EXAMENSARBETE INOM TEKNIK,
GRUNDNIVÅ, 15 HP
STOCKHOLM, SVERIGE 2017

Indoor navigation techniques for underground subway stations

Analyzing Suitable indoor navigation technologies for underground stations

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Stockholm, Sweden
18 June 2017

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Abstract

Indoor navigation has always been an interesting topic to look at since there are many use of it for example in airports, huge malls and underground transport stations. One interesting application area is the underground transportation since the current navigation in the underground stations in Sweden is proven to be insufficient to guide the user from the underground station to the final destination. GPS is a prominent solution for the outdoor navigation but no prominent solution has been found for the indoor navigation. Techniques used for navigation indoors vary depending on the infrastructure of the building. Therefore, this paper looks at the different indoor navigation techniques categorized based on a smartphone's sensors and find the techniques most suitable in implementing for the existing SL underground stations. The underground station is divided into two parts, the platform and the second floor. A combination of kinematic and visual navigation techniques is efficient to implement in the platform due to the environment of the platform. Wireless navigation is suitable to implement in the second floor due to the availability of WiFi access points in the second floor of the underground station. Those findings help in setting up an efficient navigation for the SL underground stations, which help in navigating users from one point to another.

Keywords: Indoor navigation techniques, indoor navigation, GPS

Sammanfattning

Inomhusnavigering har alltid varit ett intressant ämne att titta på, eftersom det finns stor användning av det till exempel i flygplatser, stora gallerior och tunnelbanestationer. Ett intressant tillämpningsområde är den underjordiska transporten, eftersom den nuvarande navigeringen i tunnelbanestationerna i Sverige visar sig vara otillräcklig för att navigera en resenär från tunnelbanestationen till slutdestinationen. GPS är en framträdande lösning för utomhusnavigeringen men ingen framstående lösning har hittats för inomhusnavigeringen. Tekniker som används för navigering inomhus varierar beroende på byggnadens infrastruktur. Därför studerar denna rapport på de olika inomhusnavigeringsteknikerna som kategoriseras baserat på en smartphones sensorer och hittar de tekniker som är mest passande för att genomföra för de befintliga SL-tunnelbanestationerna. Tunnelbanestationen är uppdelad i två delar, plattformen och andra våningen. En kombination av kinematisk och visuell navigeringsteknik är effektiv att implementera i plattformen på grund av plattformens miljö. Trådlös navigering är lämplig att genomföra i andra våningen på grund av tillgången till WiFi-åtkomstpunkter i andra våningen av tunnelbanestationen. Det resultatet hjälper till att skapa en effektiv navigering för SL-tunnelbanestationerna, vilket hjälper till att navigera användare från en punkt till en annan.

Nyckelord: Inomhusnavigeringsteknik, inomhusnavigering, GPS

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1 Introduction

Navigation is an essential part to easily find ones own destination. Many technologies have been developed throughout the years to support people with finding their destination. It started by a paper map and a compass, when the digitalization age arrived web and mobile application were developed to guide with navigation [1]. One interesting topic of navigation is indoor navigation, which is as much needed as outdoor navigation due to the development of urban and huge buildings [2].

In Sweden, underground transportation is an essential part for transportation for both tourists and residents [3]. Thus, providing a better service in terms of indoor navigation application will help in promoting SL, which is one of the biggest transportation providers in Sweden.

The direction signs provided in the underground metro stations are not sufficient to guide a tourist to find the way to their destination, even with the help of outdoor navigation systems. Example of such a situation is provided in fig.1. It shows an example of current Google map navigation from Tekniska Högskolan to Danderyd. The First image of fig.1 shows only the route between the current location and destination, second and third images are the positioning of user underground/ inside the metro station shown by GPS navigation indicated by the blue location mark far from the route. Last image shows the directions to the destination close up from the metro station.

Thus, in order to improve the navigation provided by SL to its consumers the exam thesis aims to focus on finding a suitable indoor navigation technology for underground transportation of the SL public transportation authority metro stations.

The figures below illustrates an example of the present situation and problem that appears for a first time arriver who needs to find the way to Gula vägen at the Danderyd underground station in the "Tunnelbanan".

