areas);
- Ability to check university events;
- Ability to check university news;
- Getting access to university contacts;
- User can see current location indoors and outdoors in the campus area;
- Russian, English and Estonian language support for the core application;
- Users get guidance help to key places in every university building;
- Categorized locations search for finding places;

The functional requirements were set at the start of the project keeping in mind the university needs. There were several meetings with different university representatives from marketing and IT departments to discuss possible features and priority of the functionality, this was taken into account when setting the requirements.

3.2 Views

At the current time the application consists of 8 different views that user can interact with.

Table 1 Application views

View	Description
Menu	Main view when the application has started. Is used to navigate to other views depending on user needs.
Locations	View where user can select in which venue he needs navigation help.
Places	– Depending on user location selection places in the venue are shown and organized by category (e.g. food, classrooms, restrooms).
News	Displays universities news fetched from Facebook API
Loading	Initial screen that is displayed when app launches, used to initialize needed services and load resources.
Portal	here user can get access to university information and services
Events	Displays events related to university. These are scraped from several Tallinn University of Technology related Facebook pages. Users can get information about the event and also directions to the venue.
Map	– Map view, user can explore the campus map and get guidance to desired locations. Floor plans of locations are also displayed depending on user selections or current real world position.

3.3 Architecture

Application architecture revolves around user's mobile device (client). The client communicates with outside APIs to provide the needed functionality. There are 3 groups of external sources of information and services used in this project.

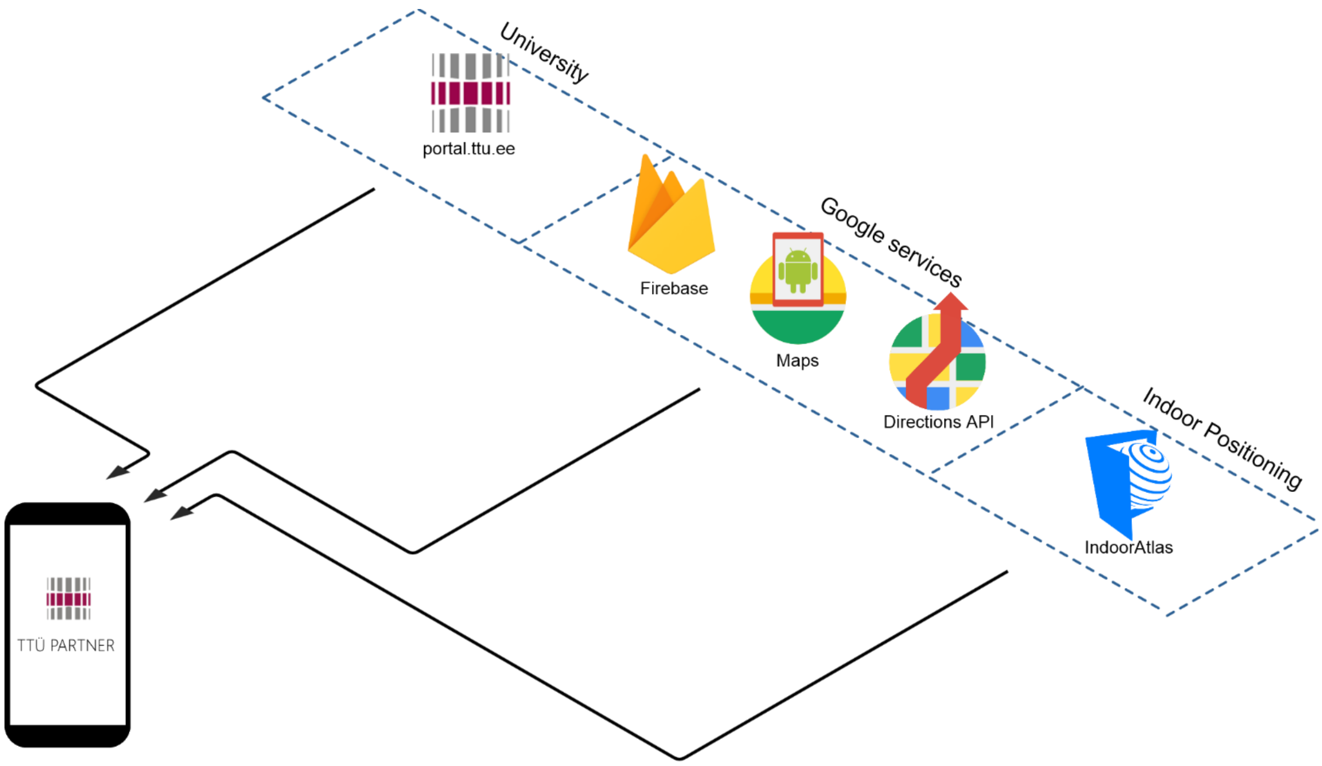

Figure 3 Architecture diagram

University

Currently university services are accessible from the portal view (introduced in section 3.2) in the application. To access the portal authentication is required via universities universal account Uni-ID that all students and university personnel have access to.

Google APIs

Project uses two services provided by Google - Firebase and Map tools. Since Android is Google's project all API's Google provides are easy to implement, this is also the reason these services were chosen for our project.

Firebase stores location information that is used by the Map and Places view. New locations around the campus can be entered to the database at any time to make them accessible through the app. Also image resources used in the project are hosted on Firebase database.

Map tools are used in the Map view. Directions API is used to help to calculate travel time and routes between places. Also Google Map allows things like custom markers and adding custom images on the map (used for floor plans) that are also used in the project.

IndoorAtlas

IndoorAtlas is an IPS that has an external API that is used for the indoor positioning part in the application. When user enters a building floor plan for the current floor is fetched and position location starts. Application communicates over the API to determine users current position by comparing device sensor values to the IndoorAtlas map data.

