Simultaneous Localization and Mapping with BLE

Liu Ke

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1 Abstract

In recent years,the Wi-Fi fingerprint-based positioning systems have been studied extensively.This method,though obtains a fair accuracy, needs a training phase to create a Received Signal Strength Indication(RSSI) database which is costly and time consuming.So we present a method to do simutaneous localization and mapping with users' mobile inertial sensors and Bluetooth Low Energy(BLE).It doesn't necessitate additional specialized measurement and devices except ordinary mobile.Briefly, this method is a kind of crowdsensing that needs data sharing.

2 Introduction

Most smartphones can sense accelaration, magnetism and angular acceleration. These sensors(Accelerometer,Magnetometer,Gyroscope) can collect vast quantities of data that are useful in mapping process.Then we use these data to obtain user's direction,step length and step numbers.Then movement trace can be detected.

In reality,every rooms and corridors are installed with some Access Points(AP) like figure 1.User's mobile can get lots of RSSIs of different APs.Here we use BLE as access point. The closer the mobile is to the BLE,the larger signal strength it will receive. Signal will attenuate when there is a wall or door on the way.Thus we can set a lower signal strength threshold according to some tests to decide the BLEs that are in the same room .In this way,we divide the BLEs into different groups.Every group represents BLEs in a certain room.An upper threshold is also needed to decide the position of every BLE in the local coordinate system(LCS).

From figure 1, user 1 may walk from room 1 to room 2.And user 2 may walk from room 3 to room 1.Then we are able to take advantage of the similarity of relative position of BLEs to do the matching work.Since we know the BLE groups, we divide user's obtained position(figure 2) into different categories.And we use KNN algorithm to cluster and construct the map.

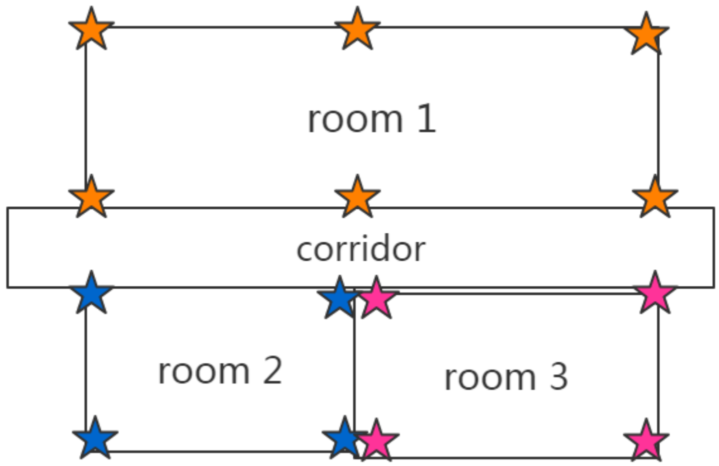

Figure 1: a possible room layout

时间信息	相对 X	相对 Y	运动类别	MAC	RSSI
1.253	0	0	0	XX:XX:XX:XX:XX:XX	-70
1.500	0	0	0	null	-100
1.665	0	50	0	XX:XX:XX:XX:XX:XX	-75
1.783	0	50	0	XX:XX:XX:XX:XX:XX	-68
2.000	0	100	0	null	-100

Figure 2: data type uploaded to server

Mobiles rely on inertial sensors and BLEs to obtain real-time data like relative coordinate and RSSI.And then user's real-time datas need to be uploaded to the server and mobile downloads the real-time position after server's process.The overall system architecture is shown in figure 3.