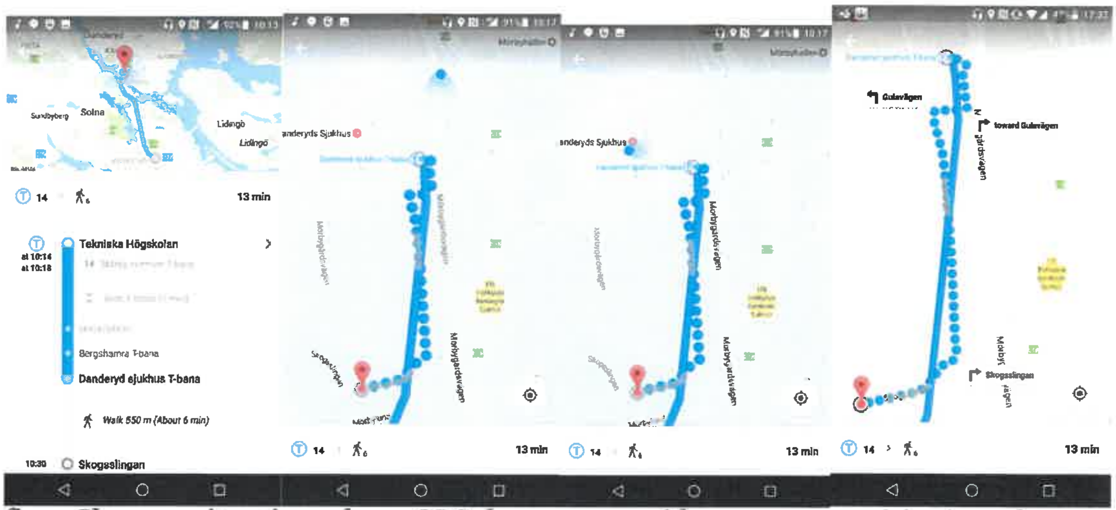

fig 1. Shows a situation where GPS does not provide accurate positioning when user is located underground.

fig. 2. Shows Signs when getting off the metro in Danderyds sjukhus station. As seen from the signs, there's no Gulavägen seen from those signs. Therefore, one need to go out of the station to find which exit was the right one to take from the metro station in order to arrive at the destination place.

fig. 3. Shows one end of Danderyds subway station. As seen in figure 3, some sign direction are also not sufficient for finding right direction in order to arrive to final destination.

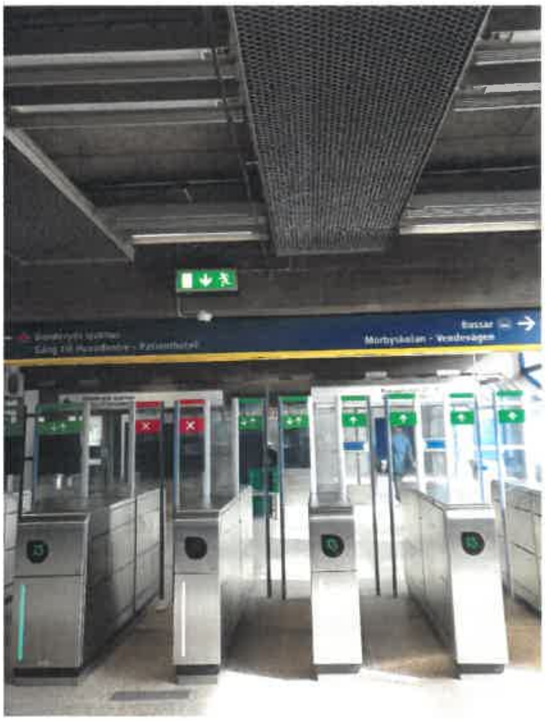

Fig.4. shows the other exit of Danderyds metro station.

1.1 Background

Navigation is an important area used in our everyday life, implemented as smartphone applications. There are two different types of navigation: indoor- and outdoor- navigation. The outdoor navigation uses satellite based Global Navigation Satellite Systems (GNSS) and GNSS-aided Inertial navigation system as methods for only outdoor navigation [4]. Therefore, in lack of GNSS radio coverage many other techniques are developed for the sake of implementing indoor navigation using different signals. Each of those techniques has their limitations and strengths.

The general categorization of Indoor navigation technologies are divided into three parts: designated technologies based on pre-deployed signal transmission infrastructure, technologies based on ”signals-of-opportunity” and technologies not based on signals [4]. The first category uses systems such as infrared or ultrasonic signals or other RF-systems. Technologies based on “signals-of-opportunities uses RF-signals initially not intended for positioning, such as WiFi, mobile telephony, FM radio and other RF-signals. The technologies not based on signals use dead reckoning that uses inertial sensors (such as accelerometer and gyroscope) and vision or camera systems for positioning [4].

1.2 Problem

The problem addressed here is that the navigation provided in underground subway stations is poor at helping non-residents and the first time visitors to a subway station with directions.

In order to solve this problem new technologies need to be used such as indoor navigation techniques. One of the major concerns is that information about the resources needed for implementing the indoor positioning system (IPS) is not provided and not easily accessed. Also, the limitations of already existing indoor navigation is another concern. So the problem to be solved is “which indoor navigation technique is the most suitable for metro stations provided existing building’s infrastructure?”

1.3 Purpose

The purpose of this thesis is to study the different indoor navigation technologies. Efficient indoor navigation technology can be very valuable for navigating in underground locations. It’s very important to choose the right indoor navigation technology in terms of efficiency, simplicity in designing and costs.

1.4 Goal

The first goal is to identify and study efficient indoor navigation technologies.

The second goal is to find out which available resources can be utilized, in underground metro stations of the SL public transportation authority.

The third goal is to find the most efficient indoor navigation technique based on the requirements combining available techniques and new ideas on how to utilize the opportunities given in the second goal above.

The final goal is to find and propose the most efficient future solutions in terms of positioning accuracy; least resource consuming and customer oriented indoor navigation technology.

1.5 Benefits, Ethics and Sustainability

All companies with underground location will have some level of usage of the results found in this thesis. Although, the intended establishment to benefit from the results described in the thesis is SL. It will also improve the image of SL as a public transportation authority, which keeps up with the latest technology and is an innovative and digitalized authority.