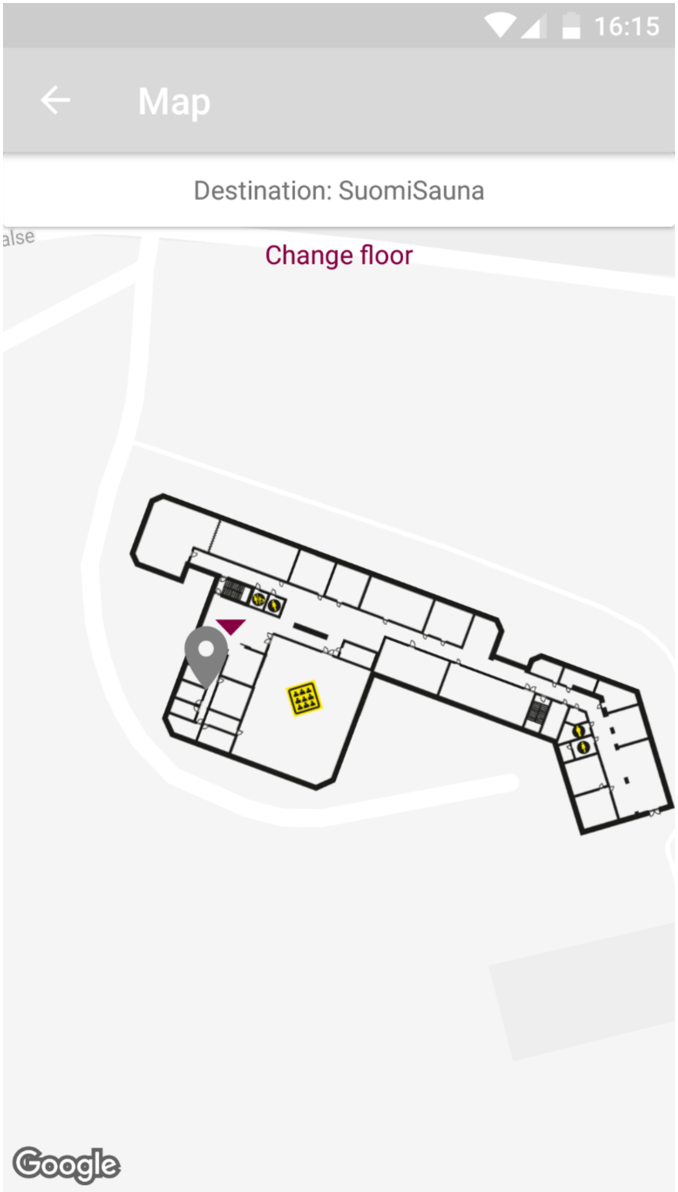

Figure 4 Campus application map view with Mektory floor plan

4 Selection of Tools and Technologies for the Development of TTU-Partner

Given we selected IndoorAtlas for the core task of indoor positioning, there is a number of other tasks that need to be solved to build a working app. For the development several tools and APIs were used. The application programming interface, abbreviated as API, is a set of subroutines, functions and procedures that offers a certain library to be used by other software as an abstraction layer [18]. These APIs are used to speed up the overall development process.

4.1 Firebase

Cloud-based backend solution for mobile and web applications was selected – the main argument was mobility here. The platform gives different possibilities for growing and maintaining the application in development. A lot of impactful features that are secure and straightforward to implement, making the development process easier as it lets the developer focus on the product and not work on the backend as much. Currently, the platform provides following features - analytics, cloud messaging, authentication, real-time database, storage, hosting, cloud functions, remote configuration, test lab, crash reporting, notifications, app indexing, dynamic links, invites, analytics and performance monitoring [18].
In the campus application real-time database, storage, crash reporting, analytics and notifications features will be utilised from the Firebase platform.

Real-time database
NoSQL real-time cloud-hosted database that syncs stored data between clients and also supports caching the data for offline usage. The database allows 20 000 document reads per day and 10GB database bandwidth per month, which is more than enough for testing the project and also remains free with a small user-base, which the application will likely have since users will be mostly visitors and new students (not long-term users). It comes with an Android SDK that allows easy and secure implementation for all database requests.

Storage

Simple file hosting for all resources that the project needs. The free plan allows for 5GB storage and 50 000 download operations per day, which is more than enough for our use cases.

Crash reporting

Crash reporting keeps track of all the crashed and errors that the users might encounter. All problems are logged and can be seen from the Firebase Crashlytics dashboard. The dashboard allows for fixing all the bugs and problems when they occur since the developer is notified immediately when something happens. Stack traces are saved and the root of problems can be found quickly.

Analytics

Firebase analytics gives an overview of the application usage. The analytics dashboard shows info about how users are using the application – what app features are they using the most and how much time are they spending on them, what versions are people running on their devices, from what countries are the users from, active user count and more. The data brings out the pattern of the application usage by the users and gives feedback about the user's adaption with the application. All this feedback is the engine for the future development – new ideas and feedback about the implemented changes.

Notifications

Push notifications for mobile devices. Messages can be sent to all app users, and they will receive them even when the application is closed or in the background. In our project, this feature is used for notifications of important university news or events. There could be more use cases like - reminders of deadlines and lectures; notifying the user when a meeting; class has been cancelled - in the future.

4.2 Android studio

Android is a widely used mobile operating system. Google has released Android Studio which is the official IDE for Android development. It comes with several of tools like design previews, virtual devices, profilers and debugging [19]. It is the most widely used tool when it comes to android development. The dominant solution on the market was also chosen for this project.

4.3 IndoorAtlas

Indoor atlas is an IPS that uses primarily earth geomagnetic field for positioning. The platform is designed for commercial use and the platform has grown fast in recent years. The solution comes with proper documentation and several tools for implementing it – iOS and Android apps for magnetic field mapping and web-app for managing locations, floor plans and mapping data. For implementation SDKs for iOS and Android need to be used to access the floor plans and positioning services from user's device.

