A New Indoor 3D Positioning Approach Using Single WiFi AP

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ABSTRACT

A feasible economic technique for indoor positioning using the received signal strengths (RSSs) of mobile devices and Global Positioning System (GPS) orbital data was developed in this study. The RSSs transmitted from a Wireless Fidelity (WiFi) access point (AP) must be detected by a mobile device and transformed into the near light-of-sight (LOS) ranges with a self-adoptive model defined for a specific indoor area. A new approach using a single WiFi AP and four selected GPS satellites was proposed and tested for indoor positioning. The WiFi-detected range and the GPS orbit-computed range can be combined into a geometric range and applied in GPS-like positioning. To absorb the biases related to the non LOS, a linear fitting and removal process was accompanied. The test results showed an 85% success rate with average positioning errors of 3.7 m and 2.0 m in the plan and vertical components, respectively. This WiFi/GPS hybrid approach has shown potential for accurate and reliable indoor 3D navigation positioning.

Keywords: indoor positioning, WiFi ranging, GPS orbital data, linear bias fitting

運用單具 WiFi 發射點的室內三維定位新方法

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摘　　要

本研究提出一項利用行動裝置獲取信號接收強度並配合 GPS 軌道資料，以進行室內定位之便捷技術。由單一 WiFi 發射點所發送的信號接收強度由行動裝置感測後，透過該特定區域之一組自適化模型轉化為近直視距離，再配合所選定之 GPS 衛星位置，即可進行室內空間之三維定位作業。此一組合式之定位方法，係運用 WiFi 感測距離與 GPS 軌道計算距離進行幾何空間距離之組合，在效益上可使用最少數量之 WiFi 發射點布設條件，配合 4 顆固定之 GPS 衛星位置，即可進行類似 GPS 的室內導航定位。實際定位時，另須引入線性偏差的擬合及移除程序，以吸收與非直視距離相關之偏差量。由現地測試成果可知，新方法的定位成功率為 85%，平面及垂直方向的定位誤差則分別為 3.7 公尺及 2.0 公尺，顯見此一運用 WiFi/GPS 的組合定位法，已在室內三維導航定位上，具備足夠精度及可靠度之應用潛能。

關鍵詞：室內定位，WiFi測距，GPS軌道資料，線性偏差擬合

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Ⅰ. INTRODUCTION

Wireless networks and mobile devices have been rapidly developed and applied in both the daily and professional lives of people. The functionality of mobile positioning has also been employed by an increasing number of mobile users [1, 2]. In recent years, the satellite-based GPS has become a crucial location-awareness system operated by most mobile devices. However, the GPS is not sufficient for use in positioning in indoor areas, because the satellite signal is too weak to be effectively received [3].

Two relevant techniques based on GPS positioning principles, namely GPS pseudolite (PL) and assisted-GPS (A-GPS), are potential applications for indoor positioning. Ground-based GPS PLs can transmit a GPS-like signal to enhance the availability of the GPS system in indoor environment [4]. In addition, a wireless handset with an A-GPS chip to receive assistant information from a wireless network infrastructure consisting of base stations can overcome the weak GPS signal in indoor areas [5]. These GPS-based location-awareness systems have made indoor positioning possible, but the cost and infrastructure required are still a problem for the service provider or mobile users. In other words, a lightly equipped and easily operated indoor positioning approach is expected for further development.

Because the popularity of wireless networks is growing rapidly, network equipment, such as WiFi, and miniaturized multi-sensors, such as GPS, can be used to conduct seamless positioning to cover both outdoor and indoor spaces; and expand the value of location-based services (LBS) [6, 7, 8]. However, most of the research used WiFi or GPS for stand-alone positioning in absence of one other kind of signal reception, or implemented WiFi and GPS for integrated positioning in the cases of insufficient number of signal sources [9, 10, 11]. In this study, single WiFi AP was employed as the only signal-transmission devices for ranging. An operation structure using pre-downloaded GPS orbital information and the single WiFi AP was designed to establish the near light-of-sight (LOS) ranges for GPS-like navigation positioning. This hybrid WiFi/GPS positioning approach facilitates avoiding the use of compound devices and is expected to be a feasible, effective and economic indoor positioning approach.