The results of the thesis will contribute to all three pillars of sustainability as follows:

Social sustainability
Help Stockholm visitors with navigation especially when they have a meeting and little time to find the location.
Since public transportation is cheaper than other means of transportation, many people use the public transportation for different destinations and therefore it's beneficial for those customers to get help with the navigation to their final destinations.

Environmental sustainability
SL traffic uses entirely renewable energy sources to generate electricity for running the subway [5]. Finding efficient indoor navigation techniques will promote/encourage the use of public transports, which in turn will decrease the use of fossil fuel driven cars. This reduces the greenhouse gas emissions. The use of public transportation instead of internal combustion engine cars reduces air pollution [6].
Another benefit to the environment and society is the decrease in heavy traffic since as mentioned public transportation will be promoted.

Economical sustainability
The promotion of SL as a digitalized authority that provides many services will satisfy existing customers and attract new customers to start using the SL subway stations. The existing customers will spread the image of SL by word of mouth as a good authority, which helps in attracting new customers. This, in turn will increase SL authority cash flow. Since it promotes the use of SL transportation to tourists, this will benefit SL economically.

1.6 Methodology / Methods

The definition of research methods and methodologies are the following "Research methods are the various procedures, schemes and algorithms used in research. All the methods used by a researcher during a research study are termed as research methods. They are essentially planned, scientific and value-neutral. They include theoretical procedures, experimental studies, numerical schemes, statistical approaches, etc. Research methods help us collect samples, data and find a solution to a problem. Particularly, scientific research methods call for explanations based on collected facts, measurements and observations and not on reasoning alone. They accept only those explanations, which can be verified by experiments.

Research methodology is a systematic way to solve a problem. It is a science of studying how research is to be carried out. Essentially, the procedures by which researchers go about their work of describing, explaining and predicting phenomena are called research methodology. It is also defined as the study of methods by which knowledge is gained. Its aim is to give the work plan of research."[7]

Quantitative research methods are used to obtain necessary information to solve the problem presented in the report. Information about indoor navigation and its techniques will be collected from books, journals and scientific articles. The latest research about indoor navigation is read and similar work related to implementing underground navigation and problems are reviewed. Interviews will be carried out to find details about the SLs underground infrastructure, statistics which prove the problem validation such as the actual demand of people asking SL employees about directions in the underground metro stations, requirements of example the idea of setting up a wireless network in the underground station or requirements on the costs, privacy or accuracy of an indoor navigation and the availability of underground coordinates.

1.7 Delimitations

Limiting in finding a solution which fulfils the wishes of SL and which is applicable for the current technology.
Limiting to smartphone performance.
Limitation to use of user using smartphone only to navigate indoors.
Not taking into consideration the time and memory complexity of the software that affects the efficiency of the program.
Limiting the project to finding the indoor navigation technologies and proposing a technical scenario due to time limits cannot carry with implementing and finding measurements of the model.

1.8 Outline (Disposition)

The remainder of this paper is organized as follows: Section 2 reviews the different indoor navigation techniques categorized based on smartphone sensors. Section 3 outlines the different requirements that the indoor navigation technique chosen is based on. In section 4 the results found after conducting the interview is presented. Section 5 analyse the results and suggests the most suitable indoor navigation based on the requirements in section 3. Section 6 conclude the research and contains an outlook on future investigations. Finally, section 7 contains the references used in this report.

2 Theoretical background

The theoretical background will give an insight into the different indoor navigation techniques, their methods, advantages of using them and their limitations.

2.1 Indoor navigation

The problem of not being able to use GPS satellites and GNSS for indoor navigation is because GPS satellites and GNSS emit signals for navigation but those signals scatter over the roofs and walls. Those signals are very low and even fluctuate indoor [8] and since the GPS sensor consume higher amount of power compared to other applications, smart phone users usually avoid turning it on. Especially in the underground, no signals emitted by GNSS or GPS can reach to the underground and currently there is no available continuous set of access points except in London [9]. Current handling of a situation where a person is navigating outside, travel through a tunnel or another indoor place, the navigation system starts using dead reckoning mode [10] which is not a reliable solution for the applications studied here.

In order to solve the problem of not being able to navigate indoor, one possibility is to combine indoor navigation techniques with outdoor navigation techniques. Another possibility would be to reproduce GPS signals indoors, this is a popular method of providing indoor navigation due to the existing knowledge of the system. Also, because of how common it has become to use smartphones that connect to wireless antennas. There are many solutions for indoor navigation but there is no prominent solution like the one for outdoor navigation. Indoor navigation has many challenges such as finding the initial position of the user, when the initial position is found, another challenge would be navigating the user and accommodating changes in indoor location environment [15].

2.2 Indoor navigation techniques

2.2.1 Kinematic navigation techniques (technologies not based on signals)

For navigation, kinematic navigation techniques use the smartphone's built-in sensors such as magnetometer and motion sensors etc. After using the built in sensors and finding appropriate information, kinematic equations are used to compute position, velocity and orientation. This technique is very simple to perform since most of the smartphones nowadays have inbuilt sensors [11]. The algorithms used for this technique is dead reckoning where a moving device is navigated by a known initial starting point, velocity and orientation [13]. So in this technique there is no need for external references.