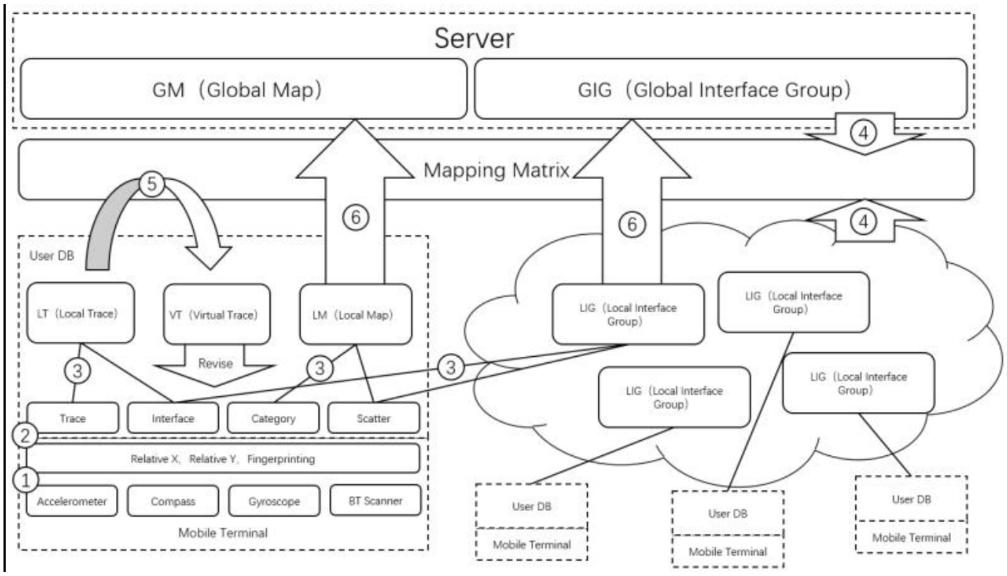

Figure 3: general plan

3 Implementation

3.1 Direction Estimation

We use SmartPDR[1],a smartphone-based pedestrian dead reckoning to obtain user's location through step event detection,heading direction estimation and step length estimation.In this part,I mainly focus on obtain walking direction information,and the rest was done by my teamates.

Magnetometer can provide the heading direction of pedestrian h_t^{mag} using the x-axis and y-axis components of the Earth's magnetic field outputs in Global Coordinate System(GCS) ,but the data measured by magnetometer could be interfered by surrounding magnetic field or turning a angle.We can also obtain the corresponding heading direction of pedestrian movement by gyroscope h_t^{gyro}.This pedestrian heading direction from gyroscope is determined through the integration of angular velocity.But the accuracy of integration is not good.

So we use measurements from magnetometer and gyroscope together to find the reasonable direction h_t of a user.We set two threshold h_τ^{cor} and h_τ^{mag} and use them to determine the correlation h_Δ^{cor} and magnetometer variation h_Δ^{mag},respectively.Note that h_Δ^{cor}=$|h_t^{mag} - h_t^{gyro}|$, h_Δ^{mag}=$|h_t^{mag} - h_{t-1}^{mag}|$.

If h_Δ^{mag} is larger than h_τ^{mag},it means a magnetic field mutation.The reason is probably the interference caused by nearby electronic equippment or user's making a turn.If

h_Δ^{cor} is larger than h_τ^{cor},it could be interference made by gyroscope's integration or magnetometer.

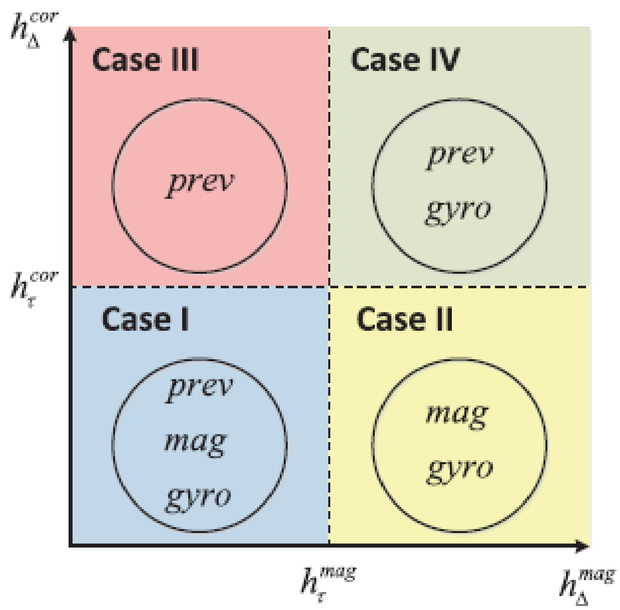

Figure 4: four cases

We analyze four situations shown in figure 4 and determine the final heading direction h_t use the following formula.

