

High-scalable 3D indoor positioning algorithm using loosely-coupled Wi-Fi/Sensor integration

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Abstract— This paper proposes high-scalable 3D indoor positioning algorithm in commercial smart-phone by combining two complementary technologies, Wi-Fi and sensor based positioning. Because a smartphone usually has low-grade MEMS sensor and heterogeneous Wi-Fi chipset, it's very difficult to achieve the globally bounded position in scalable indoor environment. Furthermore, the deployment of wireless infrastructure, e.g. Wi-Fi, is hardly controlled by LBS service providers due to the gigantic set-up cost and time. Considering this limitation, the proposed solution is most realistic and opportunistic positioning method, in especially large and complex indoor environment. Firstly, our indoor LBS platform is summarized for understanding the high-level architecture. Then the principle and concept of this proposed algorithm is described. Finally, the experimental set-up and its results are analysed and its successful achievement are presented from about half an hour test scenario.

Keywords— Indoor, Positioning, Scalability, Loosely-coupled, Wi-Fi, Sensor

I. INTRODUCTION

Year after year, the explosive growth in wireless internet services which have been encouraged by various mobile applications such as e-mail, social network service, e-commerce, video streaming etc., brings the global expansion of smart-phones. Smart-phone can provide wireless communication using a variety of infrastructure (e.g. WCDMA, LTE, LTE-Advanced etc.) but also seamless positioning using in-built sensors (e.g. GNSS, accelerometer, gyroscope, magnetometer, barometer etc.) and short-range node (e.g. Wi-Fi, Bluetooth low energy(BLE), near field communication(NFC) etc.).

In case of outdoors, GNSS or Assisted GNSS provides mobile users with standardized location information in the global coverage. In case of indoors, however, there have been several competitive candidates for commercialized indoor localization and Wi-Fi positioning system (WPS) has been in the lead due to the enormous deployment of Wi-Fi access points from mobile network operators (MNO).

Unfortunately, the accuracy or availability of WPS suffers from its dependency on the density and distribution of Wi-Fi APs in its specific indoor service area. To reduce its degradation of location performance, unsupervised as well as supervised Wi-Fi APs have been utilized to make more sensible location database (DB), e.g. fingerprinting DB or

APs' location DB [1-3]. Nonetheless, this consideration of environmental factor has little or no effect on the enhancement of location performance in Wi-Fi rare or dead zone. Furthermore, even the additional installation of Wi-Fi APs can easily increase the location performance, MNOs or service providers cannot afford the time and expense of their deployment.

To minimize the WPS's environmental dependency on the overall location performance, we propose one algorithm for robust and scalable indoor positioning using smart-phone. The basic idea includes the location-level combination of pedestrian dead reckoning (PDR) and Wi-Fi fingerprinting by using loosely-coupled Kalman filter. This complementary property of two location information enables users to locate themselves accurately and robustly regardless of the constellation of Wi-Fi APs and the accumulation of sensors' error.

In this paper, we firstly introduce our indoor location based service (LBS) platform which consists of three parts (data collection, location DB construction, localization). We then describe the principles of proposed positioning algorithm not only horizontal but also vertical location. Finally, we evaluate our algorithm experimentally in large indoor complex environment so that its combination of complementary indoor technologies can evolve users' operation time and coverage while its accuracy is bounded.

II. OUR INDOOR LBS PLATFORM

A. Data Collection Processes

As a first step in our LBS system, wireless infrastructure and sensor information should be scanned and saved for constructing location DB. To reduce the collecting time and surveyor's cost, we suggest the smart-phone based dynamic surveying technology (called WARP-P [4]), which combines wireless signal and sensor information with locations of collecting points.

The positioning accuracy of collecting points is estimated to be bounded less than 3 meters when surveyors travel 100 meters distance away. The concept diagram and detailed output flow of data collection process are shown as bellow.