4.4 Google Maps

Google Maps API provides several fundamental features for our application. Android phones come bundled with Google Maps since both are Google's products, this was also the main reason for using it in the project. Map view and directions on the map were implemented with the APIs. Google has a wide range of tools when it comes to maps. Android and Directions API were used in the project.

Android SDK and API are the general map tools that give access to the world map with zoom and location functionality. Google Maps world map is used as a base and is then further customized for our needs by adding floor plans and direction routes on top of the map layer.

Directions API is used for calculating routes between locations, in our case between campus buildings for example. Direction API gives route coordinates, which can be then further used to draw paths on the map where needed.

4.5 Facebook

There are several sources for university information, but Facebook provides a clear format for all the events and posts (for all pages). Since Facebook had already a lot of university-related pages that were actively posting events and other info, it was chosen as one of the sources of events and news for the campus application.

Facebook has several tools released for developers to use its services and data. SDKs for iOS, Android, JavaScript, PHP, and Unity make it easy to implement depending on the project needs [20]. Android SDK was used to get universities posts and events from Facebooks Graph API in the project. All data that was needed for this project is also accessible without extra permissions and is classified as public in Facebook API context.

Used data

Tallinn University of Technology has several official and non-official Facebook sites that provide useful info about events and campus. In this project, this info is used to display events and news in the mobile app. The following pages were included: Mektory, Tallinn University of Technology official page, Pööning, Kultuuriklubi, Tudengimaja, TTÜ Esport, TTÜ Üliõpilasesindus, TTÜ Korvpalliklubi, TTÜ Võrkpalliklubi, TTÜ Sport. Information is scraped from these pages' through the API and displayed to the user in an easily accessible and readable way. One view in the application gathers events, and other view aggregates all the news.

All Facebook events come with a rich metadata - details about the event, organizer and also guest info. For our use case, relevant data fields were picked out: event title, description, starting time, location (with latitude-longitude coordinates) and pictures were used for the application. Presented data gives general information about the event and also guidance on the location when needed.

For news, Facebook pages posts were used. For these posts the title and contents were fetched through the API and displayed in our application.

General Data Protection Regulation

During the development process, Facebook Graph API went through several changes due to European Union General Data Protection Regulation. These changes caused Facebook to make sudden changes which also affected this thesis project. Fetching event data was made a lot more difficult as event info couldn't be directly accessible anymore. Several adjustments needed to be made to get info about events from various pages.

4.6 Estimated costs

Low costs were one of the priorities when developing the application. So far only small investments have been made and overall costs are relatively low. Having no need for extra hardware for indoor positioning helps with keeping the initial investments minimal compared to other indoor positioning technologies.

Intellectual property fees for content used in the design were 100 euros and Android developer licence for releasing the application in the official Google Play Store platform was 25 euros.

Fixed costs for the project are IndoorAtlas and Firebase platform usage. Currently the user count is low and the project falls into the free plan for both platforms, this will change when the application grows. For IndoorAtlas the price is subject to negotiation, but has to be reasonable for the adoption of the technology in practice. For Firebase the monthly cost will be approximately 25 euros per month, which comes to 300 euros per year.

5 Development process

In this section different parts of development process are explained in detail. Big part of work when making the campus application goes to app development, but there was also a lot of communication with the university side and working on building plans, design and magnetic field mapping.

5.1 Magnetic field mapping

We selected magnetic field indoor positioning system for the project because it doesn't extra hardware and has good enough location precision for our use case. In order for the IPS to work, magnetic field mapping was required. This means mapping the geomagnetic strength vectors in all the buildings where IPS is used. IndoorAtlas has simplified this task by releasing mapping tools as a part of its positioning solution. Mapping tools include an Android application and a web application.
We divided the process into three steps: Creating the location; on-site mapping; generating maps.

1. Creating the location

A new location needs to be registered on IndoorAtlas web app. Location creation requires longitude, latitude, address and floor plans of the building being added. Floor plans need to be scaled and aligned on top of a real-world map. Scaling alignment should be done as precisely as possible for best results. Different map providers are accessible with both satellite and roadmap images, which help to complete this process. Also when adjusting several floors of a building, previous floor-maps can be used as a reference for alignment. Floor numbers also need to be marked for each plan, so that correct plan could be displayed when changing floors in the building later on.

