Final report that summaries the works on the master thesis for seminar classes

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Topic: Constructing a positioning model in underground installations with use of mobile technologies.
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What is the primary goal of your work

The goal of my work was to propose a model of a positioning system that will work in the underground installations. Model should be suited to be used with smartphones reflect the environmental parameters and the usability, robustness, scalability and accuracy requirements. Desired outcome of the work was a general positioning system architecture that consists of the selected technologies and method of estimating the position.

The outcome of the position finding system answers the question "where am I". It means that the smartphone itself is able to determine its position inside the tunnel. The challenge in such stated position finding task is to provide a method that will be suited to the specific underground environment characteristics. There was need to find the best proportions between possible methods of acquiring the position and the smartphone abilities.

A justification, why you have chosen that very topic

- *“Mining goes digital”,*
- *Smartphone as a tool,*
- *Lack of positioning information in underground installations.*

The mining, boring and underground construction industries are known for the slow implementation of a new technologies. That is because the stakeholders value proven solutions more than potential profits from the technological advancements. Nowadays those underground industries are interested in digitalization all the activities they perform. The goal of digitalization is to increase the automation of production processes.

Smartphones are treated as an interfaces to the control systems as well as task management and reporting systems. Position aware reports like the issues or work status reports need to provide the place information they are relevant. That information links the report to a specific place in the underground installation. The information is used to locate and fix the problem in the installation.

There is no position finding solution developed for smartphone devices in underground installations with accuracy similar or better than 10m. The proposed position finding method decreases time needed to determine the position in the installation, provides the scalable solution with the position information accuracy at level of 5m.

The scientific problem you address

• *How to combine smartphone features with the underground environment characteristics in order to obtain the current position?*
• *What is the environment?*
• *What are smartphone features?*

Underground environments are specific in term of their construction and related technical properties like:

- their large scale,
- dimensions varying across the tunnels,
- weak or no light,
- environmental parameters like humidity, temperature and substances that make up the atmosphere,
- electromagnetic waves propagation,
- specific communication technologies,
- safety restrictions that limits electronic equipment that can be used.

The smartphone device contains wireless communication modules such as GSM, LTE, Bluetooth and WiFi transceivers and GPS receiver. It can be also equipped with sensorics such as camera, accelerometer, magnetometer, gyroscope, photometer and barometer.

In order to propose the position finding model suited for both environment and smartphone device there were evaluated available combinations of technologies suited for the underground and available for the smartphone. As a result there was proposed solution of Bluetooth beacon based reference infrastructure that provides the static positioning information to the smartphone.

An overview of related work

• Indoor positioning solutions,
• Wireless technologies for positioning,
• Sensor based positioning,
• Visible Light Communication,
• Magnetic Field pattern matching,
• Methods of signal processing and analysis.

Because of the corridors shape the underground installations are characterised with the waveguide signal propagation. It affects heavily the methods based on the signal strength analysis because the signal strength varies in a difficult to model way. Amount of dust causes the paintings on walls difficult to read. Lack of light limits usage of image processing methods. The safety regulations enforces use of certified and safe electronic devices only. Methods of communications rely mostly on leaky feeder related technologies.

Sensors in the smartphone are used for inertial navigation applications. The current position is estimated by sensor data fusioning. The outcome drifts because of the sensors readings errors and filtering methods. Inertial navigation is not sufficient itself to provide assumed positioning information accuracy.

Visible Light Communication is a nowell method used for position finding purposes. It cannot be used in all of the underground installations as in most cases light sources are limited.

RFID based positioning cannot be applied because of lack of a reader built into the smartphone. Power of the smartphone's NFC transceiver is not enough to work on distances bigger than 10cm what makes the solution not useful.

Each technology relates to different methods of signal processing. There were reviewed methods of signal filtering with use of Kalman filter, low-pass filter, RSSI smoothing, average and median filters.

In what way you have tackled the problem

I have proposed the conceptual model of the positioning system. Then I have chosen the technologies that matches stated requirements the best. Then I implemented the model into the proof of concept smartphone application and tested the solution in underground environment in Stara Kopalnia underground corridor in Wałbrzych. Results from test were used to determine the best setup for reference beacon based infrastructure.

