Local Area Positioning System (LAPS) for Indoor Navigation and Tracking System and Building Electricity Energy Saving

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Abstract — Local Area Positioning System (LAPS) designed to provide accurate positioning inside buildings by the use of existing wireless access points as the alternative source of position reference. Originally to provide indoor navigation and tracking service for mobile devices and panic button to track separated family member within a large building. The system found additional use in smaller sized building to improve the efficiency of electricity usage in the form of dimming the room lighting where there are no people present. The program on Android smart phone will read the received signal strength (RSSI) from wireless access point (at least three) and then calculate the position by using trilateration method. The calculated position will be sent to the controller unit. By tracking the users' position, the system will control light bulb's intensity by using dimmer to dim the light bulbs, providing savings in electricity energy consumption of up to 45%.

Keywords — Local Area Positioning System, indoor navigation and tracking, Wireless Access Point, Trilateration method, electricity efficiency

I. BACKGROUND

Positioning technology is a system that is very commonly used by today's society. This technology allows users to get information about the position, location somewhere in real time. Global Positioning System (GPS) is one of the most frequently used systems for doing so. GPS is a navigation and positioning technology that utilizes satellites. GPS receivers acquire signals from several satellites orbiting the earth. Because GPS works using satellite signals, then there is a shortage when the user is within a room or building. Signals from satellites which are electromagnetic wave will experience attenuation when encountering building construction materials such as building roofs, windows, and other obstructions, this condition is called urban canyon in large cities with dense high rise buildings. Indoor Positioning System (IPS) technology is a solution to perform positioning indoors, when GPS is not able to work. IPS uses technology other than satellite to perform positioning as a radio signal from the wireless access point, magnetic signals, or acoustic signal.

Mathematical calculations to determine the position using Trilateration has reached 98% accuracy in the horizontal plane [1]. In the publication by Khan, it made use of the software on smart phones to designing indoor positioning system (IPS), utilizes motion sensors and signal from the wireless access points [2]. The system generates 95% accuracy reading position (reading time) and consistency of 96.86%. Bey and Sanz [3] carried out calculations using fuzzy logic in the system of indoor positioning system (IPS) to utilize signals from the wireless access point, the results of these trials concluded that the addition of the wireless access point will raise the level of accuracy of the IPS system. The location-related service are playing crucial role in the society such as Emergency-911 (E-911), location-based billing service, intelligent transportation systems, car navigation, elderly people tracking, and precision agriculture [4]–[6]. One method proposes the use of Wi-Fi footprints to enhance positioning system [7]–[8].

II. SYSTEM DESIGN

Figure 1. System Design

Figure 1 described the original idea and system design of Local Area Positioning System for Indoor Navigation and Tracking System. The system consists of the following components:
1. Access points as reference nodes that take over the role of GPS satellite constellation,
2. Smartphone of the user with installed software to read the strength of received signals from nearby access points and to calculate user’s position within the building,
3. A Raspberry Pi® single board computer that acts as control server for centralized positioning, and
4. Navigation map for user position mapping within the building.

Since the position of access points is already known, this is required for calculating user’s position by the use of trilateration method. The distance between user and access point is calculated from RSSI (Received Signal Strength Indication) received by user’s phone. Path loss formula is used for calculating the distance between user and access point.

When two references are used, this method can determine the location of the target by triangulation method, but this method is only effective if the target is actively transmitting signal. When the target is the receiver, there will be a small equal strength overlapping area between the two transmitters with nearly identical signal strength when the receiver is right between the transmitters. In this case, the accuracy of positioning decreased in this specific overlapping area and the target could be anywhere between the two P positions, as illustrated in Figure 4, where:

A = Wireless Access Point 1;  
B = Wireless Access Point 2;  
P = Receiver position;  
r1 = Wireless Access Point 1 – Receiver distance  
r2 = Wireless Access Point 2 – Receiver distance

To obtain higher accuracy in determining position, a third reference point can be used so that the received signal from the three references always point to a single specific location. This is then used in the trilateration method to determine the position of the receiver, where:

A = Wireless Access Point 1;  
B = Wireless Access Point 2;  
C = Wireless Access Point 3;  
P = Receiver position;  
r1 = Wireless Access Point 1 – Receiver distance  
r2 = Wireless Access Point 2 – Receiver distance  
r3 = Wireless Access Point 3 – Receiver distance
B. Distance Calculation

The relation between RSSI and Distance on Non described on this equation

\[
\text{RSSI}[\text{dBm}] = -10 \log_{10}(d) + A[\text{dBm}]
\]

Where

- RSSI = Received Signal Strength read by user
- \(d\) = distance between transmitter and receiver
- \(A\) = Received signal strength on one meter of distance