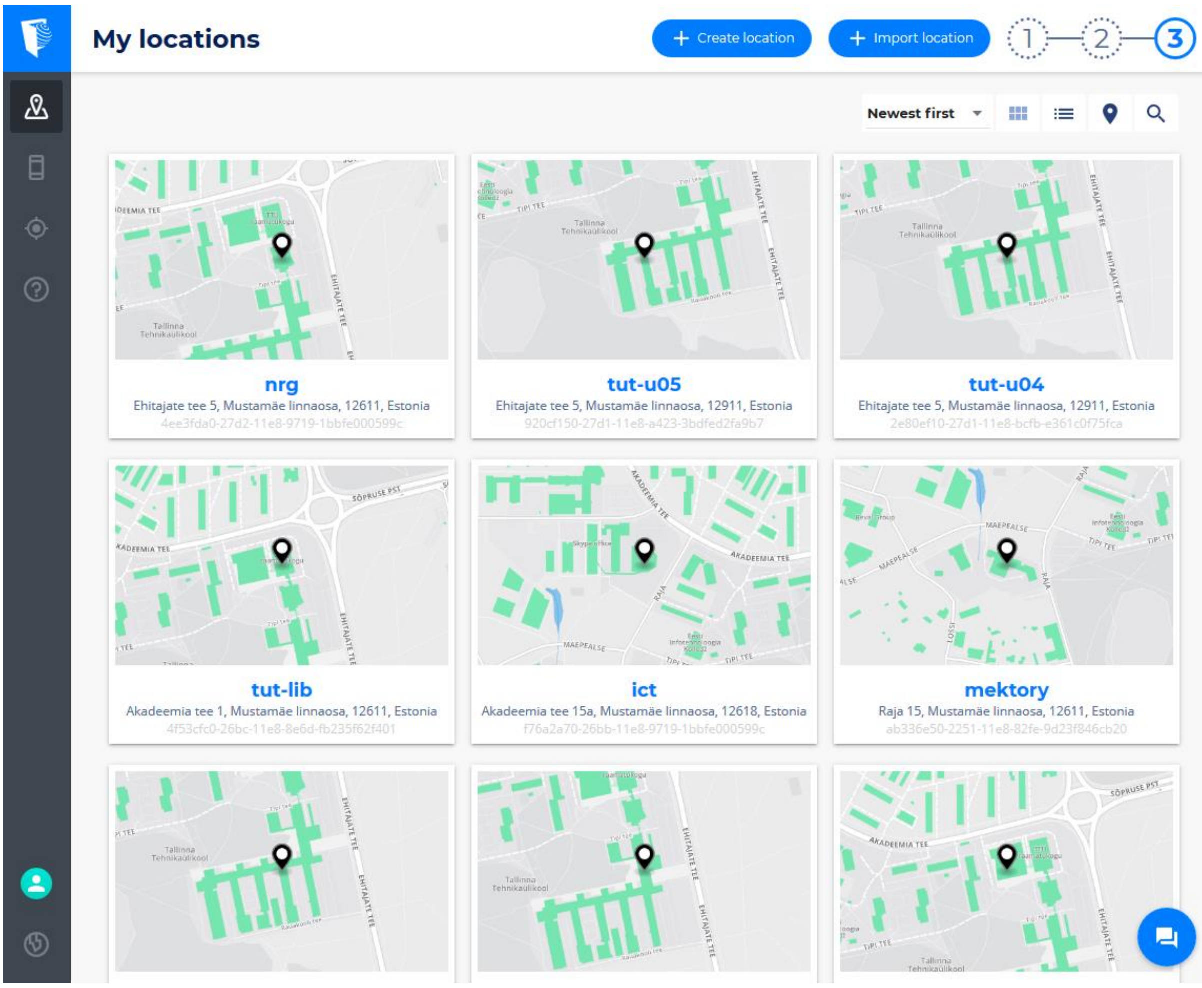

Figure 5 Tallinn University of Technology’s locations in Indoor Atlas web application

2. On-site mapping

Registered locations and floor plans can be accessed from the mobile application [21]. Before mapping the location, the plans need to be populated with waypoints, which will be used as reference points when mapping. Mapping process uses mobiles Wi-Fi, Bluetooth, GPS, gyroscope sensors. These sensors need to be also calibrated before every mapping session. Sensor calibration is also implemented in the application and is launched at the beginning of every session. When everything is setup, magnetic field can be mapped by walking between the marked waypoints. Waypoints should be visited several times and in different order to cover as big area as possible and get better data recordings.

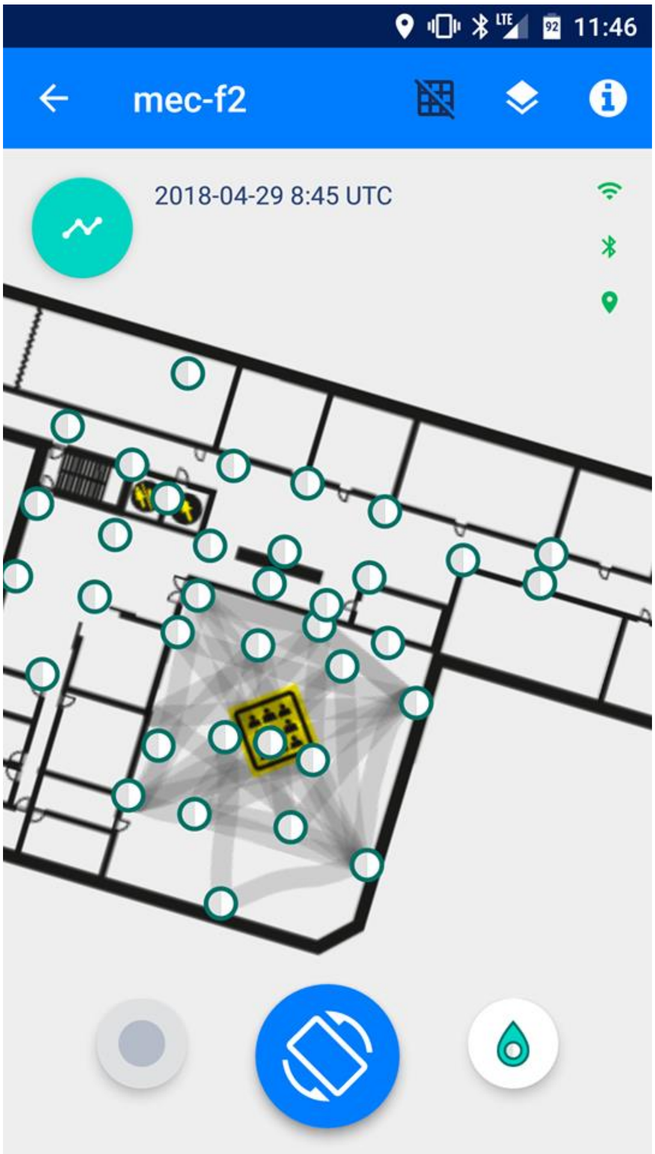

Figure 6 Floor plan with waypoints and latest mapping data as example

Figure 7 Recorded magnetic field after mapping

3. Generating map

After data has been collected, floor maps can be generated. These maps can be then accessed from the API by our application. When the user arrives at the location, floor plans can be fetched and displayed on the screen. Data recordings will be used and compared against to user phone inputs and a location can be calculated based on that, so we can display user marker on the correct position when moving around the building. In our project Google Maps will be used as a base for all the navigation and floor plans that are fetched from Indoor Atlas API will be added on top of the map based on the coordinates, scale and rotation specified in the location registration step done earlier.