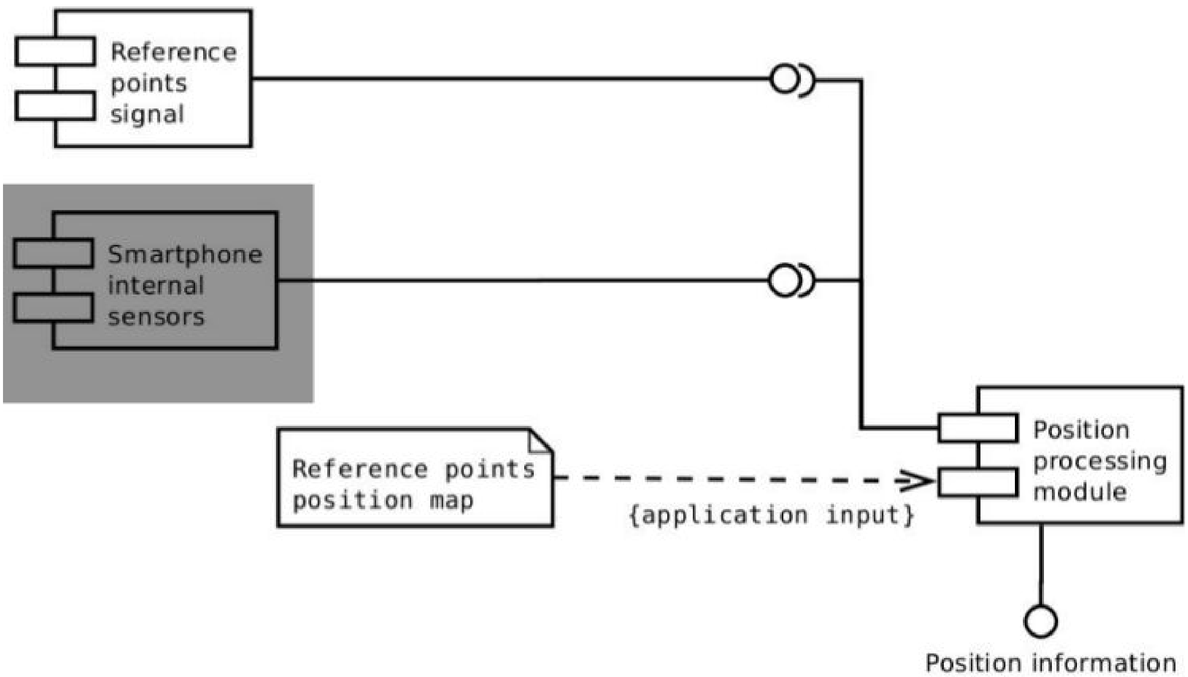

Fig 1. Proposed android application architecture. Grey part was not introduced into the proof of concept implementation.

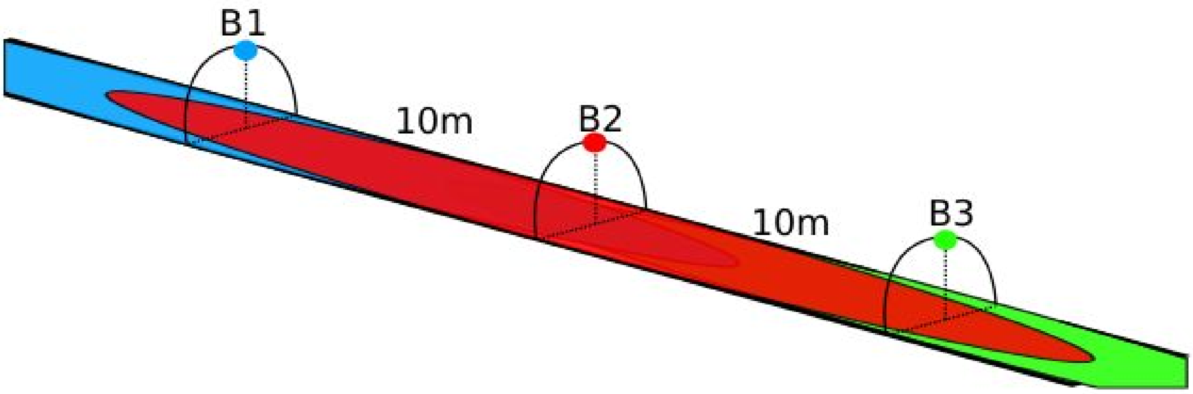

Fig 2. Proposed reference points infrastructure. B1, B2, B3 denotes Bluetooth beacon transmitters placed on the ceiling inside the tunnel. Red field denotes approximate signal range of the B2 beacon – more than 10m but less than 20m.