$$h_t = \begin{cases} w^{pmg}\left(w^{prev}h_{t-1} + w^{mag}h_t^{mag} + w^{gyro}h_t^{gyro}\right), \\ \qquad \text{for } h_\Delta^{cor} \le h_\tau^{cor},\ h_\Delta^{mag} \le h_\tau^{mag} \\ w^{mg}\left(w^{mag}h_t^{mag} + w^{gyro}h_t^{gyro}\right), \\ \qquad \text{for } h_\Delta^{cor} \le h_\tau^{cor},\ h_\Delta^{mag} > h_\tau^{mag} \\ h_{t-1}, \quad \text{for } h_\Delta^{cor} > h_\tau^{cor},\ h_\Delta^{mag} \le h_\tau^{mag} \\ w^{pg}\left(w^{prev}h_{t-1} + w^{gyro}h_t^{gyro}\right), \\ \qquad \text{for } h_\Delta^{cor} > h_\tau^{cor},\ h_\Delta^{mag} > h_\tau^{mag} \end{cases}$$

Note that w^{prev},w^{mag} and w^{gyro} are weighting parameters on previous heading direction estimate, current magnetometer-based direction,and current gyroscope-based output,respectively.And we use the weighting parameters used in the paper and obtain the result shown in figure 5.

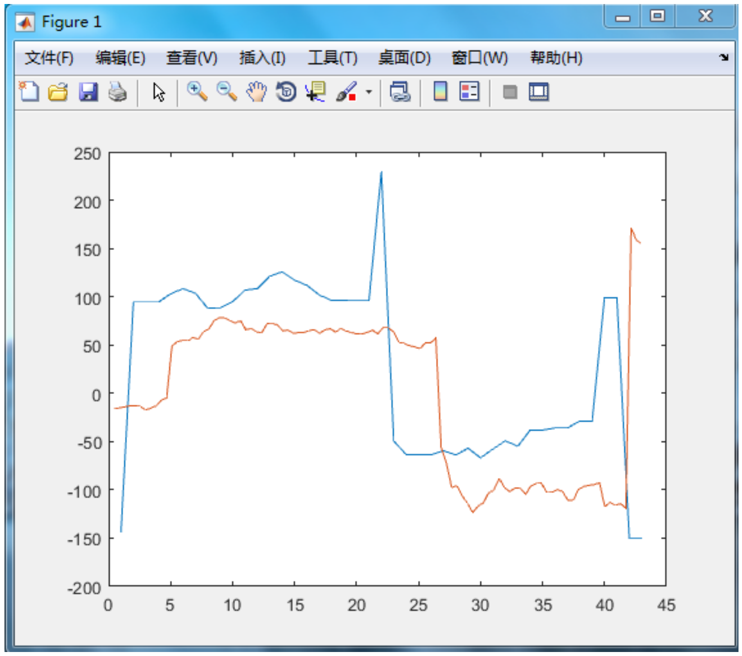

Figure 5: result in direction

3.2 Online Matching

A mobile can detect several BLE's position in it's LCS.But how can we figure out the positions of all BLEs?Two routes are shown in figure 6,user 1 went through Anchor 1,2,3,4,5 and user 2 went through Anchor 3,4,5,6,7,8.So they have Anchor 3,4,5 in the LCS in common.But position of Anchors doesn't present in Global Coordinate System(GCS).So we first anylyze the similarity of different user's data. Firstly, Anchors' position should be nomalized,and then we put the position of Anchor 3,4,5 in user 1's LCS into array A and user 2's into array B.We can obtain rotational vector and scaling factor use these two arrays like presented in equation 1 .