5.1.1 Floor plans

Official floor plans with correct measuring's need to be used as the plan need to match the real world building. So for this project collaboration with universities real estate department was required. All the floor plans came initially in DWG format, which is a binary file format used by several computer-aided design (CAD) programs (e.g. Autodesk AutoCAD [22]). These maps then needed to be reworked to be usable in the application for end users. Unnecessary and sensitive information was removed and then converted to image files usable by Indoor Atlas. As a result, two sets of plans were generated – one set for mapping purposes and another set for the end product. Plans for mapping had most of the extra features removed, but some architectural details like load-bearing columns and beams were kept to use as reference points in real-world to make magnetic field mapping easier. End product plans had almost all extra information removed from them and design was improved to be more appealing to the end user, these plans were changed with testing plans after magnetic field mapping part was done.

5.1.2 Locations

Tallinn University of technology has more than 15 different locations that should potentially be included in the application. Most buildings have also several floors, which all need prepared floor plans, mapping and also all the places/rooms on the floor to be inserted into the database. To reach a reasonable amount of areas for our thesis, we selected two university venues – Mektory and informatics faculty building. Several other locations were also mapped and the plans can be seen from the application, but in the database only these two locations were populated with places.

Mektory innovation and business centre is the location for a lot of university's events and has a large number of daily new visitors. For this reason, the location was selected. It made possible for different test groups to be assembled and get feedback for the application.

For the second location universities ICT building was chosen. Being an informatics student, it was easier to get access to rooms and also ICT buildings floor plans were one of the first plans that were shared with the real estate department.

The project will be continued and other locations will be also fully mapped, but these two venues will be focused on in this thesis.

5.2 University services

One of the ideas of this application is to incorporate organization services to the app, depending on the organization needs. In Tallinn University of Technology context there are different possibilities available. Varied functionality could be implemented for students, university personnel or visitors. Currently the app supports Tallinn University of Technology's portal [23] services. Further functionality will be implemented after the completion of the current thesis.

5.3 Database

By default, Firebase platform comes with two different database solutions, Firebase Realtime Database and Cloud Firestore. Both are real-time NoSQL databases. Firestore is currently still in beta, but was chosen for this project because it comes with more functionality and is essentially an improvement over the previous Realtime Database. For Android development Firestore comes with a SDK that helps with the implementation [18]. The real-time aspect of the database keeps data in sync across all clients and allows live changes to be made to the data. This functionality is not relevant for the current project, but can help in some use cases.

At the current time only campus locations needed to be stored in a database, other application content comes from external APIs. This solution assured a simple database architecture for the app.

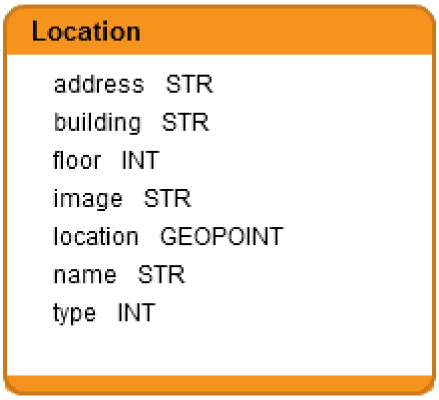

Figure 8 Location database entity

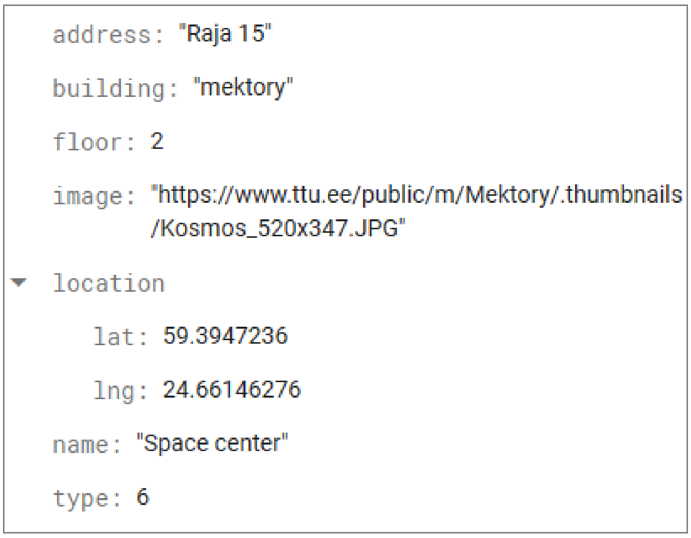

Figure 9 Example location from the Firestore database

Table 2 Location object fields in database

Field	Definition
Address	Address of the location
Building	Determines in which campus building the location is in (e.g. Mektory, ICT)
Floor	Location floor level, helps with guidance when user needs to change floors
Image	Image resource URL for the location
Location	Object that holds latitude and longitude numerical values
Name	Location name
Type	Determines the type of location (e.g. restroom, personnel, classroom)

5.4 Language localization

Tallinn University of Technology has a large number of students and visitors from different countries – additionally to the local people, foreign students and visitors from all around the world are presented here. For this reason, language localization was one of the priorities in the project. Currently the app supports 3 languages – Estonian, English and Russian. The language preference automatically adjusts to user’s phone language and the app starts with the users native or preferred language.