What you have achieved

Scope of work

Work consisted on evaluation of all state-of-the-art solutions for indoor navigation where GPS signal is not taken into consideration. Then there were checked and verified experimentally parameters of the underground installation. There were evaluated all of the components that are present in the representative smartphone device (along with the Android 7.0 compliance document) in context of their usability for positioning purposes. Then results of the evaluations were combined into proof of concept solution implementation.

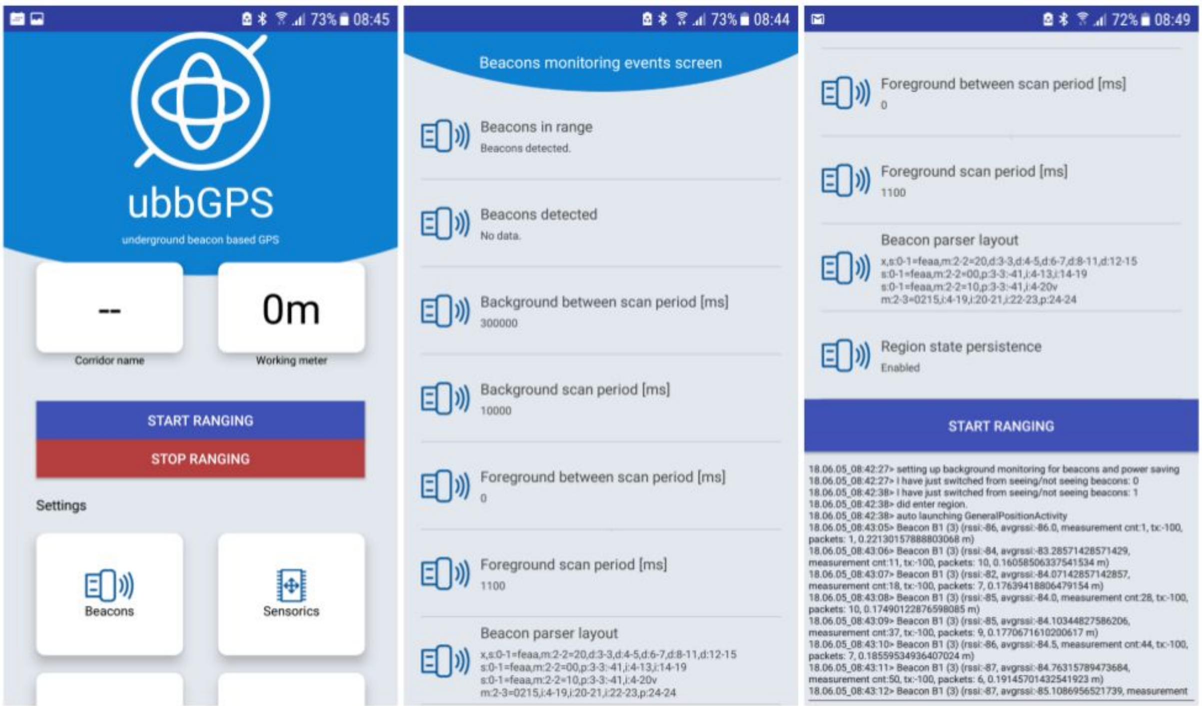

Fig 2. Views of the proof of concept smartphone application implementation. In order: view of the main application activity - position finding module; Bluetooth beacon ranging and monitoring module setup; ranging activity log - details about detected beacons.

Used tools and data

During the tests there were used Bluetooth Low Energy beacons -- 4 different models from 3 different producents. I have chosen this technology as it matches stated requirements the best. Two models of smartphones were used in the evaluation if the beacon based positioning solution in order to check if the smartphone model impacts on the received signal parameters. During tests there were measures signal link parameter -- received signal strength (RSS). The value of RSS is the basis for the proposed position finding algorithm.