Ⅱ. WIFI-ONLY POSITIONING

2.1 Range Estimation

The WiFi technology applied in this study was a wireless local area network (WLAN) under the framework of IEEE 802.11 that transmitted data through radio waves. WiFi demonstrates many advantages for indoor network access because data transmission can penetrate obstacles and is not limited by angle or direction. WiFi can provide wireless localisation in an indoor environment through the installation of APs that transmit wireless signals and connect a mobile device to an internet service [12].

Wireless localisation was originally based on the connection record of a device to a single WiFi AP to locate the position of a mobile user. However, localisation has commonly been implemented using the RSS between the WiFi AP and the mobile device as an index for location determination. When radio waves pass through the air, signal attenuation caused by a propagation medium inevitably occurs. Because the signal attenuation effect is also related to the range between the transmission point and the receiver, an RSS index can be applied to estimate the signal propagation range [13].

The measurement used in this study is mainly based on the range converted from the RSS using a self-adoptive model and a correction function for improved estimation. The position computation algorithm entailed applying the principle of circular lateration, in which 2D location is determined using the estimated distances from at least three WiFi APs of known location to the mobile station [14]. In general, when more APs are used in location determination, a more accurate location can be provided. However, the location accuracy is limited by many environmental effects, such as signal scattering, attenuation and multipath, mainly caused by the building structure, equipment and other facilities. Past research suggested that accuracy within 10 m is expected for WiFi positioning in indoor areas [15].

A self-adoptive model for range estimation using an RSS index can improve the accuracy of indoor localisation. In this modelling procedure, an experimental field located on the ground floor of an education building in a university was selected (see Fig. 1). In this 83 m x 23 m test area, four WiFi APs were installed to provide a wireless network service. Moreover, 175 data points were established to receive RSSs from the APs with a notebook computer installed with Network Stumbler software. As seen in Fig. 1, the WiFi APs were fixed by university personnel along the corridor with a geometric distribution that was insufficient for 3D positioning using all four APs. Therefore, 2D location using the plan coordinates (x, y) was solved with WiFi-based ranges. To define a local coordinate system, the locations of WiFi APs and data points were all measured with a tape measure at an orthogonal direction of x and y. The reference point of the self-defined local coordinate system with the plan coordinates of (0, 0) corresponds to the upper right corner of Fig. 1.

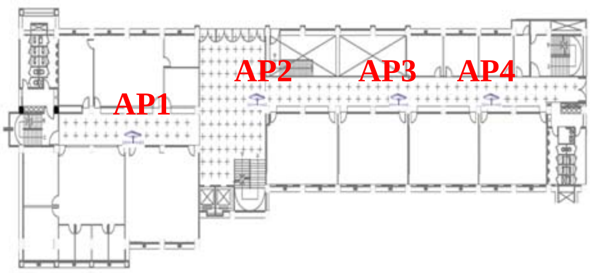

Fig. 1. Sites of WiFi APs and Data Points.

Based on the standard signal attenuation model in Eq. 1, a path loss index (n) plays a key role in indoor signal propagation and must be pre-determined for the test area [16].

$$P(d) = P(d_o) - 10n\log\left(\frac{d}{d_o}\right) + X\sigma \tag{1}$$

In Eq. 1, P(d) is the attenuated RSS, $P(d_o)$ is the RSS at a reference point with a standard distance of d_o (set to be 2.2 m for AP2 and 2 m for others), d is the computed distance from an AP to the data point using pre-measured 3D coordinates, and X_σ describes the random effect of radio propagation in the test area. When the data of P(d) were collected and d were computed between all data points and the four WiFi APs, along with the pre-set parameters of $P(d_o)$ and d_o, the path loss index of n was inversely solved for a value of 1.7 in the test area.