The formula for calculating path loss described on this equation

\[
\text{Pr}(d) = \text{Pr}(d_0) + 10n \log_{10}\left(\frac{d_0}{d}\right)
\]

Where,

- \(\text{Pr}(d)\) = received signal strength on certain distance
- \(\text{Pr}(d_0)\) = received signal strength at one meter distance
- \(d_0\) = one meter as reference distance

This following equation is for calculating the path loss exponent using equation (2)

\[
n = \frac{\text{Pr}(d) - \text{Pr}(d_0)}{10 \log_{10}\left(\frac{d_0}{d}\right)}
\]

C. Trilateration

The illustration for trilateration method is described on Figure 6. Point A, B, and C is the reference nodes, in this case these points are wireless access point position. Since the position of the wireless access points are fixed, the position coordinate of each access points can be stored for reference fix by the receiver \(P\) and then calculate the approximate position based on the strength of the received signals.

To calculate the position, for example in Figure 7, Point U is user’s position while points A, B, and C are the access points with their corresponding coordinates. The trilateration is used to calculate user’s position based on distance from the reference nodes. In order to estimate the user's position with minimal computation, the reference nodes will be represented as the following three points: the first point is the origin \((0,0)\), the second point is the point \((p,0)\) on the x-axis, and the third point is the point \((q,r)\). Trilateration formula describe on this equation

\[
d_1^2 = x^2 + y^2
\]
\[
d_2^2 = (x - p)^2 + y^2
\]
\[
d_3^2 = (x - p)^2 + (y - r)^2
\]

The substitution from equation (4), (5), and (6) to calculate \(x,y\) coordinate from the user is described on this equation

\[
x = \frac{d_1^2 - d_2^2 + p^2}{2p}
\]
\[
y = \pm \sqrt{d_1^2 - \left(\frac{d_1^2 - d_2^2 + p^2}{2p}\right)}
\]

D. Software Algorithm

The algorithm of main program in Android smart phone is reading signal strength from three wireless access point as reference nodes. Once the signal strength reading is completed, this program converts signal strength into distance between user and wireless access point using path loss formula described on equation 1. After the program have each wireless access point position, and the distance between user and each wireless access point, user’s position will be calculated using trilateral method which is described on equation 7 and equation 8. Calculated user’s position is
sent to server (Raspberry-PI) and server will determine the location based on user’s current position. Main flowchart of this program described on Figure 8.

Figure 7. Trilateration method illustration

Figure 8. Main flowchart

IV. EXPERIMENT

A. Room Plan

Room plan is described on Figure 9. The room will be divided into four zones; each zone will have one access point. These access points will be controlled by server, to be able to determine user’s position. The data of user’s coordinate and the access point will be stored on server.

Figure 9. Room Plan

B. Distance Calculation

Distance calculation using path loss formula from available wireless access point described on Table 1. RSSI is decreased by logarithmic graph as described on Figure 10.

Table 1. SSID, RSSI, and Distance calculation

<table>
<thead>
<tr>
<th>SSID</th>
<th>RSSI [dB]</th>
<th>Distance [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>wifi02</td>
<td>-48</td>
<td>1.97</td>
</tr>
<tr>
<td>wifi01</td>
<td>-48</td>
<td>1.97</td>
</tr>
<tr>
<td>WirelessNet</td>
<td>-53</td>
<td>2.57</td>
</tr>
<tr>
<td>wifi03</td>
<td>-70</td>
<td>6.24</td>
</tr>
<tr>
<td>D3M</td>
<td>-85</td>
<td>13.69</td>
</tr>
</tbody>
</table>

Figure 10. Distance calculation by RSSI

Figure 11 described the experiment on positioning using trilateration method. The experiment in a room described on Figure 9. On this experiment, system is calculating user’s position for 50 times in zone 1, calculated user’s position...
based on trilateral calculation is described with red mark on Figure 7.

Figure 11. Positioning in zone 1

The precision of this experiment, described on Tables 2 and 3. The current readings on the position are still not stable yet, this is because the strength of the transmitting access points is fluctuating. One possible method to minimize fluctuation is by averaging the signal strength for the predicted distance, and hence, more stable location readings. Another very potential method is by the use of RSS-based Voronoi Factor Graph [9].