For navigation using kinematic technique, two different techniques are used: inertial navigation mechanism and environmental-force based positioning mechanism. The latter technique is mainly used to find the initial position of user. Below is the description of each technique more in detail.

2.2.2 Inertial navigation mechanism

Navigation indoor is implemented in inertial navigation mechanism by finding data from the motion and rotation sensors. Those sensors help in detecting the device's linear and rotational movements. At a specific point of time, measurements such as linear acceleration measured by the accelerometer and angular velocity measured by the gyroscope [21] are conducted [13]. After finding those measurements, kinematic equations can be used to find the position, direction and velocity of a moving user.

2.2.3 Environmental force based positioning mechanism

Environmental force based positioning mechanism is mainly used for finding the initial position of a user. In order to find the position of a user in a specific point of time, environmental force based positioning mechanism uses magnetometer or gravity sensors. Based on the fact that the earth's magnetic force is not uniform everywhere [12], the magnetometer measures the variations in strength of magnetic force in a specific location. Those measurements will then be used to compute the position of the user. In every footstep the position measurements can be calculated using proper algorithms to navigate user. The records of the magnetometer reading are placed in a database and mapped with each location on building layout. Then, current value from the sensors is compared to the database in order to find the initial position. Although with changing environment the recorded measurements might vary.

2.2.4 Kinematic navigation technique challenges

Challenges with initial position of the user:
Finding the initial position of the user is one of the main requirements in using inertial navigation technique because it uses dead reckoning algorithm. Dead reckoning is based on knowing the initial position [15] of the user but inertial navigation technique has difficulty in determining the initial position. Solutions for finding the initial position of the user are the following:
- User deciding an initial location, where user has to start at. Typically, one could use the indoor location's entrance.
- Using the location, which the GPS signal found last.
- Using the environmental force based positioning mechanism in section 2.2.3.

Effect of a dynamic environment:
When there are any changes in the environment, this will affect the readings of a magnetometer. Thus, it needs to be taken into considerations if there are any changes in the environment such as change with the interior or similar. If there are changes in the environment, magnetometer readings in the location in question must be recalibrated.

2.2.5 Advantages and limitations of kinematic navigation technique

The kinematic navigation technique is good at being private about a user's location, there's also no external reference needed for navigation and it's good in adapting to a dynamic environment.
The limitations in kinematic navigation technique are the difficulty in finding the initial location because even with the help of environmental based force technique because the magnetometer might give the same data at different locations. It's also not recommended to have a very dynamic environment because of the use of a

magnetometer in finding the initial position. The accuracy of this technique is not very high depending on the algorithms used in this technique.

2.3 Wireless navigation techniques

Wireless techniques are based on transmitter-receiver approaches [16] and so for navigating the user, light waves or radio waves are used. Transmitter-receiver devices are distributed in specific places in the building. The places chosen for installing the transmitter-receiver devices must be carefully picked depending on calculations for transmitter-receiver devices localization. There is also the possibility of using already installed transmitter-receiver devices for the wireless navigation techniques. For determining the position of a user in a point of time positioning principles such as triangulation can be used. Additionally, for navigating a moving user navigation equation such as trilateration can be used and the detection of a user [14] can be found by methods like Received signal strength (RSS), Time difference of Arrival (TDoA), Angle of Arrival (AOA)a etc. A smart phone can then compute those calculations.

2.3.1 Wireless navigation technique challenges

Initial position of the user:
Transmitter cells based on Bluetooth, Wi-Fi or RFID are installed in different places in the building so that they cover the whole area. Initial position can then be found by receiving the signals from different transmitter cells. Signals received from the transmitter cells identify the user location based on the method used for detecting users.

Navigating a moving user:
This part of navigation depends hugely on the localization of the transmitter cells and the design of the grid of reference points. It also depends on the type of the signals used to compute different values such as if RSS is used then Wi-Fi fingerprinting can be implemented and accuracy can be improved with using fingerprinting with reduced received signal strength (RSS) observations [4].

Effect of a dynamic environment:
Wireless network is not good at a dynamic environment because positioning of transmitters must change in case of a big change in the environment [4]. The initial installation of the transmitters depends on the setting of the building interior. So a change in that interior requires a re-positioning of all transmitters with a new plan on how to make the transmitters cover the whole area.

2.3.2 Advantages and limitation of wireless network

The good thing with using a wireless network is that it can achieve a high accuracy, it uses the existing smartphone's built-in hardware and there's no need for external references for finding the initial position. The limitations of wireless network techniques are the detailed planning for the installation of transmitters, as the transmitters must be carefully localized so that the whole area of the building is covered. The cost of installing transmitter is expensive. There's also a risk for signal interference, for example depending on the number of users connected to the transmitter device, the signal transmitted might be weak [4] or the signal is absorbed by the human body [4] because the human body consists mainly of water. Another issue is the multipath propagation of the signal transmitted by the device due to metal walls [4]. The wireless network techniques also require a database to save data needed for navigation.