Because the 3D coordinates of the test points and the WiFi APs were measured in a self-defined local system, the spatial distances between each test point and the APs were also established. The range estimation errors were then calculated by comparing these distances with the distances estimated using Eq. 1, in which the measurements were P(d), the constant values were $P(d_0)$, d_0 and n, and the unknown was d. The error distribution revealed that a scale factor of $1/d_0^2$ and a linear bias function of 0.443X+2.3456, where X stands for the estimated ranges without any correction, can be introduced to further reduce the range estimation error. The self-defined adoptive model revised for range estimation was proposed and finalised as follows:

$$d = ((10^{\frac{P(d_o)-P(d)}{10n}} \times d_o) \times \frac{1}{d_o^2}) + (0.4334X + 2.3456) \tag{2}$$

Using this adoptive model, the RMS (Root Mean Square) error of the range estimation was decreased from 10.1 m to 1.1 m in the indoor area, yielding an 89% improvement in accuracy. The ranges estimated using Eq. 2 with the main measurements of P(d) between the locations of WiFi APs and the mobile device were applied in WiFi-only indoor positioning.

2.2 Positioning Tests

As seen in Fig. 1, the geometric distribution of the four WiFi APs was not adequate for 3D position determination. Therefore, only three APs were applied for 2D positioning in the test area. The plan coordinates of all the test points, applying the RSSs received from the nearest three WiFi APs, were obtained using the least-squares computation. The computed coordinates at all the test points were also compared with the pre-measured values to identify WiFi positioning errors. Fig. 2 shows that most of the positioning errors were located within the interval of 4 m to 6 m. The average RMS error for all the test points was 3.83 m and 4.22 m in x and y components, respectively. The 2D vector error of WiFi-only positioning was 5.70 m.

The x component provided a lower RMS error than the y component because the WiFi APs were geometrically distributed along a corridor corresponding to the x direction in the local coordinate system. To investigate the effectiveness of WiFi positioning, four routes designed as Fig. 3 were tested in the indoor test area. It has been seen in Fig. 2 that WiFi positioning accuracy was within approximately 5 m, but the average success rate, listed in Table 1, was only 59%, indicating that more than one-third of mobile stations could not successfully implement WiFi positioning in the test area. Therefore, WiFi/GPS hybrid positioning approach was employed to overcome problems of insufficient accuracy or deficient geometric spacing of WiFi APs.

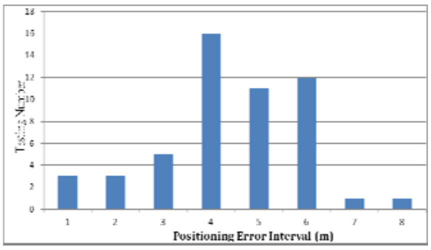

Fig. 2. Distribution of Positioning Errors based on WiFi-only Range Data.

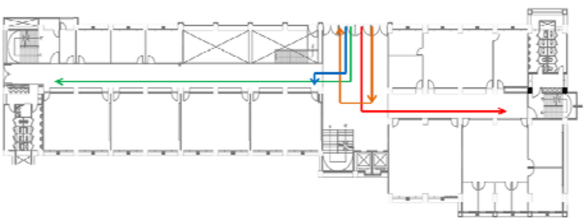

Fig. 3. Four Routes Tested for WiFi-only Positioning.

Table 1 Success Rate of WiFi-only Positioning.

Assessment	Route			
	1	2	3	4
Points/All Points	14/25	8/9	12/19	11/39
Success Rate	56%	89%	63%	28%
Average	59%			

Ⅲ. WIFI/GPS HYBRID POSITIONING

3.1 Range Composition

The use of GPS and wireless networks in location services has drawn increased attention in recent years [17, 18]. The second phase of this study focused on installing less than three WiFi APs in the test area, which is an insufficient number of measurements for standard WiFi range-based indoor positioning. The approach proposed in this paper using a single WiFi AP is an effective solution to this problem. Because GPS orbital data must be combined with a WiFi range for navigation positioning, this newly developed indoor positioning approach is termed WiFi/GPS hybrid indoor positioning.