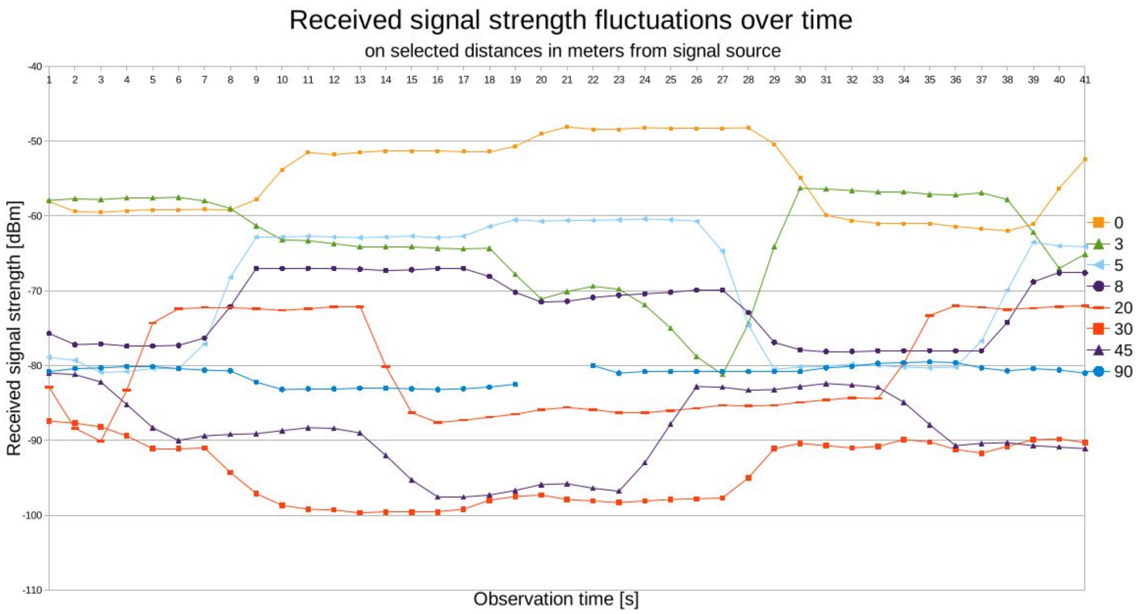

Fig 3. Received signal strengths measured each second at different distances between signal source and smartphone. Each line represents received signal strength obtained at given distance.

Data was gathered by the smartphone device and stored into csv file after each test. The Csv files were imported into LibreOffice Spreadsheet. There were generated charts that graphically presents the results.

The results and their verification

• *Radio attenuation curve on short distances is similar to that in free field distribution,*
• *Beacon placed horizontally on the ceiling ensure the best signal coverage and smaller fluctuations,*
• *Recommended values were determined statistically,*
• *Accuracy of the proposed method is 2.5m.*

During the tests there were used following equipment:

- a measuring wheel for measuring the distance between subsequent distances taken into consideration for signal attenuation charts,
- smartphones with application that was collecting and storing the data (Bluetooth Low Energy receivers) and
- prepared beacons – Bluetooth Low Energy transmitters.

There were performed two type of tests:

- static tests - signal strength measurements taken on distances from the signal source: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12,5, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90 meters; each measurement consists of at least 30 measurements of the signal parameters,
- dynamic tests - signal measurements made during the walk. Aim of those tests were to check how the attenuation curve changes with the change of the distance between receiver and transmitter.

Results obtained in the test session confirm the findings about the specifics of underground installation. There was observed the waveguide propagation effect on distances bigger than 10m from the signal source. It was observed that on the short distances from the signal source (0m–10m) the attenuation curve is similar to that in free field distribution. That means that on such distances there can be applied same RSS analysis methods as are used in the indoor positioning techniques.

The tests verified the values of recommended beacon parameters. The proposed value of transmission power resulted with expected signal range that matches with the concept of signal redundancy. It was also verified that the proposed value is sufficient for different orientations of the smartphone.

