On Indoor Positioning

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Abstract— **This paper presents the survey of the modern indoor positioning technologies and systems. We discuss Wi-Fi and Bluetooth based positioning systems, light-based and magnetic field systems. It is our first attempt to classify indoor positioning techniques. We try to highlight the advantages and disadvantages of various indoor positioning technologies and systems, compare their accuracy, applicability, working principles and performance parameters.**

Keywords—**indoor positioning, Wi-Fi, Bluetooth, light, magnetic, inertial navigation.**

I. Introduction

Due to the signal attenuation caused by construction materials, the satellite based Global Positioning System (GPS) loses significant power indoors. In addition, the multiple reflections at surfaces cause multi-path propagation serving for uncontrollable errors. So, indoor positioning requires own techniques. Actually, we should avoid any solution which uses electromagnetic waves from indoor transmitters to indoor receivers.

An indoor positioning system (IPS) is a solution to locate objects or people inside a building using radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices [1]. There is no de facto standard for IPS design.

This paper presents our first attempt to classify indoor positioning techniques. We would like to cover the following approaches: Wi-Fi indoor positioning, Bluetooth beacons, light-based systems, sound-based systems, magnetic systems and the usage of mobile cameras for indoor positioning.

II. Wi-Fi positioning

Wi-Fi indoor positioning can be divided into two main categories. One category is based on wave propagation and relies on computing distances among mobile devices and points whose coordinates are known. The second category is based on mapping by combination of signal strength measurements and geographical coordinates, called a radio-map [2].

Locating a mobile device with a radio-map consists in matching a measurement with some point of the radio-map. This matching could be either deterministic [3] or probabilistic [4].

For the first category, indoor positioning systems measure distance between transmitter and receiver based on RSSI (Received Signal Strength Information). This distance computation requires radio wave propagation modeling to express distance according to signal strength value. By our estimation, this approach is rarely used in the modern mobile services (at least in its pure form).

In general, Wi-Fi radio-map based positioning includes two phases: the training phase where the wireless map of the environment is determined using field measurements and the positioning phase where position estimation is performed based on the wireless map. Most of the existing approaches need readings from at least 3 Wi-Fi access points at each location to provide sufficiently accurate estimates of position. There is an interesting approach in [5] for using only one Wi-Fi access point.

The training phase is the main obstacle for this approach. This phase is an offline process and it needs to be redone if there have been major changes to the wireless propagation environment (e.g., relocation of access points, redesign, etc.). Building a signal strength map by measurements implies moving physically to every location on the map and performing a measurement. Technically, we can use the simulation for some wave propagation model, but any such model cannot take into account the existing indoor obstacles.

When a signal strength map is available, mobile positioning is achieved by matching the map content with a signal strength measurement provided by the mobile or the wireless network architecture. Such matching is either deterministic or probabilistic. In deterministic techniques, location area is subdivided into smaller cells and readings are taken in these cells from several known access points (the training phase). In the positioning phase the most likely cell is selected, i.e., the cell that best fits the current measurement. Probabilistic positioning techniques use a probability distribution of the user's location in the area of the movement. The goal of the positioning is to reach a single mode for this distribution, which is the most likely location of the tracked.

In passive Wi-Fi localization, we can use beacon frames distributed by the mobile terminal [6]. In this case Wi-Fi access points (Wi-Fi router) receive and analyze signals from mobile devices. The positioning is possible for several measured devices being deployed simultaneously.

We should mention in this connection a very promising (by our opinion, of course) area of proximity based services. This area is described in several our papers [7,8]. For many applied task the positioning is actually not a goal. Data about positioning are simply used further for obtaining any information (service). The main idea behind proximity-based services is to link information snippets (services) directly to network measurements and avoid costly radio-map preparation and training.