The range composition of the WiFi/GPS hybrid positioning approach is shown in Fig. 4. In the operation of this approach, a single WiFi AP provides a signal to the mobile device, which converts the signal into a range measurement (R_{RSS}). Moreover, four well-distributed GPS satellites are selected from GPS orbital data to constitute the four range measurements required in the least-squares adjustment for 3D position determination. The instant positions of the four satellites in space are then combined with the 3D geo-referencing coordinates of the WiFi AP to form four geometric ranges ($R_{GPS\text{-}AP}$).

Fig. 4. The Range Composition of WiFi/GPS Hybrid Positioning.

The measurements used in GPS navigation positioning are the LOS ranges between GPS satellites and a mobile station, which are similar to the formation of $R_{GPS\text{-}AP}$ and R_{RSS} shown in Fig. 4. It is true that the combined ranges are not easily satisfied with the LOS ranges. However, if the small range scale between R_{RSS} and $R_{GPS\text{-}AP}$, approximately 10 ppm (based on 200 m: 20,000 km) is considered, a near-LOS measurement ($R_{GPS(Near\text{-}LOS)}$) representing the range from a GPS satellite to the mobile station can be supported. This near-LOS range proposed by this study can then be combined and formed in a collinear way as follows:

$$R_{GPS(Near\text{-}LOS)} \fallingdotseq R_{GPS\text{-}AP}+R_{RSS} \fallingdotseq$$

$$[(X_{GPS}-X_{AP})^2+(Y_{GPS}-Y_{AP})^2+(Z_{GPS}-Z_{AP})^2]^{1/2}+R_{RSS} \quad (3)$$

where (X_{GPS}, Y_{GPS}, Z_{GPS}) denote the 3D position of a GPS satellite, which can be computed from GPS orbital data, and (X_{AP}, Y_{AP}, Z_{AP}) represent the 3D coordinates of a WiFi AP, which has been pre-measured in the service area.

A multipath-like range error exists in the near-LOS measurements. To improve the range accuracy, a correction model based on the triangle formed by a GPS satellite, a WiFi AP and a mobile station must be established. However, because the calculation of this triangle would increase the difficulty of computation, the near-LOS measurements are considered the ranges applied to the navigation solution at the testing stage in this study.

The combined ranges of $R_{GPS(Near\text{-}LOS)}$ can be easily formed by selecting four GPS satellites with well constellation geometry. This advantage allows the indoor hybrid positioning approach to provide 3D coordinates, which cannot be easily achieved using only WiFi-based ranges if the number of APs is less than four in the working area.

3.2 Operation Procedures

To comprehensively describe the proposed hybrid positioning approach based on the combined ranges of GPS orbital data and WiFi signals, its basic requirements and operation procedures are shown in Fig. 5 and explained as follows:

(1) Operation equipment

- WiFi wireless network AP: single AP with known geo-referencing coordinates required.
- Mobile device: one mobile device equipped with a WiFi signal strength-detecting function, internet access for downloading GPS orbital data and WiFi/GPS hybrid positioning software.

(2) Operation procedures

- Step 1: Initiate positioning command with mobile device;
- Step 2: Receive signal strength index from a single WiFi AP;
- Step 3: Apply a self-adoptive model to estimate the range (R_{RSS}) between AP and mobile station (MS)；
- Step 4: Pre-select four GPS satellites and convert orbital data into Cartesian coordinates;
- Step 5: Compute the ranges ($R_{GPS\text{-}AP}$) between the GPS satellites and the AP;
- Step 6: Combine R_{RSS} and $R_{GPS\text{-}AP}$ into $R_{GPS(Near\text{-}LOS)}$;
- Step 7: Determine the navigation solution to show 3D coordinates of MS.