Different beacons requires calibration in order to make their signal propagation parameters similar. The attenuation curves of their signals have similar shape. It means that signal related methods chosen for the proposed solution can be applied to various beacon models. Different smartphone models do not influence the signal strength readings as well. The attenuation curve obtained from the both of Samsung and Blackberry devices have the same course and signal levels ±2dBm.

The beacon placement and it’s orientation highly impacts the attenuation curve. It has been experimentally proven that beacons mounted horizontally on the ceiling have better signal coverage than in other configurations. It was also observed that signal is less prone to the distortions caused by objects located inside the tunnel.

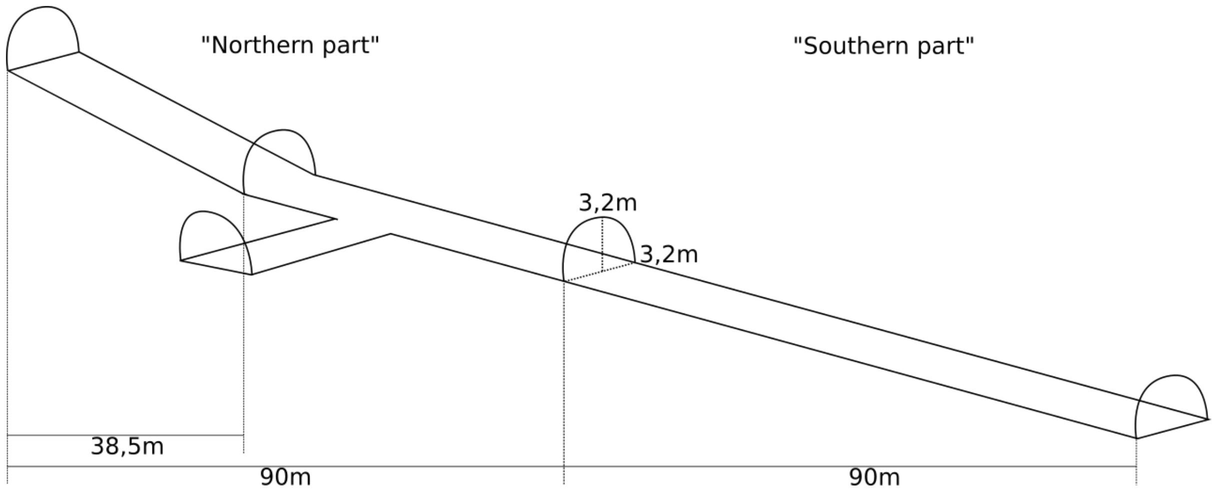

Fig3. Test place scheme. The reference points (beacons) were installed in the center part of the corridor (90m) in order to avoid ifluations from corridor endings.

What have you learned

• *Underground installations have to be extended by digitally recognisable landmarks in order to do the positioning,*
• *Sensing the beacon based infrastructure is a suitable solution for underground installations,*
• *Smartphones contains components making the position estimation more precise.*

Now i know the signal propagation specifics of the underground environment as well as state-of-the-art concept in the indoor positioning filed.

Where you are now

Experiments

• *Exclusively focused on radio propagation,*
• *Measure the installation configuration impact on the radio link parameters.*

There were performed one test in the underground environment. It's purpose was to check if the proposed solution is good enough to estimate the position of the mobile phone there was performed tests of chosen hardware components as well as the proposed Beacon-Infrastructure serving as the referencing system. Finally there were performed tests the prototype software application in the real environment in the underground part of Stara

Kopalnia museum placed on the site of the former Coal Mine in Wałbrzych.

Fig 4. Picture from the test side. Beacon is placed vertically on the wall.

The thesis – number of already written pages

Final version of thesis was delivered to the supervisor. It consists of 74 pages. It consists of 6 chapters:

- Goals an thesis scope,
- Underground environment description,
- Position finding solutions for indoor environment,
- Mobile technology based positioning model
- Positioning model prototype implementation tests
- Conclusions

Complete list of contents:

References – their number and what they are

There were used 59 references in the master thesis. They are about the underground environment characteristics, indoor navigation methods, usage of smartphone in context of a problem of position finding and a communication technologies used in underground installations.

the predicted date of the defense

Date of defence was set to 2'th of July 2018.