Infrastructure free indoor positioning system

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Abstract. Latest technological advancement uncovered new social and entrepreneurial opportunities in fields like civil engineering and facility management. While most outdoor location challenges have been addressed in the past few years, with declassified military technologies such as Motion Imagery Standards Board and North Atlantic Treaty Organization Digital Motion Imagery Standard being integrated into solutions that enhance real-time emulation of surveillance video streams over digital maps, there is plenty of room for innovation when indoor location is considered. The market associated to indoor positioning is expected to significantly grow in the following decade since people spend more and more time indoors and promising advantages of such technologies have been identified in healthcare, retail, logistics and leisure. Yet, conventional indoor positioning systems mostly rely on costly and difficult to maintain infrastructure. Discordantly, the hereby paper is introducing an infrastructure free indoor positioning web application designed for routing people inside facilities and building evacuation scenarios. The proposed architecture is independent on external hardware or beacons, relying on a generic sensors framework that exposes the underlying capabilities of a mobile phone for data collection and internet connection for assessing current location and providing guidance in respect with an already known topography. Therefore, this design might be easily extended to various facilities, individualizing through no initial costs for sensors deployment and light resource consumption for the user, since data is not processed on a native application. Such flexibility is considered to optimize the navigation inside large public places and reduce the time required to find products, people or shops, offering the users more time for what matters.

Keywords: indoor location, infrastructure free positioning, web application, routing, facility management.

Introduction

On the one hand, during the last decades the technological advancement facilitated solutions for most of the outdoor localization and people routing challenges. Currently, at the comfort of their smart gadgets, individuals can navigate through never before explored areas and successfully reach a desired destination, might constantly share their location for easier encounters with friends or rescue teams and use the global positioning system (GPS) network of satellites for regularly sending/receiving updates to/from purposely designed applications like Waze or Snapchat that established a crowd-powered innovation model.

On the other hand, the same flexibility is not yet available when it comes to indoor location. The rich infrastructure that turned outdoor location into a trivial task is ineffective indoors, the signals being lost in urban canyons where abundant vegetation, physical properties of building materials, environmental noise and high distribution of tall buildings tend to interfere. Moreover, when comparing outdoor and indoor location, different reference features are brought into discussion. While in most outdoor scenarios an error of several meters is reasonable, in indoor positioning context such errors might mean a different room or even building. Nevertheless, many outdoor location scenarios involve a two-dimensional analysis, since what matters in the end are the latitude and the longitude values. In contrast, indoor location introduces another dimension as the actual floor of a shop, room or office is a relevant information for evacuation or routing scenarios.

Other characteristics worth mentioning are the complexity and the absence of generalization that describe indoor location. Whilst outdoors topographical features associated with location retrieval (signal strength, lack of fluctuations) tend to remain homogenous for large areas, neighbor buildings might present different properties. As a result, what is currently a limitation for indoor positioning systems is that proposed solutions usually address a specific setup, they lack generalization. Up to now, efforts have been made in various directions, with academic initiatives that used image-based recognition techniques for indoor location (Koch, Neges, König, & Abramovici, 2014), with neural networks particularly trained for one building (Falcon & Schulzrinne, 2018) or with grids of beacons deployed inside structures (Rajagopal, Miller, & Kumar, 2019), just to mention a few.

From a different perspective, disruptive technologies like NATO Digital Motion Imagery Standard (NATO STANAG 4609) (GWG, /misb/docs/nato_docs/STANAG_4609_Ed3.pdf, 2009) and Motion Imagery Standards Board (MISB) (GWG, /misb/docs/misp/MISP-6.6.pdf, 2014) granted large flexibility and enhanced the possibility of overlaying a video stream taken from surveillance cameras over cartographical representations of preset areas of interest – with large extent in fields like warfare and target localization.

In addition, the boost augmented reality received in the past years, due to the increased capacity of graphical processing units to render content, created the premises for innovative initiatives in environmental planning and civil engineering. Several already developed applications that address such problems include an augmented reality flood simulator (Haynes, Hehl-Lange, & Lange, 2018) or an artificial intelligence-based AR solution that identifies water pipes inside walls (Baek, Ha, & Kim, 2019).

Under these circumstances, indoor positioning is still an uncharted field with plenty of room for innovation and experimental techniques. Given the challenges the domain raises, an out of the box approach must be considered. A combined strategy that involves optical image/symbols recognition, augmented reality elements, internet of things principles and statistical and mathematical models would hopefully lead to unexpected and fruitful outcomes.