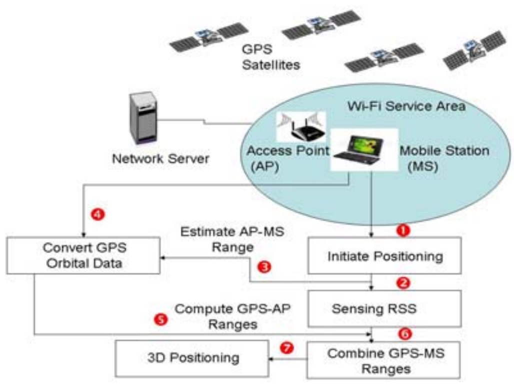

Fig. 5. Operation Procedures of WiFi/GPS Hybrid Positioning.

(2) Operation advantages

- Equipment: Only one WiFi AP and mobile device are required.
- Measurement: No real GPS signal reception; GPS orbital data can be downloaded through internet; and only R_{RSS} is measured.
- Computation: The processing algorithm is similar to that of GPS navigation positioning.
- Location: Geo-referencing, not self-defined, location is provided with 3D coordinate components.

Ⅳ. INDOOR TESTING

4.1 Near-LOS Ranges

To investigate the effectiveness of using the proposed WiFi/GPS hybrid approach, the same indoor area tested in Section II for WiFi-only positioning was selected. To prove the main benefit of using single AP and identify the positioning errors, eighteen test points along the corridor were established in the open space (see Fig. 6).

In the test area, the (X, Y, Z) coordinates of four WiFi APs were pre-measured using GPS static observation at the corresponding points on the building roof. In addition, a vertical distance measurement between the building roof and the corridor ceiling was made for the height reductions of APs. The eighteen test points, which were all set up on the floor, were initially measured with a tape measure in the self-defined (x, y, z) local coordinate system. Because the four APs were also measured to have both (X, Y, Z) and (x, y, z) coordinates, a transformation model composed of seven parameters, including three origin shifts, three axis-rotation angles and one scale factor, was established from these four common points. Therefore, it was possible to provide the geo-referencing (X, Y, Z) coordinates for the eighteen test points. The location was then treated as a standard value to compare with the coordinates solved by the proposed WiFi/GPS hybrid positioning approach.

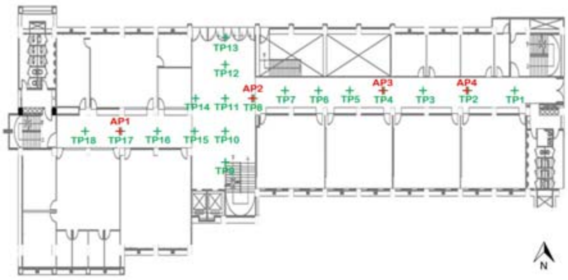

Fig. 6. Indoor Area with WiFi APs and Test Points (TPs).

The ranges (R_{RSS}) between the WiFi APs and the mobile device using RSSs exhibited accuracy within approximately 1.1 m using the self-adoptive model in the test building. The estimated accuracy of range ($R_{GPS\text{-}AP}$) between a GPS satellite and a WiFi AP depended on the accuracy of GPS orbit. The broadcast ephemeris applied to provide the position of the satellite in space demonstrated accuracy within 1 m [19]. After combining the two ranges, the near-LOS measurements ($R_{GPS(Near\text{-}LOS)}$) used in the navigation solution exhibited an estimated accuracy within approximately 1.5 m.

As seen in Fig3 6, four test points, namely TP17, TP8, TP4 and TP2, were directly beneath the four WiFi APs of AP1, AP2, AP3 and AP4, respectively. These four TPs have the same (x, y) local coordinates as the corresponding APs, and a regular vertical difference of 2 m or 2.2 m existed in the z component. Because (X, Y, Z) coordinates of the four TPs were believed to be the most accurately transformed and exhibited the fewest non-LOS errors, they were first tested with the proposed hybrid positioning approach to investigate the accuracy of positioning performance. Table 2 displays the test results of northing (N), easting (E) and up (U) coordinate components.

Table 2. WiFi/GPS Test Results Using the Fewest non-LOS Ranges.