TABLE 2. STANDARD DEVIATION CALCULATION

<table>
<thead>
<tr>
<th>Zone</th>
<th>Real Position</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Y</td>
<td>X</td>
<td>SDx</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td>R</td>
<td>SDy</td>
</tr>
<tr>
<td>1</td>
<td>1.5</td>
<td>1.7</td>
<td>1.67 ± 0.14</td>
</tr>
<tr>
<td>2</td>
<td>3.6</td>
<td>1.8</td>
<td>2.58 ± 0.89</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3.6</td>
<td>2.36 ± 0.37</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>6.5</td>
<td>3.7 ± 0.14</td>
</tr>
</tbody>
</table>

TABLE 3. STANDARD ERROR CALCULATION

<table>
<thead>
<tr>
<th>Zone</th>
<th>Mean</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Y</td>
<td>SEx</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td>SEy</td>
</tr>
<tr>
<td>1</td>
<td>1.5</td>
<td>1.67 ± 0.02</td>
</tr>
<tr>
<td>2</td>
<td>3.6</td>
<td>2.58 ± 0.13</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1.54 ± 0.05</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>3.7 ± 0.02</td>
</tr>
</tbody>
</table>

C. Electricity Saving

One of the by-products of this experiment is the possibility to control the illumination of rooms by adjusting the brightness depends on whether any occupant is nearby a light bulb. Room illumination is controlled by a low power single board computer, when controlling the bulb’s brightness is shown in Table 4 and Figure 8. In this project, user’s position is used to control the electricity as one of the application of Local Area Positioning System.

As in Figure 9, each zone is installed with one light bulb. The data of light bulbs coordinate and the access point will be stored on server. These bulbs will be controlled from server, based on user’s position. Figure 12 shows the extended system design of Local Area Positioning System for Indoor Electricity Usage Efficiency. The system consist of three access points as reference nodes, smart phone of user which installed software to calculate user’s position, control server and several light bulbs to control.

D. Control System

Figure 12. LAPS from Figure 2 combined with Room Lighting Control

Figure 13. Control System
Figure 13 described that the control unit is a server which accept HTTP Request from the user’s mobile phone, and can send command to the light bulbs using RF signal. The control unit using Raspberry-PI, single board computer which running with 5 Watt power. In this system, light bulb is provided with an API to control the brightness to dim the bulb. User’s mobile phone will send the calculated position using as the result of equation (7) and (8) to the server using HTTP Request. After getting the user’s position, server will determine the zone of user’s current position and send command to every bulb on that zone to set brightness up. The server will send command set brightness down to bulbs on the other zone which doesn’t have user around. With this method, there will be an efficiency of electricity usage.

<table>
<thead>
<tr>
<th>Lamp Location</th>
<th>10% Brightness (Watt)</th>
<th>Full Brightness (Watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>0.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Zone 2</td>
<td>0.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Zone 3</td>
<td>0.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Zone 4</td>
<td>0.5</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Figure 8. Light bulb with 10% Brightness

<table>
<thead>
<tr>
<th>Zone usage</th>
<th>Power Usage (Watt)</th>
<th>Control Unit (Watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Normal 5.5</td>
<td>22</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Dimmer 0.5</td>
<td>7</td>
</tr>
<tr>
<td>Zone 3</td>
<td>Dimmer 0.5</td>
<td>7</td>
</tr>
<tr>
<td>Zone 4</td>
<td>Dimmer 0.5</td>
<td>7</td>
</tr>
</tbody>
</table>

Power usage efficiency is calculated using equation (9).

\[ \eta = \frac{\Delta P}{P_{\text{max}}} \times 100\% \]  

Based on calculation result from Table 5 by using Equation 9, power usage efficiency is up to 68%.

<table>
<thead>
<tr>
<th>User Zone</th>
<th>Zone usage</th>
<th>Power Usage (Watt)</th>
<th>Control Unit (Watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Normal 5.5</td>
<td>22</td>
<td>7</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Dimmer 0.5</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Zone 3</td>
<td>Dimmer 0.5</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Zone 4</td>
<td>Dimmer 0.5</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

Power usage efficiency include control unit server is described in Table 6. Sample calculation for power usage efficiency is described below.

\[ \eta = \frac{22 - 7 - 5}{22} \times 100\% \]
\[ \eta = 45.45\% \]

V. CONCLUSION

From the research that has been done, it is possible to build Local Area Positioning System (LAPS) for Indoor Navigation System. The positioning system is used to determine user’s position in the building, and send the information to control server. The least error level of this system is ±0.02 m for the mean of x-axis coordinate, and ±0.014 m for the mean of y-axis coordinate.

As one of the application of Local Area Positioning System for efficiency electricity usage, the server will control the light bulbs or the other electricity based on user’s position, if there is any unused zone the light bulbs on that zone will be dim into minimal brightness or turned off. The efficiency of power usage to turn on the light bulbs is up to 68% with calculation of control unit power usage the efficiency is up to 45%.

REFERENCES