Literature review

Indoor localization has acquired more and more interest in recent years, since the Internet of Things permitted a large variety of devices to be interconnected and exchange data. Extensive layouts of sensors connected to the internet that regularly send information are no longer something novel. Lashkari et al. classified existing indoor positioning systems (IPS) into crowdsourcing – systems that require explicit user input and crowdsensing – systems that require implicit user input. (Lashkari, Rezazadeh, Farahbakhsh, & Sandrasegaran, 2019) The subtle difference between them is that in crowdsourcing the information is collected from people, while in crowdsensing it comes from sensors. Both categories have received attention from the business and academic environment recently and better precision and efficiency is expected for one and the other.

However, as Radoi et al. emphasized there is disorganization in the field of indoor location due to the fact research initiatives are sporadic, there is no joint action that aims to achieve a common goal incrementally and most of the researchers have commercial aspirations, pursuing a future acquisition from large companies. (Radoi, Cirimpei, & Radu, 2019) Consequently, different teams will inevitably resolve the same issue in different ways, ineffectively allocating resources. But since the field is still in its infancy this is understandable

and perhaps in future nongovernmental institutions will try to impose order and draw a common direction.

Among the most popular technologies in indoor location nowadays, infrared radiation, ultrasonic waves, wireless local area networks, radio-frequency identification, Bluetooth or video data processing are just some worth being mentioned. A more in-depth analysis of each of these technologies has been developed by Mainetti et al. (Mainetti, Patrono, & Sergi, 2014).

Each of these technologies has its strengths and weaknesses and what is suitable in one scenario might be inappropriate in another, since IPS are sensitive to environmental particularities. Anyway, depending on what might be the most convenient approach in one context, indoor location algorithms will often consider one or many of the following localization methods: triangulation, fingerprinting, proximity, dead reckoning or image recognition.

Beside these, probably the most interesting method in terms of potential results is the one using machine learning. An extensive comparison and assessment of indoor positioning accuracies using machine learning proved that localization based on the classification method is less effective than the one using regression. (Li, Kang,, & Qiao, 2019) Moreover, the same study compared the performance of four different ML algorithms in indoor location context and revealed the most appropriate choice for such purpose would be the Gradient Boosting Decision Tree algorithm.

The problem

For the purpose of this paper we are going to consider the following classification. Currently, two main categories of indoor positioning systems can be distinguished – one dependent on external hardware resources and one that uses software to overcome this dependency.

The former category uses artificial markers for dead reckoning, noticing whenever the target is in proximity of an already known location. It must be mentioned this approach requires larger initial costs for deploying effective networks of beacons and sensors and it is the landlord the one responsible for installing them. Therefore, such choices might be suitable for airports or large shopping centers, but for other agents that do not have enough financial resources for such infrastructure investments like universities, museums or hospitals it might be a bottleneck. In addition, such deployments might hamper other existing networks and their effectiveness is strongly dependent on structure materials, building shapes, congestion, sensors placement, environmental refraction or signal propagation. Also, the networks imply maintenance costs, since someone must constantly check the sensors are functional and replace them when needed. Researchers have analyzed such scenarios and developed optimum layouts (Abielmona & Groza, 2007) for given buildings, yet their results are relevant in their actual setup and extrapolation does not guarantee the same performance.

The latter category moves the process of data acquisition from the environment where the target is monitored, further referred as the server scope, to the actual individual, referred as client. A subtle difference is that in the first case the building system knows where a target is at a certain timestamp, the informational flow goes from the server to the client, while in the second case, the control is delegated to the target, the client is sending data to the server in terms of image sequences or inertial measurement unit values for processing. This approach is more financially convenient for the landlord since there is no sensors deployment and maintenance cost involved. Yet, it brings far more complexity as it needs to guarantee high accuracy for indoor location and such purpose might be hard to achieve considering the influence of various heterogeneous external variables – target's equipment performance, signal strength, noise, surrounding environment.

Some proposed solutions that belong to this category and rely on the phone camera have been tackled as state-of-the-art projects in universities. (Cankaya, Koyun, Yigit, & Yuksel, 2015) (Sui & Wang, 2015) (Zhang, Ma, & Tan, 2016). Anyway, this approach where the client is gathering information about its current position through camera and tries to identify the location relative to some data stored on the server is impractical since they are energy intensive and lead to battery drain, the reference building image models stored on the server must be kept updated and faithfully reflect the actual environment. Nevertheless, researchers underlined the challenges of a cross-domain comparison between a stream of captured images and a 3D rendered model (Ha, Kim, & Park, 2018), suggesting the use of artificial intelligence for meaningful processing.