AP	Test	Positioning Error (m)		
Site	Site	N	E	U
AP1	TP17	4.77	-4.88	-6.64
AP2	TP8	0.89	-1.84	-1.88
AP3	TP4	-0.01	-1.72	1.51
AP4	TP2	2.06	-1.28	-0.81
RMS		2.64	2.82	3.56

Table 2 shows the results of testing the combined ranges received directly beneath the WiFi APs, which were believed to have the fewest non-LOS errors. The positioning errors extended from 0 m to 5 m in the horizontal component and 1 m to 7 m in the vertical component. The largest errors occurred at TP17, which corresponds to AP1. The overall positioning errors were approximately 3 m and 4 m in plan coordinates and height, respectively. However, errors in the N component were nearly all positive, whereas errors in the E component were nearly all negative. This systematic error likely existed in the positioning solutions, and had to be detected and removed.

4.2 Linear Error Removal

As seen in Table 2, the range combined at TP17 (AP1) demonstrated the lowest accuracy. Therefore, AP1 was used as the WiFi signal provider at all eighteen test points to investigate any possible biases in the operation. The positioning errors of all test points and their distance from WiFi AP1 are plotted in Fig. 7, Fig. 8 and Fig. 9 for N, E and U components, respectively.

It is evident from Fig. 7, Fig. 8 and Fig. 9 that the positioning errors in all the three components were significantly correlated with the distance between AP1 and the test points. Even the lowest correlation coefficient found in the northing component was still 0.95. It was determined that a distance-related bias existed and had to be removed using the best-fitting linear function for different components. The positioning error corrected by linear removal is shown for the northing component in Fig. 10 as an example. Both the RMS errors based on the results of the distances of all the TPs to AP1 and the error reduction rate when linear correction was applied are shown in Table 3.

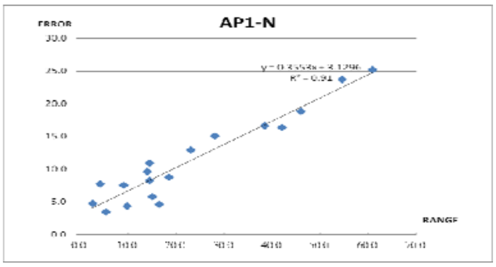

Fig. 7. Positioning Errors and Linear Correlation based on AP1 (N Component).

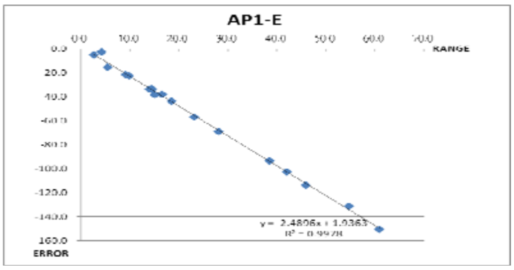

Fig. 8. Positioning Errors and Linear Correlation based on AP1 (E Component).

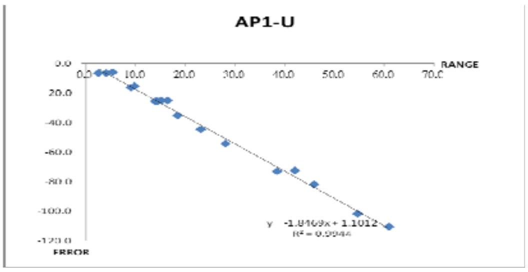

Fig. 9. Positioning Errors and Linear Correlation based on AP1 (U Component).

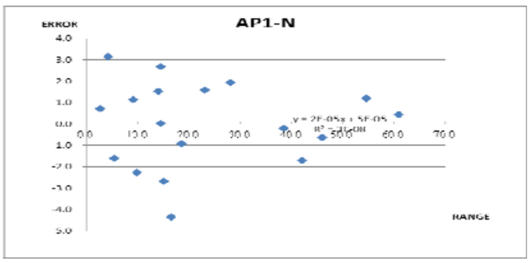

Fig. 10. Positioning Error in the N Component when Linear Correction was Applied.

