Thesis proposal

Working topic

Enchancements of smartphone-based magnetic fingerprinting and dead reckoning localization technique for infrustructure free localization indoors.

Background and problem statement

The problem

> Development of software system for indoor location services applications, with system properties (price, accuracy, features) being optimized for specific chosen user case.

Indoor navigation is a market with no real working solution. Various companies are trying to provide localization services indoors, but they can't reach GPS level properties. The main problems in this area are the price and scalability of the whole system. For example, in several locations this system are working and installed - airports, railway stations, hospitals. However for smaller applications there is also a need of this technologies, but the price and the complexity of the whole system is too high for worldwide implementation.

Several companies and researches are now developing the infrastructure free approaches. This means that the system works without any additional hardware installed "on-stage". Usually, there is a transmitter and receiver needed for communication and localization of people. On human side there is always a smartphone or any tracking device, sometimes only a passive mark such as RFID or NFC. On the facility side there may be different complex architectures of equipment. Usually WiFi transmitters (office facilities), RFID antennas (in marketplaces) and other special devices. The alternative of having no additional equipment on facilities side is the topic of this research.

The infrastructure-free approach however is not stable, the final accuracy changes from many factors.

The reasons for the choice of the thesis project topic:

- it is possible to create and deliver working system in less than one year
- all technologies on the market have similar level of accuracy >> we focus on improving system to be universal and stable
- we have researched the market for this technology and product, we see the oppurtunity to create startup and deliver services based on this technology after this product is done

Objectives

The project statement is

> "Development of software system for specific chosen user case." We aim to develop system that is not just any, but a system with specific properties.

We aim to create an indoor navigation system. For that we need to have a set of algorithms for localization, mapping and other practical tasks.

Before we write the code of a project, we do research of what technology we have to develop.

We valuate technologies on several important criterias: cost, complexity, accuracy, time of development. With this, we test hypoteses of what technology is more suitable to build the navigation system.

Based on previous research, we have chosen magnetic field technology for this project.

The main hypotese is

> Current systems on the market (WiFi, BLE) are not suitable for standalone application in common usecase.

The second hypotese

> Competitive technology of magnetic field navigation is perspective. This technology may be implemented and fine-tuned for several common usecases.

We define the scope of a project

> Specific focus on technology and common applications. Fine tuning of magnetic technology according to hypoteses 1 and 2.

Literature review

Indoor navigation solutions is a wide range of products and services. While "indoor routing" functionality that guides people through the buildings is important, there are lots of services which support it, such as content management system, mobile and web applications, indoor and outdoor localization, social networks, data analytics and many others.

Why do we need indoor navigation and positioning? This is because of convenience of global Geo-services, and because of GPS reception problems inside buildings.

One of understandable example of such kind of products is a Google Maps, which are scaled to work inside the buildings.

The situation is much more complicated, the market of indoor positioning is resegmented - different applications from security applications and assets tracking in business and manufacturing to the proximity advertising in retail - from fully protected to broadcast solutions, from cheap high range proximity to high precision solutions in robotics. Indoor positioning systems is a growing industry with hundreds applications.

Different applications have different technologies behind it. Over 15-20 different working technologies is known, about 3-5 of them are widely used now (WiFi, Bluetooth Low Energy, Image Based).

Table 1. technology comparison

IPS Technology	Type	Accuracy, m	Scalability	Complexity	Cost
Geomagnetic	fingerprinting	2	Low	Low	Very Low
Photo	camera	1-10	Low	High	High
Barcodes	camera	1-10	Medium	Low	Low
Video, AR	camera	1-10	Low	High	High
Bluetooth Low Energy (BLE)	Radio	1-3	High	Medium	Medium
RFID, Active	Radio	1-10	Medium	Medium	Medium
RFID, Passive	Radio	1-10	Medium	Medium	Medium
Wi-Fi	Radio	5-10	High	Medium	Low
Ultra Wide Band (UWB)	Radio	0.15-0.5	Low	Medium	Medium to Low
Zigbee	Radio	3-5	Low	Low	Low
FM		2-4	Low	Low	Low
Lighting-Based – Infrared LED	Lighting	0.15-3	Low	Low	Low
Lighting-Based – Visible LED	Lighting	0.3-3	Low	Low	Low
Audible	sonic	0.5	Low	Low	Low
Ultrasound	sonic	0.05-0.25	Low	Medium	Low to Medium
Inertial	supplementary		Low	Low	
Pressure	supplementary				
GPS	supplementary	6-10	Low	High	

We will provide explicit review of all papers.

As for now, we want to repeate any reasonable fingerprinting technique.