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III. Bluetooth beacons

Bluetooth low energy (BLE) as a technology started as a project in the Nokia Research Centre. Later it was adopted by the Bluetooth Special Interest Group [9]. Apple has been embedding Bluetooth Low Energy in its devices since iPhone 4s. Since iOS7 release, Apple has released iBeacon API. It is programming interface to low energy sensors from Apple (iBeacons). De-facto, iBeacon technology and Bluetooth beacons became synonyms. Of course, there are several other vendors except Apple. E.g., Estimote, Qualcomm [10]. Figure 1 illustrates the main idea behind iBeacons [11]

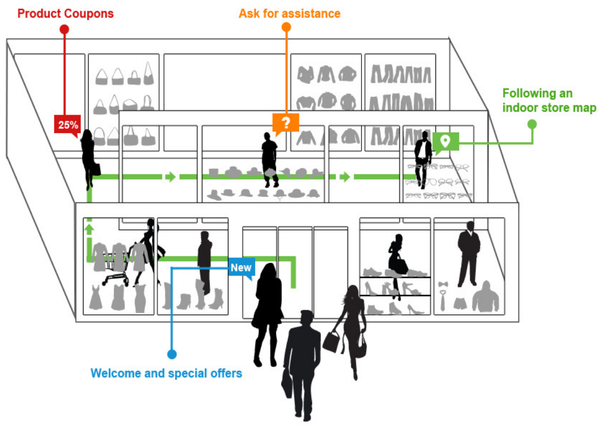

Fig. 1 iBeacons on practice [12]

De-facto, iBeacons technology looks like a typical network proximity based service. A mobile client will get data (it may not necessarily be push notification only) depends on the proximity to some network node (Bluetooth tag). For the classical positioning task the use case here looks similar to the above mentioned Wi-Fi based positioning. Technically, we can use both triangulation and trilateration with several iBeacons. We can talk about a radio-map for installed iBeacons, etc.

In this connection we should mention about a new E911 initiative. On January 29, 2015 the FCC adopted measures that will provide a solution to accurately identify the location of wireless 911 callers when the caller is indoors. The FCC is requiring carriers to provide more accurate indoor location information by 2018. The carriers will be required to provide location accuracy in the horizontal location (i.e., address) and vertical location (i.e., floor level) [13]. This Indoor E911 regulation will propels the indoor location-based services industry that consists of Wi-Fi and BLE beacon (iBeacon) solutions.

The next remark targets Bluetooth tags. Let us see the core idea of iBeacons. We have some constant broadcast data stream and a set of receivers. We need BLE just because broadcasted devices have no external power. But any Core Bluetooth node in discoverable mode is also a broadcaster. We can treat the MAC-address as a UUID [14]. In other words, a Bluetooth node in the so-called discoverable node (it is visible for other devices) is a tag too. E.g., many modern cars have Bluetooth nodes. So, we can treat them as tags too [15]. It could be a real replacement for BLE tags. Especially, when Bluetooth nodes (tags) are created directly on the mobile phone (Figure 2).

Fig. 2 Bluetooth node observed by mobile phone

IV. Light

This technology would operate based on the instantaneous response of LEDs in on-off cycles that could transmit data to the camera of a smartphone without humans detecting the light changes. The customer would presumably download an app to utilize the technology. The communication link from luminaires to the smartphone would deliver the location data and other offers (Figure 3).

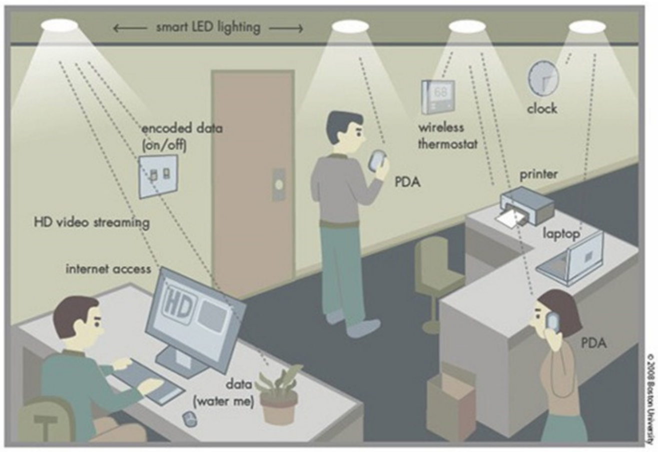

Fig. 3 LED communications [16]

As examples of such systems we can mention papers [17 – 19]. The key moment here, of course, the application, required for “light” reading (it should be preloaded) and lack of standards.

V. Sound

Audio-based localization uses sound signals transmitted from known locations. They can be used to determine the position of a moving sensor (e.g., a mobile device with a microphone) through the analysis of the received sounds from these sources. At any point of time, the relative position/orientation of the sources and sensors can be calculated using a combination of information that is known about the sources and derived from the signals captured on the sensor or a sensor array [20].