2.4 Visual navigation techniques

Visual indoor navigation evaluates the objects that are visible through camera and therefore it's a camera based positioning technique. QR- code or barcode is used as a reference object that contains the location information in encoded form [17]. The content of the objects is location information of the user in the building and the objects could also contain more useful information that navigates the user in the building. Visual indoor navigation can be used by all smartphones as they come with functionalities that evaluate images visible in the camera. Although, this technique is very accurate for navigation since it provides the user with detailed positioning information it is not suitable for a hurried user that want immediate help with navigation. The user needs manually to find the reference object and scan them in order to find the location information. To simplify for the user when it comes finding the information about location layout, reference objects will be distributed in many locations in the building. Another way of implementing visual navigation is when a user takes an image of their current place; this image is then digitized meaning smoothed and filtered. After digitization the image is compared to a database containing images of each point of interest [18]. This technique depends heavily on the quality of the smartphone's camera and the logic written for both fetching information from database and digitization.

2.4.1 Visual navigation technique challenges:

Finding the initial position:
Initial position can easily be found by using the reference objects, which provides the navigation information. There is no need to use any other method in order to find the initial position other than the one mentioned above.

Navigating a moving user:
In visual navigation technique the user has to scan the object reference in order to access navigation information of the building layout. This approach is very accurate but it slows the user due to high requirements on access to data base and lots of image processing and since the user has to go to the reference object and scan it which takes longer time than outdoor navigation system.

Effect in a dynamic environment:
With major changes to the environment, an update of the object reference location and an update to the information the object reference contain must be conducted. In case the interior of the building changes than if the database contains images must also be updated.

2.4.2 Advantages and limitations of visual navigation techniques

Visual navigation has a very high accuracy and it's the least expensive. It also does not require major infrastructure changes such as installation of additional devices like wireless network techniques. More helpful information than navigation can be provided to the user using visual navigation techniques. The limitation of this technique is that it does not provide immediate help to a moving user who is rushing to find his/her destination.

3 Methods

Quantitative research methods will be carried out where an interview with Storstockholms Lokal trafik (SL) will take place. In the interview SLs requirements is presented and those requirements will help in finding the final indoor navigation technique suitable for SLs underground stations.

The requirements on choosing suitable indoor navigation technique are:

- Low cost of the hardware and network setup. This is also linked to the resource consumption, the goal is to use a technique that does not cost a lot and that requires the least resources so that the next requirement maintenance won't be very necessary.
- Maintenance required of the technique, example a wireless and visual techniques require more maintenance than kinematic technique. This is due to wireless and visual techniques using external reference object, which cover the building.
- Accuracy is another important factor that needs to be taken into consideration. Achieving accuracy is essential in this case but it's not the first priority of choosing a navigation technique.
- The technique needs to also be easy to setup, for example setting up wireless and visual navigation requires detailed planning of positioning the objects in the point of interest.
- Coverage area is another important factor that needs to be taken into consideration when making the decision of a suitable navigation technique. The bigger the area of a building is covered, the better help with navigation it provides to the user and the higher accuracy the technique would have. For example wireless navigation with a bigger coverage area would have a higher accuracy due to the more access points found in the area.
- Error correction is ability to correct errors of the navigation, which is a significant factor to look at when choosing a navigation technique. Since it contributes to the accuracy of the navigation. Although error correction is more relevant than accuracy since accuracy is more focused on the detailed navigation while error correction is on the whole picture. Techniques that have a good error correction are the ones that use an external reference object.
- Interference with other signals: Wireless navigation can be inaccurate due to the interference with other signals while kinematic navigation techniques do not have a problem with signal interference because it does not have an external reference object.

4 Results

After interviewing SL the following, inputs were obtained:
SL has conducted research on this subject before, an indoor navigation technique was developed by, Uppsala university for them. They intended to use beacons in order to achieve navigation indoor. A pilot study was not carried out due to the consequences of setting up a network of beacons found in the research. Some key limitations for SL found of using beacons were the maintenance required after installing the beacons. Additionally, setting up the network of beacons was found to be too complicated to implement.

Related situations
A related work to this report is the case where SL tries to keep track of their employee's position for more efficient relocation of workforce. SL solves this problem by using a GPS receiver that locates the employees, but it's not accurate and can show very wrong positioning if the employee is located at the metro platform.
SL ongoing navigating improvement
Currently SLs solution to navigating its customers is using direction signs and future solution is to use improved direction signs with 3D map of the underground metro stations.

Infrastructure
A typical SL station has more than one floor, one for the entrance and exits and the other floor contains the metro platform as can be seen in figure 5.
The current infrastructure of a typical SL underground station includes Wi-Fi access points close to the exits of the metro station. There are also all kind of metallic materials found in the rooms close to the metro platform. A ventilation system and electrical supplies are also found in the metro platform.

Requirements
SL was not sure about making their internal WiFi accessible by public if indoor navigation technique requires wireless setup to implement indoor navigation.

Accuracy
The accuracy needs to be good enough to navigate the user from platform to required exit in order for the user to arrive at desired final destination.

Change in environment
The underground metro stations do not undergo a major change often. The only dynamicity in the environment is the amount of people passing the metro stations everyday. Therefore the only concern of a dynamicity of environment is the people found in the metro station and not furniture or architectural changes.

