Technology of Development of the Low-Cost Indoor-Navigation Services

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***Abstract*—An efficient and low cost indoor navigation system is strongly required for different types of buildings consisting of many rooms and floors. In this paper the technology of creation such services is described and real examples of technology assessment are shown.**

I. Introduction

Indoor-navigation is a demanded and promising trend. From the one hand, such services should help people to navigate inside different buildings (indoor-navigation), from the other hand IoT solutions and Cyber Physical Systems need navigation too (for instance, automated warehouse).

Analysts predict growth of the global market of geo-location services, and indoor services. It will rise by 2019 to $ 4 billion (according to ABI Research and Markets and Markets).

As we will see, despite some indoor-navigation solutions are in the market, there is no a large spread of such services on real objects and they does not meet people's needs.

In this paper we describe how the created technology of development of the low-cost indoor-navigation services works and what services is already created by using this technology.

II. Review of Popular Available Technologies for Indoor Navigation

A. Statement of problem

Initially we set following task: developed indoor-navigation service for the main building of the Saint Petersburg State University of Aerospace Instrumentation (SUAI), which located in the Saint Petersburg, 67, Bolshaya Morskaya street, Russia. Many peoples, including workers, teachers, students and visitors, have difficulties to find some audience.

During the Coursera Human Computer Interaction course one of our teammates designed interface of the future indoor-navigation service for the university. After that, we started to search a technology, which will allows us with minimal finance help potential users to find rooms and routes in the university by using different type of device, including smartphones, tablets and PCs on different operation systems.

One of the most important part of any indoor-navigation service is a location definition inside the building with acceptable accuracy. For instance, nobody wants to use program, which mistakenly define the floor.

Let's consider the most popular location definition technologies.

B. Satellite technologies

Satellite positioning systems (GPS, GLONASS) has unacceptable accuracy inside buildings (depending on the quality of the signal from satellites, precision 5–8 meters). Besides, the task of floor definition is almost unsolved with this technology because the height is defined with accuracy around 10 meters. Moreover, the received signals are too weak to provide an accurate location using those technologies [1].

C. Inertial navigation systems (INS)

INS are one of the most widely used dead-reckoning systems. Dead reckoning is the process of estimating the current position of a user based upon a previously known position, and advancing that position based upon measured or estimated speeds over elapsed time and course. Errors occurring in the position fix are cumulative, growing with every step the user takes (Indoor pedestrian navigation system using a modern smartphone).

The initial orientation is set when the user scans the 2D barcode (QR-technology).

The data read from the phone's sensors, combined with the reference map of the place, gives the actual position of the user without connecting to any external or pre-installed positioning system such as GPS, RFID, or WiFi trilateration.

Before starting the application, the compass needs an accurate recalibration. This recalibration is necessary because the compass is subject to several errors: initially it has an inaccuracy of maximum 5 degrees, depending also on the used device and on the presence of electromagnetic interferences [2].

D. Wireless LAN

Many buildings are equipped with WLAN access points (shopping malls, museums, hospitals, airports, etc.), it may become practical to use these access points to determine user location in these indoor environments. The location technique is based on the measurement of the received signal strength (RSS) and the well-known fingerprinting method [1], [3], [4]. The accuracy depends on the number of positions registered in the database. Besides, signal fluctuations over time introduce errors and discontinuities in the user's trajectory.

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To minimize the fluctuations of the RSS, some filtering is needed. A simple temporal averaging filter does not give satisfying results. Kalman filtering [1], [5], [6] is commonly used in automatic control to track the trajectory of a target.

WLAN technology has problems with floor definition. In some solutions, developers are trying to solve it by using atmospheric pressure sensor.

E. *Short range communication technologies*

Bluetooth is a simple, compatible short range communication technology which requires expensive receivers; and the position accuracy depends on the amount of cells used [7]. If smartphone has a Bluetooth, it is not a guarantee, which it could interacts with Bluetooth beacon.