Table 3. Positioning Errors with or without Linear Correction based on AP1.

Assessment	RMS Error		
	N	E	U
No Correction	13.06 m	70.48 m	52.58 m
With Correction	1.93 m	2.04 m	2.39 m
Reduction rate	85%	97%	95%

Comparison of Fig. 10 and Fig. 7 demonstrates that the linear error was effectively removed. Fig. 10 shows that the error distribution changed from a linear type to a random type, and the maximum error was reduced from 25 m to 5 m when the distance-related linear error was corrected. Table 3 also shows that distance-related positioning errors were substantially reduced from tens of meters to approximately 2 meters (an average error reduction rate of more than 90%) when linear correction was conducted. For all test points connecting with WiFi AP1, the hybrid indoor positioning approach with linear correction can exhibit average errors of around 2 m and 2.5 m in plan coordinates and height, respectively. In practical, such a linear error correction model needs to be pre-calibrated and defined if the real-time positioning is carried on.

4.3 Positioning Errors

Because linear error correction was ensured to work effectively with the hybrid indoor positioning approach, linear error correction was conducted on the computations at all the eighteen test points in relation to all four WiFi APs. Positioning errors more than twice the standard deviation (2σ) were regarded as failure points. The number of success points and the success rate are listed in Table 4. The positioning errors based on all observation data are listed in Table 5.

Table 4 demonstrates that high success rates occurred when AP1 and AP4 were used for all test points. The average success rate for hybrid positioning was 85%, which is higher than the average success rate of using only WiFi data (59%). As seen in Table 5, larger RMS errors occurred in the operation of AP2. However, average positioning errors were lower than 3 m and 2 m in plan and vertical coordinates, respectively. Compared to a 5.7 m error in 2D positioning using only WiFi data, the

WiFi/GPS hybrid approach provides an improved performance of 3.7 m (35% reduction rate) in 2D positioning. Table 5 also shows that the vertical positioning error was less than 2 m. The range observations used in hybrid positioning are believed to be free of atmospheric delay and have potential to provide reliable navigation solutions for indoor positioning.

Table 4. Success Rate of Using WiFi/GPS Hybrid Positioning.

Assessment	AP in Use			
	AP1	AP2	AP3	AP4
Points/all points	18/18	11/18	15/18	17/18
Success rate	100%	61%	83%	94%
Average	85%			

Table 5. Positioning Errors when Using WiFi/GPS Hybrid Positioning.

AP Site	RMS Error (m）		
	N	E	U
AP1	1.93	2.04	2.39
AP2	2.65	7.72	2.94
AP3	2.49	1.23	0.66
AP4	1.73	0.96	1.81
Average	2.20	2.99	1.95
2D Average	3.7		-

4.4 Precise Orbital Data

The main benefit of using the WiFi/GPS hybrid positioning approach is the application of a single WiFi AP in the operation. One other operation requirement is that GPS orbit data must be downloaded and used to provide the four selected GPS satellites' positions in space to construct the combined ranges for positioning. This draws attention to the quality of the GPS orbital data affecting the positioning accuracy. According to the IGS, real-time GPS orbital data also provides an ultra-rapid ephemeris featuring accuracy within 5 cm [19]. Therefore, the ultra-rapid ephemeris was employed to improve the geometric accuracy of the range (RGPS-AP) and further decrease positioning errors (see Table 6). A comparison of 3D positioning errors between using the broadcast ephemeris (BE) and the ultra-rapid ephemeris (RE) is shown in Fig. 11.

Fig. 11 shows that hybrid positioning using an ultra-rapid ephemeris to provide higher accuracy of GPS orbit data reduced positioning errors in all three coordinate components. Comparison of Table 6 and Table 5 demonstrates that positioning errors were reduced from 3.71 m to 3.05 m (an 18% reduction rate) in the 2D vector and decreased from 1.95 m to 0.57 m (a 71% reduction rate) in the vertical component. These results support the effectiveness of the proposed WiFi/GPS hybrid indoor positioning approach.