Bearing in mind the downsides previously detailed, there is still large potential in indoor location and market studies expect a significant growth in future for the field since people spend more time inside than before and promising use cases have been outlined in logistics, healthcare or retail. Effective indoor location is a social entrepreneurship opportunity that once achieved will produce both sustainable development and large profits.

The opportunity

Yet complicated, expensive and often ineffective, indoor positioning systems are thought to reveal atypical use cases in real-time personnel management and monitoring, asset tracking, indoor navigation, from infrastructure mapping to modelling, contextual details retrieval and surveying, as well as disaster management and emergency services. More and more industries get oriented towards indoor positioning, as high returns of investments are expected due to its intrinsic ability to maximize efficiency, reduce the operational costs and increase profits.

According to several market analyzes – Reports and Data (Indoor Positioning System Market Size & Forecast, 2019-2027, 2019) and IndustryARC (Indoor Positioning and Navigation Market Research Report: Market size, Industry outlook, Market Forecast, Demand Analysis, Market Share, Market Report 2018-2023, 2018), indoor positioning global market is going to grow from 6.92 billion dollars as of 2017 to a value between 23.6 and 24 billion dollars in 2023, at a compound annual growth rate of circa 28%. The pivots of this staggering growth will be the developed countries of North America and Europe, where the largest markets are predicted to be. Since this might get expected as countries like the United States, the United Kingdom, European Union member states or Canada have actively contributed as innovative technology promoters in the past decades, an interesting perspective is coming from Asia Pacific where China, Japan and the Four Asian Tigers are going to be major contributors in this market as well. It is worth mentioning, the greatest compound annual growth rates will be registered in Asia, surpassing by 3, respective 6, percentages the rates in North America and Europe. Overall, the indoor positioning market is expected to achieve a year over year growth of 30.5% in the years to come.

The hereby paper is proposing a software application that is going to endeavor this opportunity and provide a solution for the problem, being both infrastructure free and friendly with the phone battery, providing a proper mixture of both perspectives.

Methodology

For developing a web application that can accurately predict the current location I have firstly proceeded with qualitative research of already proposed software architectures and solutions, read about the limitations my forerunners faced and tried to identify some possible solutions.

As my initiative is intended to be infrastructure free, I have chosen the smartphone as a portable gadget that can collect information about the current location, since nowadays it is

widespread and implies no additional cost. Considering that experiments using the phone camera lead to battery drain and such solutions are not suitable for long time usage, I have investigated the possibility of relying on the sensors already available in modern phones. My inertial measurement unit system consists of three sensors available in most smartphones: accelerometer, gyroscope and magnetometer. Based on the data collected from these sensors I have tried to classify the information acquired in form of constant updates from the smartphone into 3 different states:

- moving target
- stationary target
- stationary target that moves the phone

An effective classification prevents measurement errors and contributes to accurate estimations. With data from the accelerometer, I have computed the acceleration magnitude as the difference between the square root of the sum of squared decomposed accelerations and Earth's gravitational acceleration.

The average step length of an individual required for computing distances was accepted around 65 cm, considering the findings in the following studies. (Diaz, Disdier, & Labrador, 2018) (Sayeed, Monsonis, Catala, & Cabestany, 2013). Integrating the data from the gyroscope and the magnetometer I have used an attitude and heading reference system implementation to compute orientation relying on generic web sensors API. (Waldron, Pozdnyakov, & Shalamov, 2019)

Having both the average step length and the orientation, the target movement has been recorded and the user could further inspect the path he has followed in respect with some predefined metadata about the building.

The general data flow of the proposed solution is detailed in Figure 1.

Figure 1. Data flow in the application.

Source: Authors' own research contribution

Results and discussions

Using the information gathered in the qualitative research phase, I have further integrated the findings into an experimental study consisting of a client-server architecture that tries to estimate the current location of a user indoors. A server hosted remotely exposes an endpoint that the client can access from the browser. Once opened, the client webpage acquires data from the physical sensors via the web sensors API and sends them asynchronously to the server for processing. This light approach does not involve high battery consumption since the sensors already run in background and asynchronous requests demand far less energy than native application computations. After the server processing part is completed and an orientation estimation is made, it is recorded in a repository as a bundle containing the timestamp, the orientation and the current position. In Figure 2 it is portrayed a tridimensional representation of the attitude and heading for the reference device at a certain moment in time.