- RinQ Fingerprinting: Recurrence-Informed Quantile Networks for Magnetic Resonance Fingerprinting https://link.springer.com/chapter/10.1007/978-3-030-32248-9_11
- Scene-LSTM: A Model for Human Trajectory Prediction https://arxiv.org/pdf/1808.04018.pdf
- Magnetic Resonance Fingerprinting using Recurrent Neural Networks https://paperswithcode.com/paper/magnetic-resonance-fingerprinting-using
- Multicompartment Magnetic Resonance Fingerprinting https://arxiv.org/pdf/1802.10492.pdf
- Magnetic resonance fingerprinting https://mriquestions.com/uploads/3/4/5/7/34572113/mr_fingerprinting_nature11971.pdf

Metodology / theoretical framework

Preparation landscape research

First we define current state of the art, we build the model for existing technologies, analyze products on the market, list key players and IP owners, create Pareto frontier. This part is intended to make a visible and understandable landscape of this technology segment.

Procedures list

- collection of magnetic fingerprints dataset with smartphone sensors: Gyroscope, compass, IMU.
- development of a model for localization using this dataset

- experiments using model, estimation of accuracy
- implementation of possible techniques, benchmarking
- fine-tuning of perspective technique
- comparison to other products on the market, interpretation of results

Techniques

There are several ecnhancements of techonogy we want to test:

- Relocalization technique (air imaging approach) >> improve mapping
- Kalman filters for dead reckoning (extended Kalman filter) >> improve stability
- Bayesian methods of user coordinate prediction >> improve localization
- Smartphone-based magnetic fingerprinting (usual approach) >> infrastructure-free navigation system

We use data of Microsoft competition as a starting reference (D. Lymberopoulos, J. Liu, X. Yang, R. Choudhury,V. Handziski, S. Sen, F. Lemic, J. Buesch, Z. Jiang,H. Zou, H. Jiang, C. Zhang, A. Ashok, C. Xu, P. Lazik,N. Rajagopal, A. Rowe, A. Ghose, N. Ahmed, andP. Hevesi, "A realistic evaluation and comparison ofindoor location technologies: Experiences and lessonslearned," 04 2015.).

In table(not presented), we have time of development and resulting accuracy for the different technology choice of different teams participated. We may use these dependencies to understand, what time is needed to achieve each level of accuracy for different combinations of technologies.

We choose the best performance in technologies by multiplication of all of parameters. Performance = 1 / (development time * accuracy). The selected technologies are presented in table below.

Table 2. Preferable technology choice

Technical Approach	**dev.time**	**RMS error**
SDR Time-of-Flight	4	3.87
2.4GHz Time-of-Flight	5	2.58
WiFi+IMU Fingerprinting	9	2.81
WiFi+Modulated LEDs	12	2.04
WiFi Fingerprinting + Neural Network	12	2.22
WiFi+IMU Fingerprinting + Neural Network	36	1.96
2.4GHz Phase Offset	60	0.72
Bayesian Filter + WiFi Fingerprinting	96	1.56

From the project scope we defined, we may implement WiFi+IMU Fingerprinting, Bayesian Filters, Neural Network filter, magnetic field fingerprinting.

Timeline

stage	**time estimation**	**timeline**
customer interviews	completed	--------
market research	completed	--------
product design	completed	--------
business model formulation	completed	--------
market and competitior analysis	completed	--------
product prototyping	2 months	20.11.2020
technology enchancements	2 months	20.12.2020
experiments on product performance	1 months	20.01.2021
marketing strategy development	to be defined	20.04.2021
final mobile application	3 months	20.05.2021

Innovation impact

The roadmap on the scope of indoor positioning systems is almost finished. With this results, we have a landscape of existing technologies and products and we may desing a specific product.

For now we have a first draft of a business model.

Innovation reseacrh

a solution that provides a service to guide users inside of the building. This solution is primarily aimed at social events and commercials, such as exhibitions and expo centers. Also, some of the possible applications are stationary public indoor places, such as museums and Skoltech new campus.

Product and technology development is a key part to complete this project in any variation.

- Roadmap presentation https://docs.google.com/presentation/d/17Y4y7kEfnQPwoDM8SHt8FAUGgpr_LoDErFYHAzCHLqE/edit#slide=id.g8801f1f3c0_0_43
- Roadmap paper https://www.overleaf.com/read/fdjmmbbtwnkn
- Service for indoor navigation on forums and exhibitions, customer discovery: https://docs.google.com/presentation/d/1OGzwogQPFiY9SddoreiYfuIoOX-pSv75EbnpgBfXfGk/edit?usp=sharing

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Last updated 2020-10-16 13:22:31 +0300