The sound-based positioning approaches require no additional infrastructure to perform indoor positioning.

Passive sound fingerprinting uses ambient sound to generate position estimates, whereas active fingerprinting approaches emit and then record a specific sound pattern for the positioning [21].

The authors in [22] have developed a mechanism that can identify the different rooms based on a relatively small dataset gathered in advance. Their system is essentially a form of echolocation. Emit a sound and then listen for the return which will be distorted in a way that depends on the size and shape of the room, the materials on the walls and floors as well as the furniture and people within it.

The *RoomSense* system emits a short acoustic wave and measures the impulse response. This response is further processed as a sound fingerprint of a within-room position and eventually the extracted sound features are classified to estimate room and within-room position. The sound pattern models of room positions are derived in a training phase based on annotated acoustic impulse response data [21].

In the paper [23] authors consider the problem of estimating room geometry from the acoustic room impulse response (RIR). Most of the existing approaches addressing this problem exploit the knowledge of multiple RIRs. In contrast,

The authors in [23] are interested in reconstructing the room geometry from a single RIR.

And the practical pioneer in sound-based mobile services area is Shopkick [24]. Shopkick created a highly accurate inaudible audio signal that is unique to each store that can be detected by smartphone users who have the Shopkick application installed, when the app is open.

VI. Magnetic systems

This is a relatively new area for indoor positioning. For example, IndoorAtlas [25] uses your phone’s built-in compass and measures the anomalies in the Earth’s magnetic field (Figure 4) to pinpoint your location in a building with the accuracy ranging from 0.1 meters to 2 meters (3.93 inches to 6.56 feet).

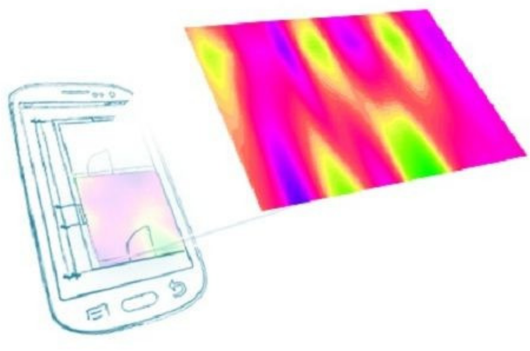

Fig. 4 Earth’s magnetic field anomaly [25]

The idea of magnetic fingerprinting arises from animals that determine their position from local anomalies of the Earth’s magnetic field. Likewise, in buildings, each location has its unique signature of its magnetic flux density.

These fluctuations in space arise from natural and man-made sources, such as metal building material, electric power systems and industrial devices. As a result, each location has its unique signature of its magnetic flux density [26].

The above-mentioned anomalies of the magnetic field usually have a sufficient variability in space. It lets detect them by a magnetometer. With the assumption that magnetic field indoor is approximately constant (actually, the similar assumption we did for wireless sensors) we can define magnetic fingerprints. So, instead of radio-map we can use magnetic map. And for positioning we can use the same approach as with wireless radio fingerprints. We can compare the current flux density with the flux density values stored in the database.

Technically, we can artificially add magnetic tags (beacons) and create a magnetic map for them. The biggest issue here is again the preliminary scene preparation for the future positioning. As well as the need to constantly maintain an initially obtained map in the valid state.

VII. Camera based systems

There are several aspects of usage of mobile cameras (smartphones with cameras) for indoor positioning. One of the oldest approaches are QR-codes. 2D barcodes could be recognized by mobile cameras. The recognized data source could be a navigation map, a text information, etc. The software for QR-code recognition can obtain information about the mobile device. Also, we can use context-related information during the scanning. As an example we can mention our paper [27].

For augmented reality application QR-codes could be replaced with images [28].

The more generic approach is an analogue for the above mentioned fingerprints (image-map). The camera-phone (mobile user) captures images and sends them to a web server. The web server has a database of images with their corresponding location. Upon receiving an image, the web server compares it with stored images, and based on the match, estimates the user’s location [29]. As the practical implementation we can mention [30].

The authors in [29] claim that room-level accuracy can be achieved with more than 90% probability, and meter-level accuracy can be achieved with more than 80% probability. The key advantage of using this approach is that it does not require any infrastructure. Neither custom hardware, nor wireless access points are required. But, of course, we need to provide a “mapping” (collect images a priori). And of course, this should be constantly maintained in order to keep the image base in the actual state.

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