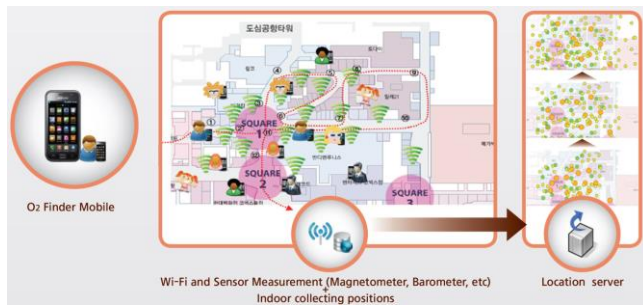


Figure 1. A concept diagram of data collection process

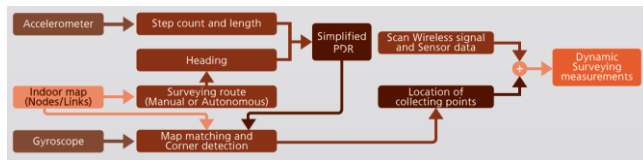


Figure 2. A detailed output flow of data collection process

B. Location DB Construction Processes

When the data collection process is completed and all scanned data is uploaded to the server, location DB is ready for construction. The location DB construction S/W loads and filters the raw collected data and checks positions of the collected data and separate the target indoor area into several cells. Then it analyses the data of a cell to calculate heat-map of each measurement type. The supported measurement types are Wi-Fi RSSI, magnetic field, barometric pressure etc.

The benefit of our S/W is to quickly generate location DB in the service area just after data collection process. This rapidity enables the service provider to make a cost-effective location DB and to save working-hours by evaluating a user's location performance just after the location DB process is done.



Figure 3. A concept diagram of location DB construction process

C. Localization Processes

Before localization process, not only location DB, which can include AP position DB and Radio-map DB, but indoor map DB of the service area are downloaded to the target device via internet. In our LBS system, UE (User equipment) based positioning is primarily supported and several indoor positioning algorithms can be executed. In this paper, we only focus on the hybrid positioning algorithm based on loosely-couple Kalman filter. The detailed explanation of proposed algorithm will be described in the next section.

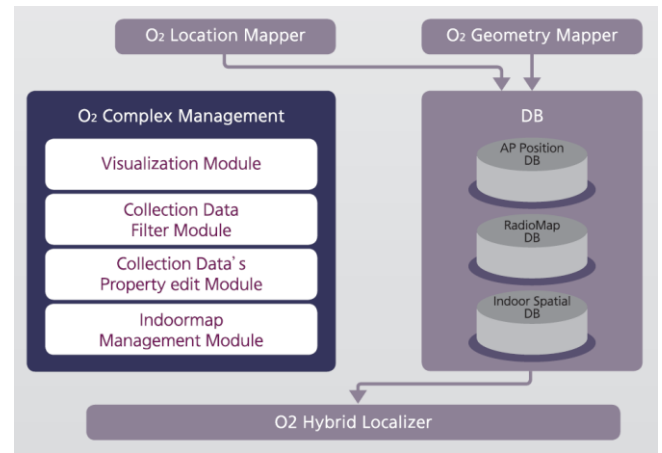


Figure 4. A concept diagram of localization process

III. LOOSELY-COUPLED WI-FI/SENSOR INTEGRATION

In this research, two complementary positioning methods, Wi-Fi and PDR (Pedestrian Dead Reckoning), are combined to provide more robust and accurate position in a scalable indoor environment. Wi-Fi based positioning using fingerprinting (or heat-map) can provide absolute location even the large variance of location estimate may be calculated due to the complexity of indoor environment. While PDR based positioning can provide relative location so that the initial absolute position should be calculated or supported. It also has the benefit of short-term positioning accuracy but the position error is accumulated due to a bias and drift error of sensors over time.

Considering these complementary characteristics, the best approach is to compensate Wi-Fi for PDR. In outdoors, GPS (absolute location) and DR (relative location) using automotive sensors are generally combined to overcome the deterioration of GPS position accuracy in urban canyon areas. However, in indoors, the combination Wi-Fi with PDR needs to be more evaluation when considering the low quality of MEMS sensor in smart-phone, diverse users' motion state and unforeseeable wireless signal propagation in indoors.

In this paper, we propose high-scalable 3D indoor positioning algorithm, which general architecture is shown in bellows. The applied filter is loosely-coupled Kalman-filter. In case of time update, a prior 3D location estimate is modelled to a present 3D location using PDR and barometer based height estimation. In case of measurement update, 3D location (X, Y, Floor) calculated from Wi-Fi fingerprinting engine is used as a measurement.