6 Evaluation

After finishing the application, testing was done to measure different aspects of the finished product. An experiment was conducted to measure the precision of used indoor positioning system. Also the app was tested by university employees to get feedback on the usability and dependability. These endeavours were meant to give a better overview of the application – how helpful is it, what parts could be improved and what could be the next steps for the project.

6.1 Positioning precision

To get a better understanding of the precision of IndoorAtlas magnetic positioning system and suitability for our application an experiment was conducted. IndoorAtlas positioning data was compared against high precision Eliko KIO Ultra-wideband positioning systems results.

6.1.1 Testing site

Several places around the campus were considered as a testing site. For the best results Elikos product line manager was involved in the setup process. Because in our experiment KIO positioning system was used as a measuring tool, it was a priority was to set up the system in good conditions to guarantee high precision and avoid any possible errors in data. For the system to work 4 anchors are used to form a rectangular area wherein user's location can be determined based on distance data between user and anchors. Mektory's main hall was chosen for the experiment - big rectangular room with an open area that's without walls or other obstacles hindering the signals used by KIO RTLS.

6.1.2 Experiment setup

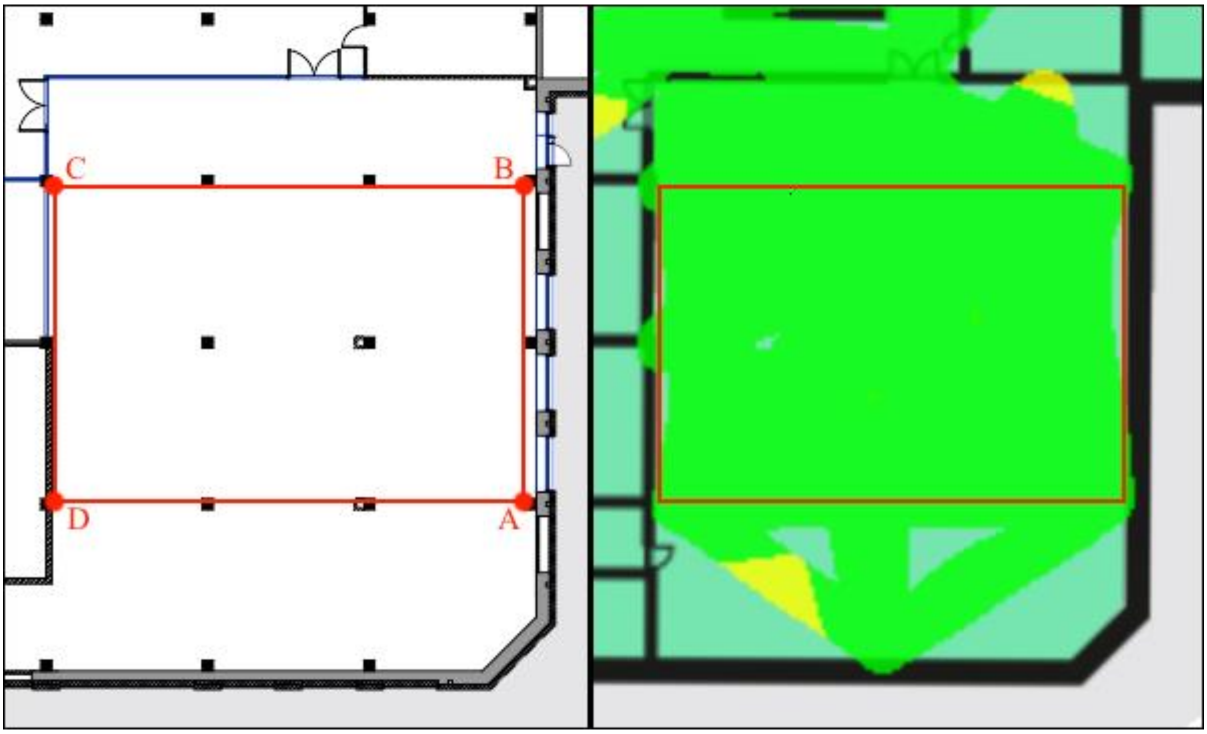

Figure 10 Mektory main hall. On the left Eliko KIO anchor positions, on the right IndoorAtlas magnetic field mapping coverage, red square on both images shows the testing area

A rectangular testing area was formed with KIO anchors (Figure 10 Mektory main hall. On the left Eliko KIO anchor positions, on the right IndoorAtlas magnetic field mapping coverage, red square on both images shows the testing area). The size of the area was approximately 18x12 meters, where anchor B was used as the starting point for the measurings and the positioning system. The magnetic field for the same area was thoroughly mapped to get the proper results from both systems. The anchors were set up based on the floor plans and real word measuring's.

KIO positioning system works on 4 anchors, positioning tag, and backend software. The system requires client and server to run from a Linux terminal to record the positioning data from the tag and anchors. The recorded data consists of timestamped tag positions, based on an arbitrary Cartesian coordinate system that uses a user selected point as the center. In our case, the center is anchor B. The positions are then given in meters as X and Y coordinates from the center.

For IndoorAtlas a separate script was added to the application to write positions with system timestamps to the database. Unlike the Eliko KIO system, IndoorAtlas uses a geographic coordinate system for its locations and the data is given in latitude and longitude coordinates. These coordinates were saved to the database together with timestamps and then exported as a log to be further used.

The general idea for the results was to collect location data and log that data with timestamps so that the locations from both systems could be compared to each other based on the timestamp later. Epoch timestamps were used for both positioning systems. Before starting the experiment, system times were synchronized on both Linux and Android OS used in the test.

