Exploiting Smartphone Sensors for Indoor Positioning: A Survey

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***Abstract*—Due to an increase in the demand of context-aware applications, there is a higher requirement for an accurate user location information. Todays mobile devices contain embedded sensors like gyroscope, accelerometer and electronic compass. Researchers are exploiting these sensors to estimate user position and location in different environments. This paper surveys the latest trends of using these sensors for indoor mobile localization.**

I. Introduction

Recent advances in mobile devices, embedded sensors and hardware makes it possible to envision a large scale wireless network of smart devices. Today's smartphones are programmable and come with a set of cheap yet powerful embedded "sensors", such as a GPS receiver, accelerometer, gyroscope, digital compass, microphone, and camera, which are enabling a new generation of personal and participatory sensing applications. Each device can be viewed as a "virtual lens" acting as eyes and ears for surrounding physical space [12].

The smartphone is emerging as the main technology platform in the mobile marketplace with the number of users expected to exceed one billion by 2014 [19]. The so-called third screen is increasingly finding itself at home alongside the TV and computer screens. Research has found that 60% of mobile web usage is now taking place indoors, bringing smartphones closer to the promise of being "always on" devices [10]. So we see Mark Weiser's vision becoming a reality [29].

Apart from the advances in mobile devices we also saw a worldwide growth of Internet users due to which the networking technologies and infrastructure evolved to an extend of what we have now and it continues to improve as the user demand increases. This new level of ubiquitous network connectivity and pervasive devices have enticed a new category of context-aware applications. Context is any information which can be used to characterize the situation of an entity. An entity can be a person, place or object that is considered relevant to the interaction between a user and an application including the application and user themselves. Hence, smartphones bring us new opportunities to exploit user context, and make innovative mobile applications.

In the next section we discuss the importance of location as a context. In the third section we discuss the different available technologies for localization. In the fourth section we survey recent system in Mobile localization which exploit the sensors in smartphones. We discuss the evalution and performance of these systems in section five and conclude in section six.

II. Location as Context

There are various aspects of contexts that can be useful to personalize the service to the user. User identity, orientation, history, time, purpose of use, physical surroundings, system properties, social and cultural situation are different areas of context in which research is being done. One of the most important dimensions of context is location. It allows information and services to be localized. A user's location can be physical, logical or both. Physical or absolute location can be described by geo-referenced coordinates whereas logical location is relative, for example, inside a room or near some building. This information can be exploited in a variety of applications for instance, targeted advertisement, geo-social networking, gaming etc. We are already seeing its impact on different industries like tourism, marketing, information and emergency services. Recent years has witnessed the explosion of location based applications (LBAs) with the iPhone App Store alone having over 6400 LBAs [26]. The Android Market also has around 1000 LBAs with many applications being added on a daily bases [26]. Loopt [4], GeoLife [14], Foursquare [3], Dodgeball [1] and more recently Facebook Places [2] are a few examples which exploit location information of the user in their applications. With advances in mobile commerce and the further development of software related to mobile location, the LBAs market is forecast to reach $21 billion by 2015 with over 1.2 billion subscribers [5]. Researchers have been working on Location Based Serivices (LBS) for the past few decades and we see their applications in the form of vehicular tracking and other navigation based services. However, due to the growth of mobile devices, new opportunities and challenges have come to surface.

III. Overview of Current Localization Technologies

GPS [11] based localization systems are widely successful in outdoor applications but they are not precise for indoor environments since microwaves will be attenuated and scattered by roofs, walls and other objects. As satellites signals become Non Line Of Sight (NLOS), the Time to First Fix (TTFF) and Time to Subsequent Fix (TTSF) become larger and hence the responsiveness of the system decreases.

There are several range-based techniques such as Time-Of-Arrival (TOA), Time Difference Of Arrival (TDOA), Angle-Of-Arrival, and Received Signal Strength Indication (RSSI) to estimate the distance from a particular node. Absolute location then can be computed using Triangulation, Trilateration, Fingerprint matching or other probabilistic methods.

Using the above mentioned techniques, some Cellular [27] and Wi-Fi [22] based solutions are proposed which are less accurate than the GPS but give better performance in indoor environments. Place Lab [6] creates a wireless map of a region by war-driving in the area. War-driving is an act of driving around different location with an antenna to collect wireless radio information of existing wireless networks. The wireless radio map is composed of sampled GPS locations, WiFi Access Point (AP) MAC addresses with RSSI and cellular towers cell-ids at these locations. When a user travels through the mapped area, it scans for beacons from such AP's and cellular towers. The list of collected information is then compared to the wireless radio map available to estimate its location.

Active Badge [28] is one of the early centralized indoor personal positioning system making use of the infrared technology. However, due to its limited range and propagation problems caused by obstacles Active Bat [13] was developed which used ultrasound pulses. The Cricket [21] location system uses a proximity-based lateration technique to calculate the absolute location by computing the difference between the arrival time of radio frequency (RF) signals and and that of ultrasound. There are also systems available which use RFID and UWB technology for locating objects inside the building.