Maintenance
From the case described above where SL was researching the installation of beacons in Uppsala to achieve good navigation indoors, one of the major concerns of installing the beacons were the time and resources required to invest on maintenance costs of the beacons. Therefore, maintenance is not accepted by SL in future indoor navigation techniques.

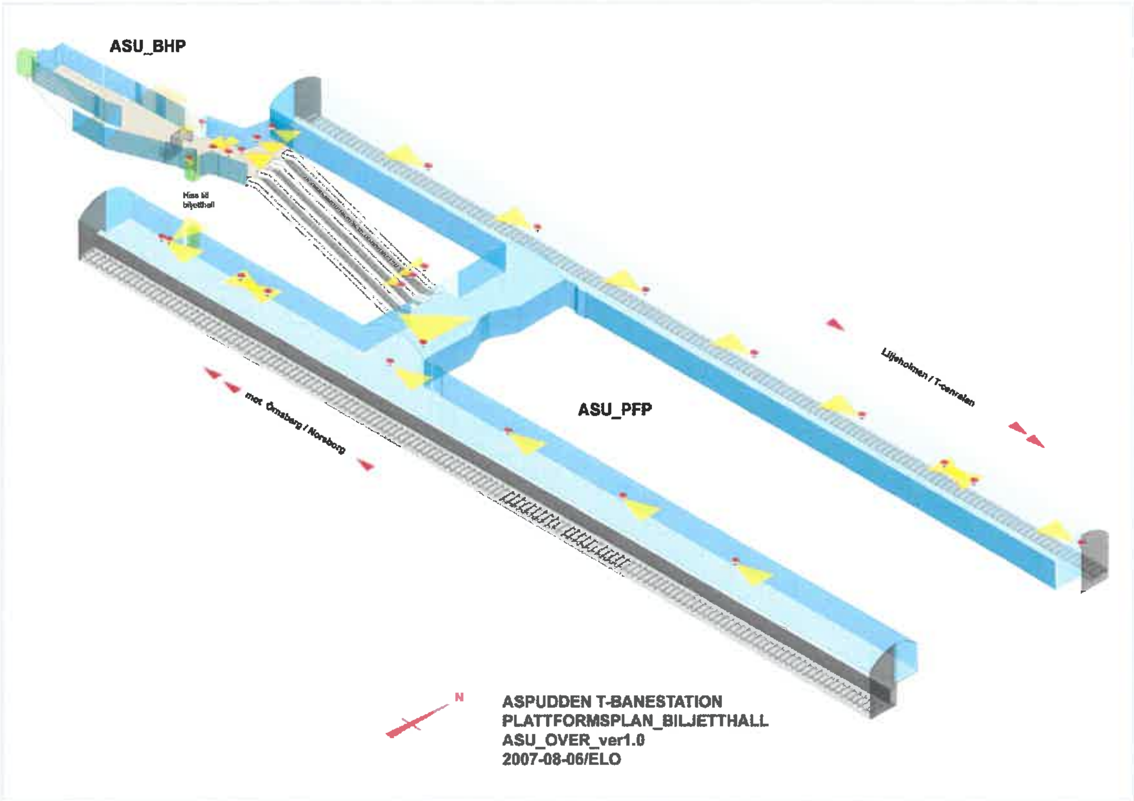

fig. 5 shows an example of the typical SL metro station infrastructure, with the first floor as the platform and at the second floor the exits are located.

5 Analysis and suggestions

From the results, it can be seen that SLs priorities is to have a technique which requires less time and resources to maintain because it results in high costs in the future if the technique requires maintenance. The existing underground metro station infrastructure can be optimized to navigate indoors.

The infrastructure of SLs underground stations requires more than one technique to implement. That's due to the layout and materials in the infrastructure, which contains WiFi access points only, near the exits and metals and signals that cause multipath propagation that interfere with the intended signals for navigation [4]. The layout of the metro stations usually contains two floors, first with a platform and the other with exits as mentioned in section 4. The dynamicity in the environment of metro stations is the movements of people, where people usually are located at the platform. Therefore, wireless navigation techniques would not be the most suitable technique to implement in the platform where people and metals are found. Human body contains mostly of water and water absorbs signals [4], which result to a falsified signal and therefore it's not preferred to use wireless setup in the platform of a metro station. This leads to different preferred techniques in different places of the underground metro station due to resources and layout of the station.
Indoor navigation techniques are many and fall into three categories as described in 1.1. The first category; designated technologies based on pre-deployed signal transmission is not considered in this report since it's very expensive and requires a lot of maintenance. It's also hugely dependent on very expensive resources and requires more complex platform to be used. Thus, it has not been taken into consideration in this report.

Platform area:
Kinematic and visual navigation techniques are most suitable for navigating user in the platform since no signals are emitted and so no false readings of position are measured. Although both of the suggested techniques have benefits and limitations, such as the visual navigation might be very accurate and cheap if implemented without digitization but it slows down the user because the user have to scan the reference object every time they walk a certain length. While kinematic navigation technique do not have a good accuracy but that depends hugely on the computations used to measure the position of user. Initial position of user needs to be known when using kinematic navigation techniques. It improves the accuracy to have a correct initial position of user but in the metro station's platform it is very difficult to find the initial position of user.
A solution for improving kinematic navigation technique is to use Bayesian filters or smoothing techniques because it improves the accuracy as seen by recent studies of kinematic navigation [13] [19] [20].