Figure 2. Real-time attitude and heading for the reference device.

Source: Authors' own research contribution

The main advantage of this approach is the usability it provides for both the end users and the stakeholders interested in implementing such solution.

The web page opened from the phone browser just sends data with a preset latency to a listening computer and displays static content, like for any regular website. Because the statistical filtration methods and computations are applied on raw data on a different device, the smartphone is saving battery power. Since the goal of this project is to become a viable solution for real life scenarios, an application that drains the battery is not something to consider for long time usage. Persons interested in effective travelling between different points in large shopping centers need a tool that can perform well for couple of hours.

Besides, a software application that is accessible via the internet and provides tracking services is clearly a better solution for large venues than regular grids of sensors. The latter tend to be ineffective in highly dense areas where people crossing might interfere with the signals, noise can be induced and if not deployed properly blind spots might appear. In comparison, the proposed architecture is independent on the external perturbing factors, since the radio waves communication circuits are bypassed. The device collecting data is the same that sends them for processing, which grants high accuracy. Figure 3 illustrates a graphical representation of the followed path inside a building within a limited time frame.

Figure 3. Path followed based on sensors data.

Source: Authors' own research contribution

The application has been tested so far against two different buildings in various motion scenarios like linear crossing, intermittent walking, turns against different angles. Such an initiative opens perspectives in both social entrepreneurship and digital innovation.

On the one hand, an online instrument of this kind allows supermarket managers and shopping mall owners to identify and track the position of customers, determine the time they spend inside each shop and what the most visited areas are. Consequently, marketing departments get access to large amounts of open data that describe customers patterns and thorough analyzes might get done to determine the acquisition likelihood, find additional circumstances that enhance predisposition and understand underlying human behaviors. Moreover, information retrieved from an indoor positioning system can be used to identify correlations between different types of customers, the amount of time they spend shopping and the variety of products they buy, ultimately to pin down proper product placement for increased sales. Nevertheless, a software solution that can accurately track customers inside a building might as well be used for submitting complaints, reporting incidents, damages or expired products.

On the other hand, a guidance application inside large public venues (hospitals, universities, theaters, public institutions) can reduce the time spent trying to find certain rooms/offices, combining societal objectives like fast and accessible public services with modern and impactful management solutions. Routing capabilities can also be provided to help citizens find the shortest path to an exit or guide them in emergency scenarios.

In order to get customers/citizens willing to use such an application, gamification techniques might be introduced as a stimulus for encouraging usage. Treasure hunts, methods for rewarding users, discounts or vouchers granted to those being proactive in reporting incidents can enhance user engagement.

Conclusion

It must be mentioned that this architecture is a proof of concept and there is still large room for improvements. Until now, the solution behaved well inside the test facilities, but it would be naive to consider the application would prove the same level of performance in any other setup. Moreover, the way the information is exposed in the web interface so far is trivial and a more accurate display of the floor plans would represent a plus in terms of user experience. Also, including a neural network component for an intermediary filtration phase (using linear quadratic estimation) for better distinguish between the three states in which the target might be should be taken into consideration.

Anyway, the hereby paper proposes a client-server architecture that uses the latest open source platforms for browser-smartphone sensors interaction, which facilitates a better decoupling between components, allows them to behave as separate services and preserves the energy consumption. Therefore, this approach might be easily extended for crowded areas like shopping centers, hospitals or public venues, where stakeholders can provide routing services for their clients, patients or citizens, which can reduce the waiting time and prevent places from getting crowded as regards public institutions. If perceived as a dedicated service to users that have to log in, the application can also send notifications about promotions or recommendations based on their usual or previous activity.

Compared to traditional localization methods that rely on sensor grids, a software solution is likely to bring better returns of investment in time. In financial terms, the initial deployment costs are lower as you need a server that exposes the localization service for your customers anyway, the maintenance costs are reduced since your single point of failure is the actual computer where the application is installed and you get a flexible solution that can be extended without difficulty. Last but not least, through engaging and intuitive addons the localization service can also act as a reporting platform which will improve the mean response time to given incidents, assuming the customers will use the platform or as a custom tailored advertisement service that can eventually bring more sales and profits.

Such initiatives can simultaneously address individual and business needs using technology for yet stringent social problems, being a relevant example of social entrepreneurship.

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