6.1.3 Conducting the experiment

The testing was done by attaching the KIO RTLS positioning tag to a mobile device running the campus application. In parallel, the positioning systems were applied. Mobile device capturing location based on the magnetic field and saving it to our database and KIO TAG logging locations based on the ultra-wideband technology and outputting everything on the Linux server. Later these outputs were normalized to the same format, and measuring system and the data were compared based on the timestamps.

Three separate test runs were done with different route setups and completed twice.

Table 3 Test runs ordering and reasoning

Test run	Route (anchor order)	Reasoning
1.	B-A-D-C-B	Walking on the outer part of the test area, testing areas on the side and close to the anchors.
2.	B-D-C-A-B	Crossing the test area, testing the centre part compared to corners.
3.	B-A-D-C-B	Same route as test run 1, but walking further away from the anchors and testing they centre area.

6.1.4 Results

KIO and IndoorAtlas positioning systems output data in different formats. When setting up KIO IPS, a central point somewhere in the building is defined and all measuring's come in form of x-y coordinates from that central point. IndoorAtlas returns data in geographic coordinate system, so latitude and longitude is used there. For the data to be comparable, IndoorAtlas data was converted to local coordinate system used by the KIO IPS. Converting was done by using Estonian Land Board geodesy calculator for coordinates [24]. Calculator transforms latitude and longitude to a local coordinate system based on meters. When setting up the experiment, anchor B was used as the origin of the coordinate system used by KIO RTLS. Using the floor plans, origin rotation, latitude and longitude were determined. Based on the origin position and rotation IndoorAtlas data was converted to the local coordinate system. Because both datasets were timestamped they could be further compared after conversion.