There are many ways to supply the kinematic navigation with initial position of user, such as:

- Last position signalled by GPS of the user
- A determined starting point which the user need to start from
- Environmental force based positioning mechanism.
- Visual navigation technique

When the metro is running the GPS signals are very inaccurate as shown in fig 1 when the metro drives underground and it's running very fast, which makes the GPS signals inaccurate. Therefore, it's not recommended to use last position located by GPS of user.

A determined starting point might be very tricky for tourists, especially since the whole problem is to be able to navigate people in unfamiliar areas. Using a point which the user have to locate and start from there to navigate is very inefficient since finding the location to the starting point might be just another challenge. It also take a lot of time to find a predetermined position and thus it will slow the user making it very inefficient to use to find the initial position of user.

Environmental force based positioning mechanism is described in section 2.2.3 and its limitations are described in section 2.2.5.This technique lacks flexibility because as shown in section 2.2.3 it depends on the magnetometer readings which are compared to saved readings in a database to find initial position. The readings of the initial position might be inaccurate because the initial position measured might not be unique, thus the same at different locations. SL metro stations do not have a dynamic environment that will affect this technique since no big changes of the metro stations are occurring within the next decades. So when it comes to the dynamicity of environment this technique would be suitable but its accuracy is very lacking and finding the right initial position is very essential for the navigation in the metro platform to work.

Visual navigation technique is very cheap as shown in section 2.4.2 and does not require a lot of maintenance unless troublesome people tear the QR code off. This can still be fixed by placing the Qr code reference objects with the map and other information SL provides in the metro station platform as shown in fig.6. This will include the already counted costs of maintenance for the board shown in fig.6. It is also beneficial in using when it comes to communicating other relevant stuff to the people. Recognition for the positioning of the QR code is required at first to guide the traveler to scan the QR code. This can be achieved by SL setting up direction signs to the QR codes or using other marketing methods at the beginning of the product launching in order to make the traveller aware of the QR code objects. The QR code will supply user with their initial position in order to solve the problem of kinematic navigation technique requiring an initial position to function and depending on the initial position the accuracy might be good or bad.

Close to exits:
The existing infrastructure close to the entrances can be utilized to navigate user in the underground stations. Information about the resources available close to the entrance was obtained during the interview. WiFi access points are available close to the entrance, so wireless navigation is recommended for this location. As mentioned the number of people found in this location are not many, which is very beneficial for using wireless navigation. Depending on the underground chosen for pilot study, there might be no shops with microwaves and metal doors that might interfere with the WiFi signals and falsify them.
The spread of the WiFi access point close to the entrance is not known and thus more information about the accuracy cannot be determined. Further studies need to be taken in order to determine further the suitability of using this method.

Overview of the steps taken for navigation
To solve this problem, it's suggested to use visual techniques where the user go off the metro shown in fig.7 scan a reference object that contains the exact initial position of a user as shown in fig.8. Then kinematic technique is used to take the user from platform to the floor with exits shown in fig.9. From there, wireless navigation is used to guide user to take the right exit shown in fig.10 and lastly the user is back to GPS, which navigates the user to the final destination.

fig.6 shows the basic information board located in all SL metro station platforms.

fig. 7 shows user getting off the metro while using smartphone for navigation.

fig. 8 shows user scanning qr code from the information board in the metro station to find initial position of user.

fig. 9 shows user navigating in the metro station platform after scanning the qr code.

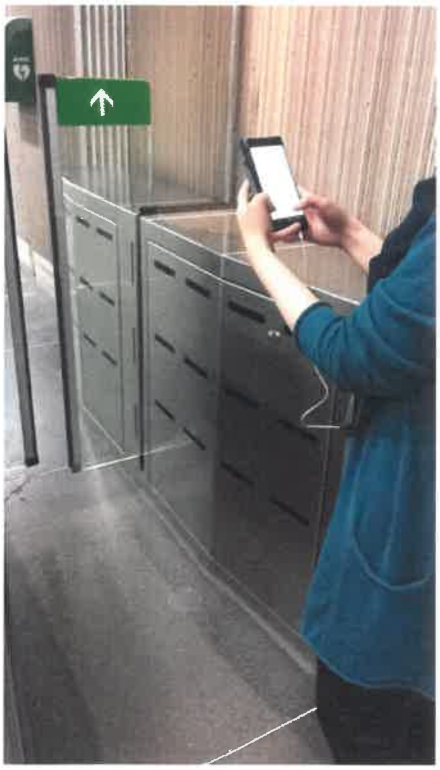

fig. 10 shows user being in the second floor, closer to the exits where the navigation is switched to wireless.

6 Conclusion

Travellers of Stockholm everyday face troubles and hurdles in navigating to their destinations when using SLs underground metro transportation. Current solutions of SL are not sufficient in finding the right direction and therefore a prominent solution is required to help in the navigation of the underground stations. Different indoor navigation techniques were studied and the typical infrastructure of SLs underground metro stations were found. Depending on the found infrastructure it was determined to use a combination of Indoor navigation techniques in order to optimize usage of exiting infrastructure. For the platform, a combination of kinematic and visual navigation based on QR- codes was found to be most suitable to use. Near the entrance doors, wireless navigation that utilizes WiFi access points is chosen as an enhancement of the QR code base service and for navigation second floor. Those results were found to be the most suitable techniques to use when implementing indoor navigation in SLs underground metro stations.