Computer vision has also been used in localization. Microsoft's Easy Living [17] uses real-time 3D cameras to provide stereovision-positioning capabilities in a home environment. Design based on phone cameras [24] is also attempted yielding decent results at the room level but the performance deteriorates in areas like corridor corners.

Amongst all the localization technologies mentioned in this section, WiFi/GSM based solutions are more popular. Skyhook collects raw data from Wi-Fi access points, GPS satellites and cell towers. It then uses advanced hybrid positioning algorithms to determine device position with 10 to 20 meter accuracy. These types of solutions are feasible for indoor environments and a valuable enhancement to GPS based localization, as they reduce location acquisition time significantly. However, there is still room for considerable improvement.

Skyhook currently employs hundreds of drivers who continiously war-drive to create GSM/Wifi maps of new regions and update the existing ones. Still, there is large area of space which remains uncovered, including walking paths, shopping plazas, apartment buildings, parks and other indoor enviroments.

Relaying on Skyhook like solutions has another problem. As they are dependent on GSM/Wifi infrastructure, large portions of the world doesnt have such radio coverage. Hence, these solutions are not scalable. Furthermore, there is a serious tradeoff between localization energy and accuracy [9]. GPS is more accurate then WiFi based schemes but it consumes more energy than both WiFi and GSM based localization. Figure 1 shows the power consumption comparison between GSM, WiFi and GPS.

Fig. 1. Power Consumption among different technologies [9]

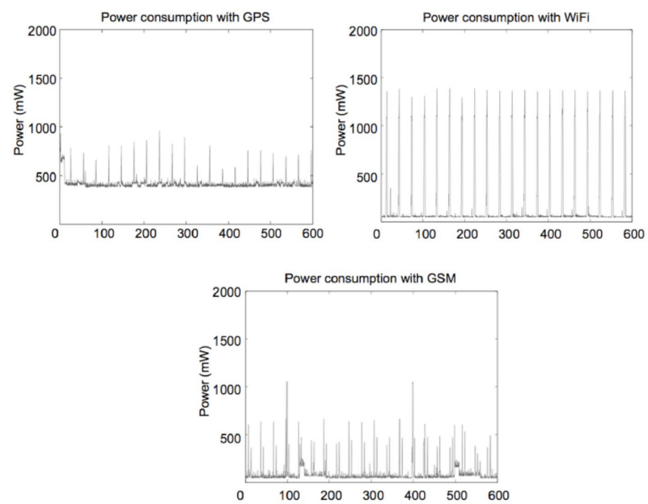
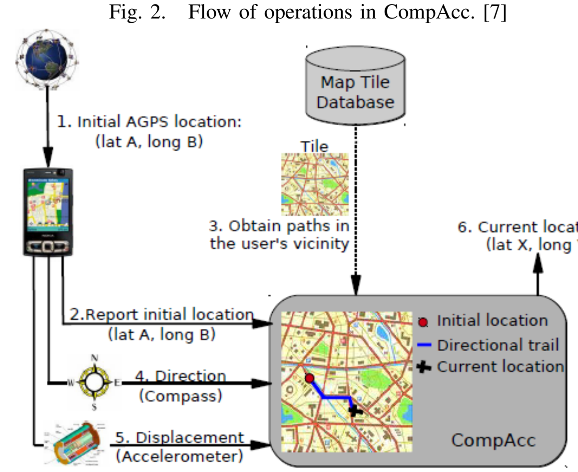


Fig. 2. Flow of operations in CompAcc. [7]



IV. Sensor Driven Indoor Positioning

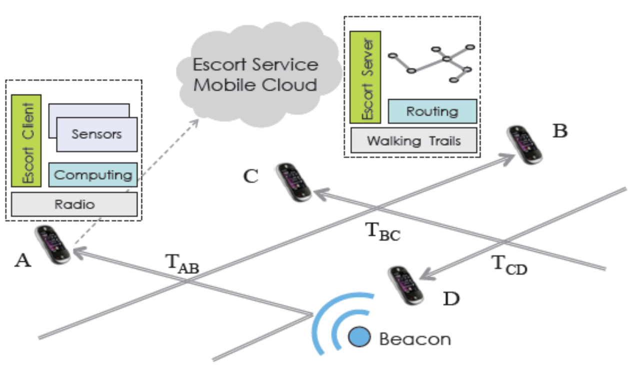
The proliferation of mobile phones is motivating researchers to look at other ways for more reliable and energy efficient indoor positioning of users which are not only accurate but also scalable. To minimize deployment and infrastructure costs, different techniques and technologies are being explored. In robotics, mobile devices typically use initial sensors, laser rang-finders and computer vision to provide accurate localization without the requirement of fixed infrastructure. One type of sensor which seems applicable to people tracking is inertial measurement units (IMUs). Accelerometers and Gyroscopes are being embedded in most of the latest smartphones. Accelerometers measure the 3D linear accelerations of the device whereas gyroscopes give the rotational accelerations. Most of these modern devices also include a magnetometer which can give raw magnetic readings and heading information.