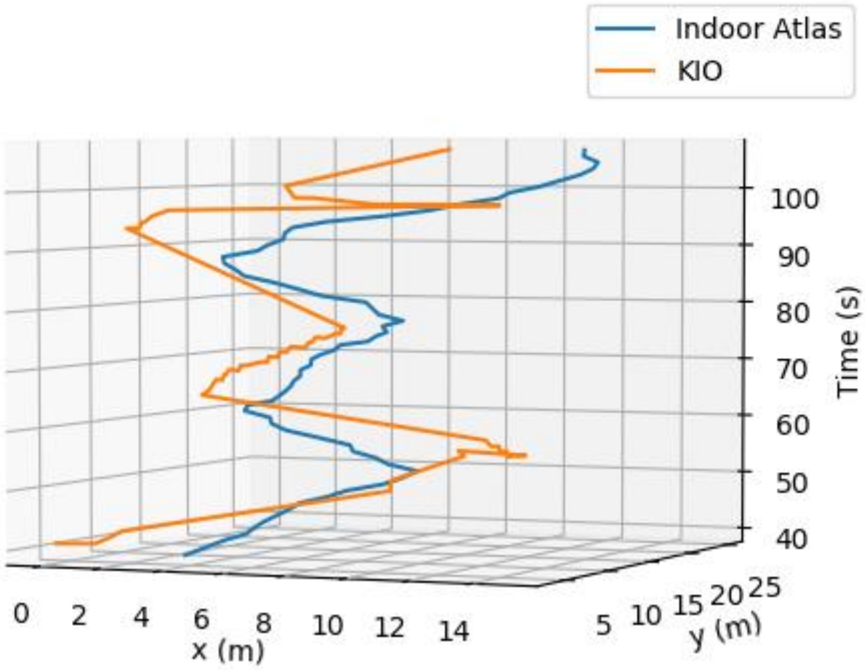

Figure 11 Test run 1 data comparison

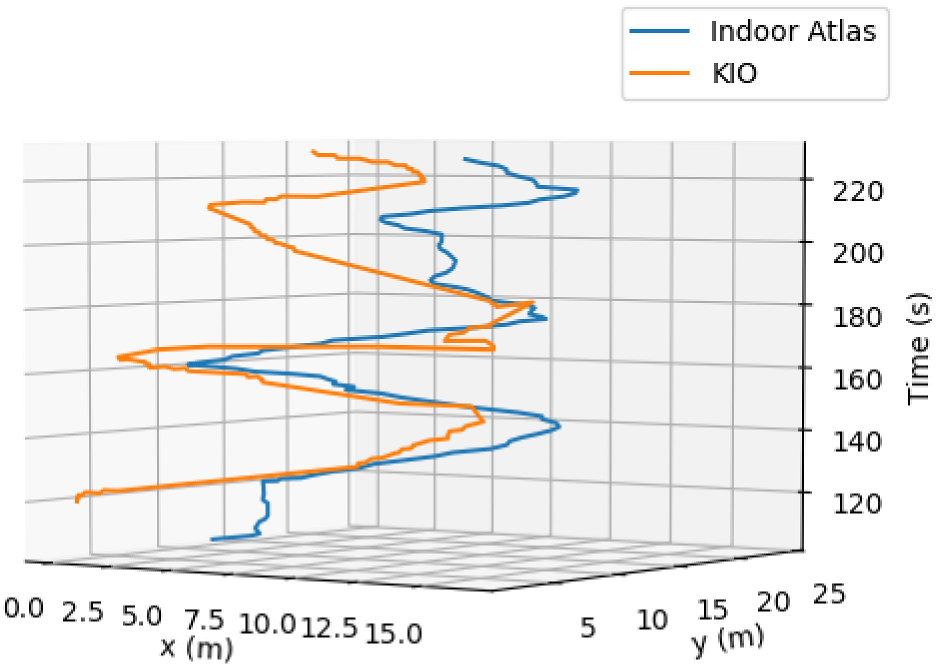

Figure 12 Test run 2 data comparison

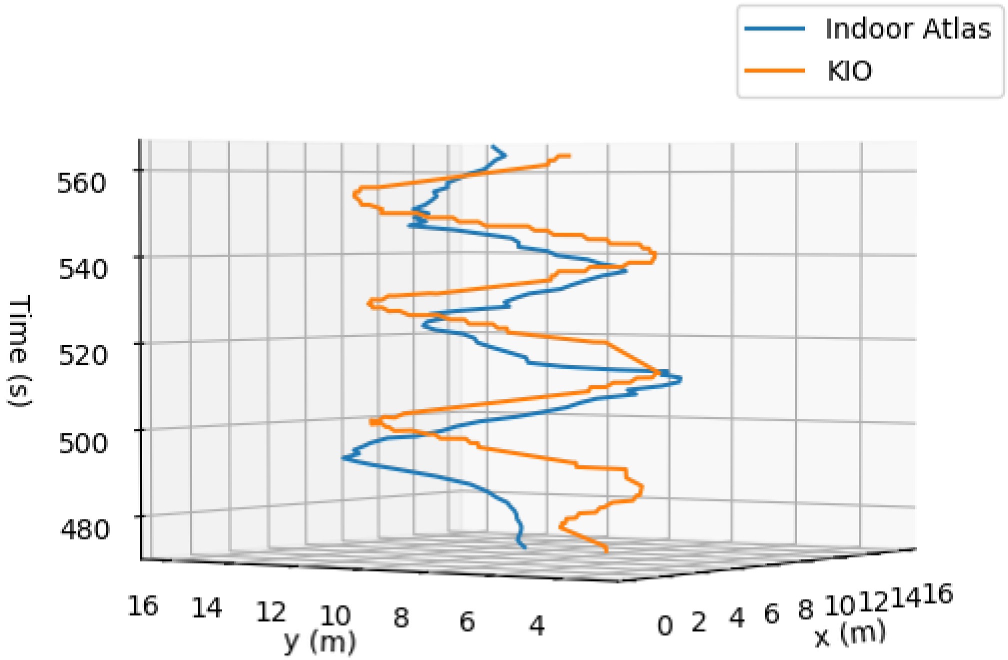

Figure 13 Test run 3 data comparison

As seen from the figures there are sharp jumps in KIO RTLS data which indicate problems in positioning. On the test run 3 figure we can see that the lines are much smoother and without big changes. Since the third test run was done in the centre we can assume that the positioning problems happen on the edges of the test area. Problems seems to occur when user is near the corners or the edges of the rectangular test area, which is caused by the tag not being in reach for all of the anchors. On the test run figures raw data was used, but for the error calculations extremums where removed to get a more realistic overview of the results. The normalized results with extremums removed were as follows:

Table 4 Test runs average error

Test run	Average error (meters)
1.	2.047
2.	2.322
3.	2.491
All runs	2.287

Overall the measuring's show a ~2.25-meter error in IndoorAtlas system when compared against Eliko's KIO IPS. The difference is a little higher than expected, but still acceptable for our use case – approximate position inside the building that shows the user in which room is he or she currently in. Also it should be noted that the final error is a rough estimate since the Eliko's KIO system positioning doesn't give us high enough precision to use it as an absolute reference and also the error from different coordinate system conversions needs to be factored in. The precision could have been increased with additional beacons and additional calibration time, but it was decided that for the evaluation of the usefulness of the app the above results are sufficient.

6.2 User feedback

A test group of Mektory personnel was assembled to test the application.
The feedback from Mektory was meant to provide better understanding of two areas – overall application design and indoor positioning. Users tested the application and filled out a feedback form with various questions.
Design questions asked the users how do they like the user interface, functionality and reliability. Positioning questions focused on the speed and reliability, also tried to find out if any problems had occurred during the testing. Users were also asked about potential new features that they would like to see in the future.
Overall the feedback was positive. Users agreed that the interface is good, application was intuitive to use and reliable. When asked about app functionality 3 different features stood out apart from indoor positioning: university contacts, food info and campus events. For positioning there were users that had problems with finding the initial location when starting the app also location precision was rated average. Otherwise there were no reported crashes or problems in other areas (e.g. problems when changing floors, wrong floor plans).
Feedback gave an initial understanding how the application will perform in the hands of a real user, there were small changes suggested that will be taken into account when developing the app further. Feedback showed that the used technologies work and there is potential in the project.

7 Future steps

This thesis was a case study for indoor positioning application for Tallinn University of Technology – selecting best technologies for the task and testing them. The end product of this thesis is not a complete product that is fully usable for university students, visitors and personnel. To be commercially usable the project needs further development and improvements.

7.1 Tallinn University of Technology

The application that was created as a part of this thesis is not yet a finished product. Talks with the university are currently in the process to continue with the project further. Next steps would be to expand the application working area from Mektory and ICT building to all campus venues. Another goal is to incorporate more university services to provide more content and value to the users. The user feedback has given great ideas for the future and has given a clearer development path to follow.

7.2 Other organizations

With positive results with the project in Tallinn University of Technology campus there is potential to expand the project to other organization. The application made during the thesis has shown that the architecture and technologies are suitable enough for an indoor positioning app. The architecture is flexible enough to use in other organization when switching out university services with other ones depending on the organization needs. Suitable partners in the future could be hospitals, airports and shopping malls.

8 Summary

The thesis aimed to study possible indoor positioning technologies and apply them in the context of Tallinn University of Technology. The market for indoor positioning is growing and a lot of new positioning methods have been developed. For the thesis application, magnetic field based solution was used, which was best suited for our use case. Different technologies and services were used and incorporated to the app to provide extra functionality for the users. The final application proved to be working and got positive feedback from users. Magnetic field positioning precision was also tested against Eliko KIO’s real time location system and gave adequate results. Overall the project fulfilled its purpose - a working campus application was finished and evaluation was considered successful. Thesis showed that deploying an indoor positioning solution in a big organization is feasible with technologies currently available. The campus app made during the thesis is still not a finished product and the project will try to continue to develop further.

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