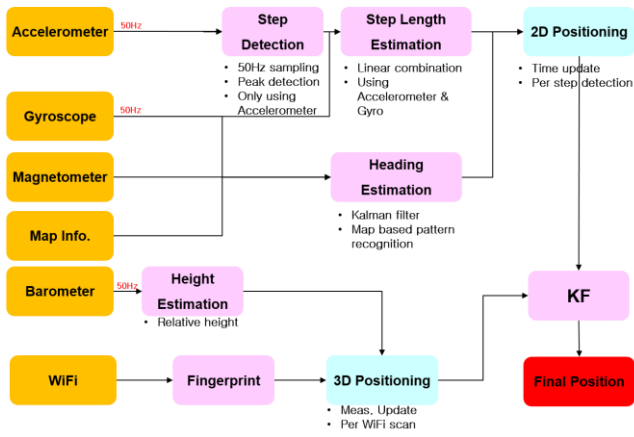


Figure 5. A concept diagram of loosely-coupled Wi-Fi/sensor integration algorithm

IV. EXPERIMENTS

For verifying the proposed algorithm properly, we select one of the largest complex malls in Korea, where the scalability and robustness of indoor position are reasonably tested due to its complex indoor environment and lots of visitors. The detained specification of our test-bed is described in bellow table.

TABLE 1. SPECIFICATION OF TEST-BED

Test-bed	COEX (complex mall)
Test Floor	1- 4F
the area size of each floor approximates	About 36,364m2
Complexity of indoor structure	High

Also, the configuration of test devices, applications and maps are summarized in the next table.

TABLE 2. SPECIFICATION OF TEST CONFIGURATION

Phone	Samsung Note 1
OS	Android
Supported H/W	Wi-Fi, Accelerometer, Gyroscope
Scan rate	About 1Hz(only 2.4GHz scanning)
Indoor map	2.5D indoor map from our dedicated authoring tool
configuration	Adaptive step length supported

The test scenario is designed for evaluating the sustainability of long-term positioning accuracy. The bellow

figure is shown a test route, which includes go forward – 5 turns – go backward scenario. The straight path is intended for verify the accuracy of linear pedestrian motion and the repeated 5 turns is for testing whether a user's positioning error is bounded or not when complementary filter is applied in scalable indoor environment.



Figure 6. A test scenario of the test-bed

V. TEST RESULTS

Test experiment is conducted in test-bed along with proposed test scenario. In case of the proposed test scenario, the elapsed test time is about 22 minutes and its distance traversed is about 2,114 meters. Also these tests were repeated while each Kalman filter tuning parameter (e.g. covariance value of measurement innovation) and devices are differently applied. Below figure shows the result of overall position trajectory. In case of straight course, the position is well estimated along with corridors in both forward and backward motion. In case of 5 repeated turns, 5 trajectories are all bounded relative to a ground truth path even though the positioning errors are exceptionally increased due to inaccurate Wi-Fi location in some Wi-Fi rare or dead zone.

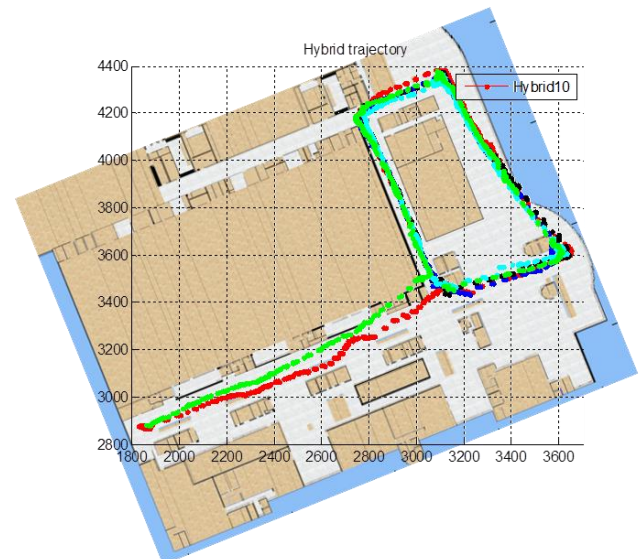


Figure 7. The qualitative positioning accuracy of the proposed Wi-Fi/Sensor loosely-coupled Kalman filter

VI. CONCLUSIONS

The proposed high-scalable 3D indoor positioning algorithm using loosely-coupled Wi-Fi/Sensor integration is implemented. Wi-Fi location is estimated by using location DB, which is generated from dynamic surveying data. PDR is used as time update model to overcome the imperfection of pedestrian motion modelling. By applying the simple but complementary loosely-coupled Kalman filtering, the test results show that the provision of a robust and accurate 3D indoor location is achievable in a scalable indoor environment. Furthermore, the test evaluates that its estimated position is more smoothed and frequently updated and its position is generally bounded. In sum, this proposed method can provide most promising location based mobile services with long enduring, scalable and environmental independent location information.

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