Table 6. Positioning Errors Using an IGS Ultra-rapid GPS Ephemeris for Combined Range.

AP Site	RMS Error (m）		
	N	E	U
AP1	1.35	1.68	0.84
AP2	1.41	6.48	0.62
AP3	2.10	1.61	0.38
AP4	1.37	0.72	0.42
Average	1.56	2.62	0.57
2D Average	3.05		-

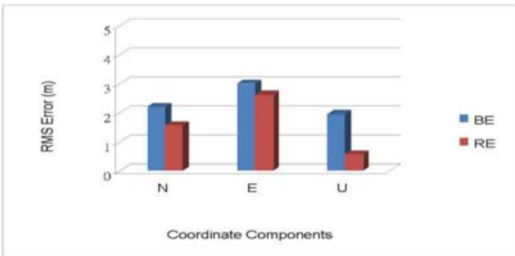

Fig. 11. Comparisons of Positioning Errors Using Broadcast and Ultra-rapid Ephemerides.

GPS orbital data used in the WiFi/GPS hybrid positioning approach is theoretically time-invariant information. In other words, the four GPS satellites with optimal geometric conditions, or small DOP values, can be selected and remain unchanged during the indoor positioning operation. The range observations varied only depending on the differences in WiFi signal strength detected at the mobile station. Because the GPS satellite position can be regarded as a fixed reference station in the observed space, the selection of GPS satellites is not a computation problem using the hybrid approach. A previous study suggested that using any satellite below the horizontal strengthens the geometric condition for higher accuracy of positioning performance in vertical component

[20]. However, because the hybrid positioning approach performed well in the vertical component of positioning accuracy, as seen in Table 6, the previous statement was not implemented in the data tests.

It is also noticed that the use of GPS satellites in this integrated solution can be imaginary. Any other GPS satellites with errorless orbit can also be used to obtain an even better 3D solution. However, it is still suggested using IGS ultra-rapid ephemeris for its near-real information, easy download and process as well as acceptable orbital error.

V. CONCLUSIONS

GPS satellite positioning has been widely used as a standard tool for navigation, particularly in outdoor areas. To extend the functionality of positioning methods, an effective indoor positioning technique must be developed. Because wireless networks have been effectively operated in indoor areas, WiFi signal transmitters are extensively available. This provides potential opportunities for using WiFi to implement positioning in many indoor applications.

In this study, a WiFi-based technique using the RSS and an adoptive model to convert the RSS into the range observations for positioning at the mobile station was employed. However, the installation of a small number of WiFi APs in the service area demonstrated the insufficient capability of using a WiFi-based technique for indoor positioning. Therefore, a WiFi/GPS hybrid approach using a single WiFi AP was proposed and tested. The range observations were combined from the geometric range between the GPS satellite and the AP, and calculated using their known positions and the detected range between the AP and the mobile device.

The data for the WiFi/GPS hybrid positioning approach show an improved performance of accuracy within 3.7 m in 2D plan coordinates compared to an accuracy within 5.7 m obtained from data using only WiFi. The vertical positioning of the combined WiFi/GPS data achieved accuracy within 2.0 m, whereas the WiFi-only data was unable using the poor geometric distribution of APs. The WiFi/GPS hybrid approach attained a success rate of 85%, whereas the WiFi-only data yielded a success rate of is 59%. Therefore, the WiFi/GPS hybrid approach is effective in indoor positioning.

Moreover, precise satellite orbital data can improve range observations and reduce positioning errors. However, the RSS self-adoptive model and the near-LOS correction model are location dependent and their use changes in different indoor environments. This presents a future work for real-time positioning because models must be designed for every interior space inside a building. In conclusion, because hybrid systems are increasingly incorporated into mobile devices, such as gyroscope, electronic compass, pedometer and inertial measurement unit, the indoor positioning approach is expected to operate in any commercial product and extend the capability of LBS.

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