In case of RFID technology, position accuracy depends on the type of the tags, which is either active or passive, as well as the amount of these tags. Existing RFID based indoor navigation solutions are generally based on usage active RFID tags and require extensive usage of active RFID tags to get good position accuracy. Contrary to passive tags, active tags contain embedded batteries in order to increase the transmitting distance. The major drawback of using active RFID tag based solutions is the high cost of the active tags.

Studies in this area [7], [13] also indicate that it does not provide an efficient tracking system.

NFC is a bidirectional short range, wireless communication technology. The user only needs to carry and use an NFC enabled mobile device (modern phones increasingly equipped with NFC). Indoor navigation application must be OTA (Over the Air) pre-loaded to the smart card. Than the user needs to simply touch to the URL Tag (NFC tag), that contains the URL of indoor map information just before entering the building or area. The map on the web site is OTA downloaded to user's mobile device from the MapServer (i.e. a web server containing the map information). The indoor navigation application on the mobile phone automatically starts and uses this map information afterwards. As the user selects destination point of voyage inside the building, the indoor navigation application provides the optimal route to destination [7].

F. *QR (Quick Response Codes)*

Some researches and services use QR-technology for position definition. One use this technology for the pedestrian navigation [8], other create QR code indoor navigation service with voice response [9, 10], there is a technique to assist the sighted and blind or people with low vision to navigate, which also use RFID [11]. In Saint Petersburg, there is a company that, among other things, does QR navigation inside buildings [12]. Unfortunately, there is no description of any real case with implementation.

G. *Conclusion*

The comparison of considered indoor-navigation technologies is shown in the Table I.

TABLE I. COMPARISON OF INDOOR-NAVIGATION TECHNOLOGIES

Technology	Required infrastructure	Cost
INS	1. Smartphone with various sensors (+-) 2. Reference map of the place (-) 3. The compass needs an accurate recalibration (-) 4. Initial orientation is needed (-) 5. No floor detection (-)	Nothing Everything is inside smartphone
WLAN	1. Smartphone with Wi-Fi support (+) 2. Wi-Fi infrastructure (+-) 3. Reference map of the place (-) 4. Reference map of the Wi-Fi signal (-) 5. No floor detection (-)	Middle ~20$ per one router
Bluetooth	1. Smartphone with Bluetooth beacons support (+-) 2. Every Beacons has a battery (-) 3. Floor detection (+)	High ~20$ per one ibeacon
NFC	1. Smartphone with camera (+) 2. QR-codes posters (+) 3. No battery (+) 4. Floor detection (+)	Low ~1.25$ per one sticker
QR	1. Smartphone with camera (+) 2. QR-codes posters (+) 3. No battery (+) 4. Floor detection (+)	Lowest Less than 0.25$ per one sticker

Some indoor-navigation solutions suggests combining several technologies, for instance, WLAN and INS. The idea is complementarity: in the case where there is no Wi-Fi in the area, INS is used instead.

A major limitation of indoor navigation systems is the high installation cost and the complexity of the system design. Additionally, most of the existing positioning systems are far from providing an accurate position in large buildings [7], [13].

After we having considered the most popular technologies that can be applied to determine the location inside buildings, we came to several conclusions, and one idea.

Basic technical constraint for us is the smartphones hardware. If we want to create widely available indoor-navigation service, we should take into account average smartphone hardware, not only modern models.

We have no money for infrastructure and want to have real result, so we need something very cheap as piece of paper. Thus we choice QR-technology to create visual marks for location detection or for route building.

Moreover, we should remember that initially our task is to create indoor-navigation service to a concrete building. Maybe we could use some specific of the building. Every door inside university building has id number (room number). Thus to find the route between two any rooms user enters four-digit number of the nearest room (determination of the exact location) and the number of the target room.

In this case, no additional infrastructure is needed (no beacons or something else). All you need is a smartphone or other device (tablet, PC).

III. PROPOSED TECHNOLOGY

This technology was fully designed, implemented and approved during the conducted work on searching information service for the main building of Saint Petersburg State University of Aerospace Instrumentation. This service is called "SUAI navigation". The developed technology has become an answer for the constant necessity for rebuilding of multicomponent solution due to making on-the-spot changes in the project. Building of the whole service is performed in one click so that it is easy to make any changes in the building structure or routes.