Further measurements needs to be carried out in order to confirm the suitability of using the techniques proposed above. From research carried out and the layout of the stations provided by SL, the conclusion was to use a combination of techniques for an optimized navigation for the user. In this study, battery capacity of the smartphone and the software development of the final product have not been taken into consideration.

7 Litteraturförteckning

[1] S. Polyzos, Ed., *Urban Development*. InTech, 2012.

[2] S.S.D. Jones and Tom S. Logsdon, "navigation - Modern navigation | technology | Britannica.com," *jul 20, 1998*, 14477BC. [Online]. Available: https://www.britannica.com/technology/navigation-technology/Modern-navigation. [Accessed: 11-Jun-2017].

[3] Annika S. Hipple, "Public Transportation in Stockholm: Getting to and around Sweden's Capital | REAL SCANDINAVIA," *June 2016*. [Online]. Available: http://realscandinavia.com/public-transportation-in-stockholm/. [Accessed: 11-Jun-2017].

[4] Retscher G., Roth F. (2017) Wi-Fi Fingerprinting with Reduced Signal Strength Observations from Long-Time Measurements. In: Gartner G., Huang H. (eds) Progress in Location-Based Services 2016. Lecture Notes in Geoinformation and Cartography. Springer, Cham

[5] Trafikförvaltningen Stockholms läns landsting, "Hållbar utveckling i kollektivtrafiken - Sll." [Online]. Available: http://www.sll.se/verksamhet/kollektivtrafik/hallbar-utveckling-i-kollektivtrafiken/. [Accessed: 11-Jun-2017].

[6] Frederic Beaudry, "Take Public Transportation - Save Money, Save The World." [Online]. Available: https://www.thoughtco.com/public-transportation-for-fewer-emissions-1203955. [Accessed: 11-Jun-2017].

[7] S. Rajasekar, P. Philominathan, and V. Chinnathambi, "arXiv:physics/0601009v3 [physics.gen-ph] 14 Oct 2013," 2013.

[8] G. M. Mendoza-Silva, J. Torres-Sospedra, J. Huerta, R. Montoliu, F. Ben?tez, and O. Belmonte, "Situation Goodness Method for Weighted Centroid-Based Wi-Fi APs Localization," 2017, pp. 27–47.

[9] Transport For London, "Station WiFi - Transport for London." [Online]. Available: https://tfl.gov.uk/campaign/station-wifi. [Accessed: 11-Jun-2017].

[10] L. Ojeda and J. Borenstein, "Personal Dead-reckoning System for GPS-denied Environments," in *2007 IEEE International Workshop on Safety, Security and Rescue Robotics*, 2007, pp. 1–6.

[11] Paresh Gujarati, "Overview of sensors used in smartphones and tablets," Techulator, 10771. [Online]. Available: http://www.techulator.com/resources/9421-Overview-sensors-used-smartphones-tablets.aspx. [Accessed: 23-Jun-2017].

[12] R. Ladbury, "Geodynamo Turns Toward a Stable Magnetic Field," *Physics Today 49*, 2993. [Online]. Available: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/eleref.html#c1. [Accessed: 11-Jun-2017].

[13] J. Racko, P. Brida, A. Perttula, J. Parviainen, and J. Collin, "Pedestrian Dead Reckoning with Particle Filter for handheld smartphone," in *2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, 2016, pp. 1–7.

[14] L. Filardo, F. Inderst, and F. Pascucci, "C-IPS: A smartphone based Indoor Positioning System," in *2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, 2016, pp. 1–7.

[15] V. Guimarães *et al.*, "A motion tracking solution for indoor localization using smartphones," in *2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, 2016, pp. 1–8.

[16] F. Dwiyasa and M. H. Lim, "A survey of problems and approaches in wireless-based indoor positioning," in *2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, 2016, pp. 1–7.

[17] G. Goronzy, M. Pelka, and H. Hellbrück, "QRPos: Indoor positioning system for self-balancing robots based on QR codes," in *2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, 2016, pp. 1–8.

[18] W. Y. Ma and B. S. Manjunath, "NeTra: a toolbox for navigating large image databases," in *Proceedings of International Conference on Image Processing*, 1997, vol. 1, pp. 568–571 vol.1.

[19] C. R. Ehrlich, J. Blankenbach, and A. Sieprath, "Towards a robust smartphone-based 2,5D pedestrian localization," in *2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, 2016, pp. 1–8.

[20] R. Hostettler and S. Särkkä, "IMU and magnetometer modeling for smartphone-based PDR," in *2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, 2016, pp. 1–8.

[21] Google developers, "Sensors Overview | Android Developers," *Google Android.* [Online]. Available: https://developer.android.com/guide/topics/sensors/sensors_overview.html. [Accessed: 15-Jun-2017].

[22] A. Strömberg, "Interview." unpublished, Stockholm, 2017.

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