Several papers have studied activity recognition using accelerometers [23] [16][15]. Others researchers have investigated Pedometer based Pedestrian Dead Reckoning (PDR) techniques [30][25][7]. Woodman and Harle showed that a foot mounted IMU can be used to track a user in a multi-floor building with 0.5m accuracy 75% of the time. They assume that the user doesn't know its starting positioning.

CompAcc [7] is a scheme which deals with mobile phone localization without war driving. It uses electronic compasses and accelerometers in mobile phone to record persons walking patterns and matches it against possible path signatures generated from digital maps. Although CompAcc [7] was evaluated outdoors as it uses GPS correction in their implementation, it has great potential for indoor environment. CompAcc was tested offline as at the time a smartphone with both compass and accelerometer was not available to the authors.

Escort [8] is a war-driving free navigating system for social environments to route humans to others in an indoor setting. The system uses a beacon which transmits an audio tone. Any mobile phone, when passing near this, can register itself. This beacon then becomes the origin of a virtual coordinate system, where user path signatures and spatial intersections represent an edge and a vertex of a graph, respectively. This graph keeps track of user location and their trails. Using this graph, a general map of the location can be built to locate humans and route them to their destinations.

Fig. 3. The overview of the Escort system: Users report accelerometer and compass readings as well as user encounters; The server forms user trails. [8]



Some researchers argue, that physical location alone, unless remarkabaly precise, may not be sufficient to express the cotext of the user. For example (figure 4), in a scenario to identify two logical locations separated by a dividing wall, Martin et al. [18] argue that even an idealized high accuracy localization scheme can place the user on the wrong side of the wall. AAMPL [20] uses GPS and google maps to shorlist possible logical locations and then use accelerometer data to classify different logical locations.

Fig. 4. Dividing wall problem [18]

Surroundsense [18] exploits diversity of a place by sensing the unique ambience of the surrounding from sound, light, color, human movement and Wi-Fi signals to create a fingerprint. This fingerprint can be matched from fingerprint database to identify the logical location. Such a solution is feasible but not scalable because it is very difficult to maintain such a database as war-sensing would be required for every logical place. War-sensing is similar to war-driving where the sensed information from the environment, for example light intensity, noise, temperature etc is collected from all the logical locations by physically going to all locations.

V. Performance Evaluation of Sensors based Positioning Systems

Woodman and Harle evaluate their system compared to BAT which is accurate upto 3cm 95% of the time. They consider BAT system to be the ground truth and match the positions. Their system gives an error less then 0.73m 95% of the time. Although they use foot mounted IMU, this kind of results is very promising for smartphone based IMUs. The IMUs in smartphones are much cheaper hence less accurate and more sensitive to noise. But human centric application doesnt need to be that accurate as humans can tolerate errors of a few meteres if their context is fully satisfied.

Similarly Compacc [7] was evaluated as compared to Skyhook. Compacc's performance is much better then skyook which is biased towards roads and streets. Energy consumption of Compacc is also much better than Skyhook and AGPS according to their investigation. Although their system is not ready for deployment for a number of issues, but their results are very encouraging for similar indoor systems.

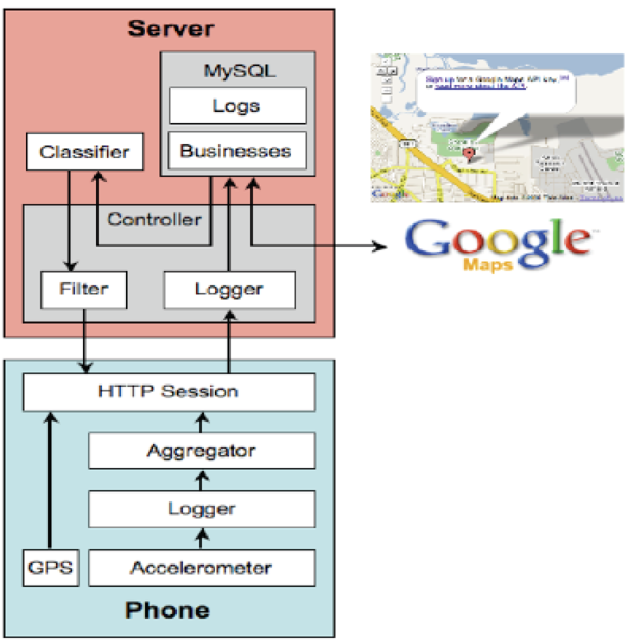
In SurroundSence [7], authors compare the results of Wifi based localization and variants of their system. One which uses sound, accelerometer, light and color, second which uses sound,accelerometer and Wifi and the third which uses all the sensors combined to create an ambience fingerprint.

SurroundSence achieves an accuracy of 87% of accurately identifying the correct logical location.

VI. Conclusion

In this paper we have discussed importance of location as context. We gave a small overview of different technologies available for localization. Through this survey we explore the latest trend of using smartphone sensors for physical and logical localization. The evaluation and performance of such systems are encouraging for researchers but further research has to be done to tackle the challenges and limitations of such systems. A possible future direction would be to explore sensor based positioning systems in locations where Wifi infrastructure is not well established like tunnels, basements and other areas where there are no RF signals or are sporadic in nature.

Fig. 5. Block diagram of the AAMPL architecture [20]



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