The discussed methodology allows to obtain a comprehensive solution:

- Navigation web-service which is accessible via almost every device and browser.
- Applications for three main mobile platforms: Android, iOS, WinPhone.

The core of the methodology is a special software for automated build of navigation service for any building. This software has the following components as an input:

1) Description of building's floors;
2) Graphical representation of each floor;
3) Algorithm for route building-up.

Let us consider each technology component in more details.

A. Building description

The building is divided to legs. Each leg contains entry points to rooms. All building's legs are connected with each other by these points or via other legs. For example, in SUAI navigation legs' sets represent a cut-off of the building by the floor. Moreover, connections between these sets can be passing either from one part of the building to another, or from one floor to the other – Fig. 1.

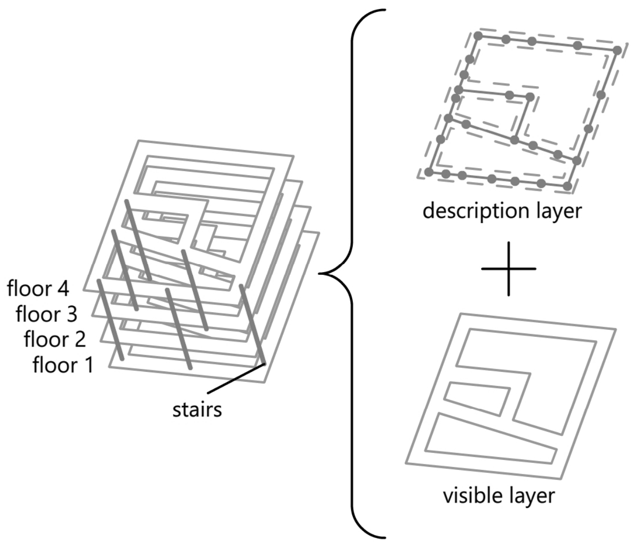

Fig. 1. Building representation concept

We have developed a special test format for building layout description: each section of the route is attached to a particular auditorium. In addition, SUAI navigation contains such kind of points, which are simultaneously connected to several auditoriums. The reason for this is that a distances between doorways is so small (<2 meters) that we can neglect their values. As a result, we can decrease the computation load for searching and building-up of the shortest route.

In terms of mathematics, the description of the entire building is a weakly connected graph.

B. Graphical representation of each building's floor

We chose a vector format SVG for the graphical representation of buildings' floors. This format has a number of advantages over other formats. Firstly, the vector format provides accuracy for the image in any scale. This is very important while solving the problem of navigation.

Secondly, SVG is the only vector format which is supported by almost all browsers without additional plugins. This allows to make a final solution available for users as fast as possible, even before native applications are developed for smartphones,

Finally, SVG format has a very user friendly semantics, which makes it very easy to connect graphics with the code (see. Algorithm for searching and building-up of the route).

C. Algorithm for searching and building-up of the route

The input data for route search are the start and destination points: rooms' numbers, identifiers. For example, in SUAI navigation they are represented by the numbers of auditoriums, departments names or dean's offices. On the basis of the input data the algorithm performs the search of these rooms in the data array. For the purpose of search time reduce, the algorithm does not scan the whole data array, but it analyses the room identifier, which helps to reduce the search to a minor set of nodes in the graph. Then it should perform a search through all these graph nodes. For example, in SUAI navigation the auditorium 1243 is analyzed in the following way: (1) is the number of building's bulk (there are 5 bulks of the university building), (2) corresponds to a floor number (there are 4 or 5 floors, depending on the bulk), and finally, (43) is the number of auditorium.

Consequently, a search space significantly narrowed even with a simple data analysis.

As long as graph nodes are found, the algorithm searches the shortest way between them. Here we use significantly modified Dijkstra's algorithm. The search time is reduced, particularly, by searching of information about the rooms in the scalable system. For example, the search can be performed between two buildings, between two bulks of one building between two floors of one bulk, etc. Such approach allows to limit the amount of processed data as well as use multilevel abstractions of data representation.

After to shortest route is found, it is necessary to display it on a multilayer map. Each graph node has its identifier which is used to connect it to a certain layer in SVG file of multilayer map. In addition, each auditorium is connected to a particular leg of the route in a separate layer of SVG file. Therefore, all auditoriums and all possible routes are "highlighted" in the building's map, but initially, this feature is switched off. The result of the shortest route search is a set of identification numbers of building's map SVG layers, which visibility features should be switched on. Then there is a transition to the start point of the route and its centering on the user's screen. The buttons of floor changing are highlighted if necessary.

There is also an option of searching a particular room, not the route. In this case the problem is reduced to searching one layer's identification number which visibility feature should be switched on.

D. Approbation

SUAI navigation web application which is available via the majority of browsers was launched in 2014 [14].

From September to October 2016 there were more than 1000 visitors. More than 60% of traffic from smartphones. First week of September – 150 visitors. Last two months the average number of visitors was about 20 people per day.

September 29, 2015, we launched a native application for Android OS (Fig. 2). By October 2016 the Android app was installed 914 times. On October 14, 2015 we launched an application for Windows Phone (Fig. 2). By October 2016 the Win Phone app was installed 73 times Finally, in 2016 we plan to launch and application for iOS.

Fig. 2. Smartphones with running SUAI navigation service (Android app on Asus, web application on iPhone and Win Phone app on Nokia)

Moreover, in SUAI navigation we successfully approved visual marks on the basis of QR technology (Fig. 3).

Fig. 3. Example of tested QR codes visual marks

By request of a number of University employees we have created and published an instruction for web links and QR code creation for any auditorium or route. At present time, any University employee can easily create all necessary marks with routes for university events support such as conferences or open days.

We plan the further development of our project in collaboration with the University: introducing other university buildings, navigation service integration into the university information system.

Furthermore, our searching information service technology was applied in the developed IoT technology. It is used together with the IoT Azure cloud in our project Live Hard Ship Hard! [15]. Navigation service is used for detection of autonomous robocar location inside the building. This opens up new horizons of the discussed technology application, e.g. creation of control system for automated (semi-automated) storage equipped with robots-carriers driving via optimal routes and serving the storage. Nowadays, such kind of systems is rapidly developing, for example, automated storage of Amazon company.

IV. Conclusion

Considered technology allows to create low-cost indoor-navigation services.

As you can see technology is great in solving real practical problems. Its further development is carried out in two main vectors: navigation for IoT-systems and indoor-navigation.

Example case of IoT-systems and Cyber Physical systems was considered in Approbation. Automated warehouses can be very easy to integrate in the market of Internet shops where the cheap storage of production is essential.

We have plans in the indoor-navigation direction.

Shopping malls. Service should including not only navigation and discounts shows; it should take into account the interests of both sides (visitor and shop owner). For instance, I need a pair of new sneakers. Service builds the special route to bypass all sport stores where they could be, with indication of the approximate time that will be spent.

It is only one function, which could save visitors time and give a chance to all shops inform the possible costumer about their products.

Another case that we want to try in the nearest future – exhibitions and forums.

We are going to develop a module system, where there is no need to install separate mobile application for each building. Instead of that user will have opportunity to download needed building right through the application, like maps on navigator's application. Our estimations shows, that size of the full building map with route graph is approximately several megabytes.

Such modules are easily installed and deleted. User always will have up-to-date information on the places that are needed. For example, for student it could be map of the university, couple of shopping malls and sometimes temporary modules: exhibitions, FRUCT etc.

The technology is flexible and easily supplemented with new components; for example, in the case of expansion of range positioning methods (add beacons), it is possible to make the service that using a method of positioning each separately and both simultaneously.

The technology allows creating low-cost indoor-navigation services, which solves real people needs. The extremely low cost of implementation and flexibility of technology makes such services like SUAI navigation evaluable for a broad range of different buildings, including clinics, hospitals, universities, sport buildings etc.

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