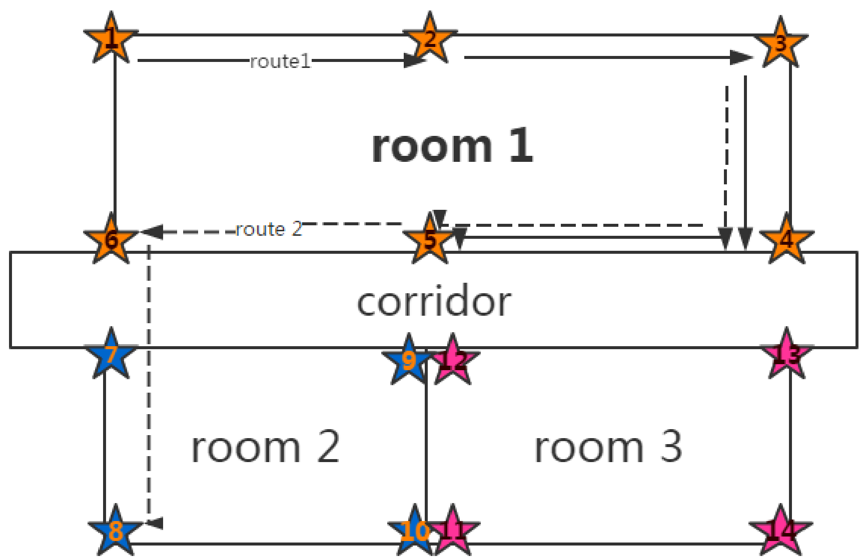

Figure 6: BLE Match

$$A^T(k\beta)^T = B^T \tag{1}$$

Where k is scaling factor and β is rotational vector .Then we can use k and β to convert route 1's positions into route 2's LCS.In the same way,we get all BLE's position in one coordinate system.We've made a simulation and its result is shown in figure 7.As we can see,The simulation result(blue circle) rotate 100 degree clockwise will roughly coincide with the original actual positions .

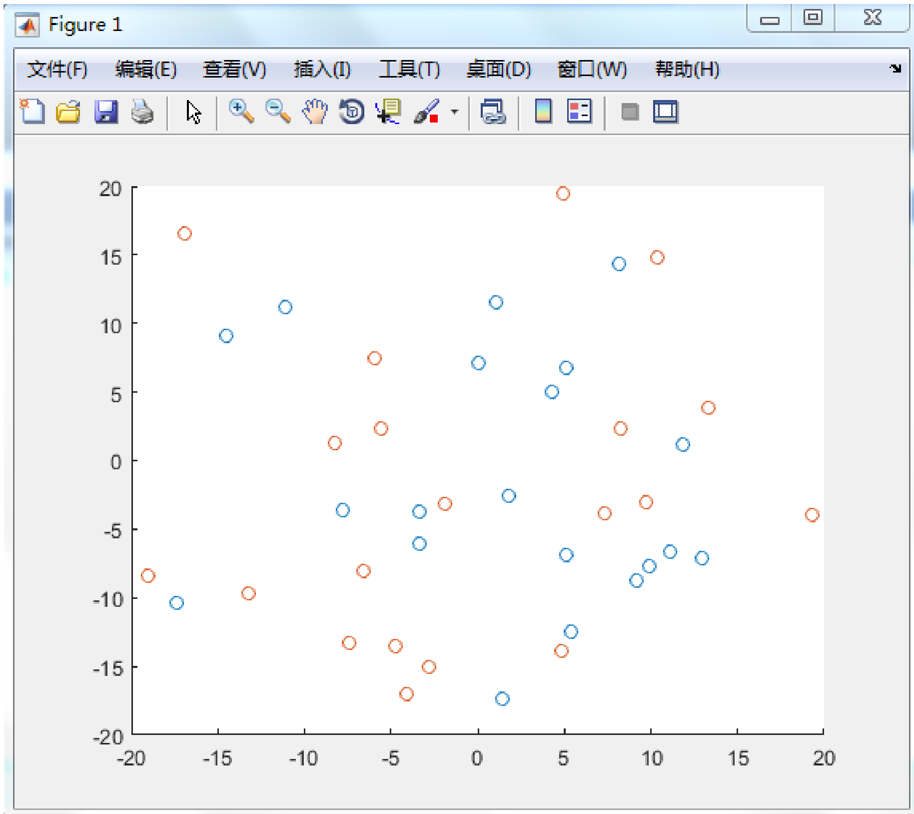

Figure 7: simulation result of online matching

3.3 Outline of Rooms

Since we know the BLE groups,we can also obtain users' positions of different groups.To be specific,we can get a lot of positions/coordinates and every coordinate is assigned with a label to show which group it belongs to.Figure 8 shows three coordinates and their GroupID.

时间	相对 X	相对 Y	GroupID
0	100	100	1
0.6	120	100	2
1.0	140	100	2

Figure 8: Input items

As shown in figure 9,we simulate 5 rooms and the little circles in it represent user's positions and the same color means they belong to the same group.Then we use KNN algorithm to depict the shape of rooms. The principle is,for every pixel, to find the nearest K nodes and find out which group most of nodes belong to.Then the pixel belongs to the same group.

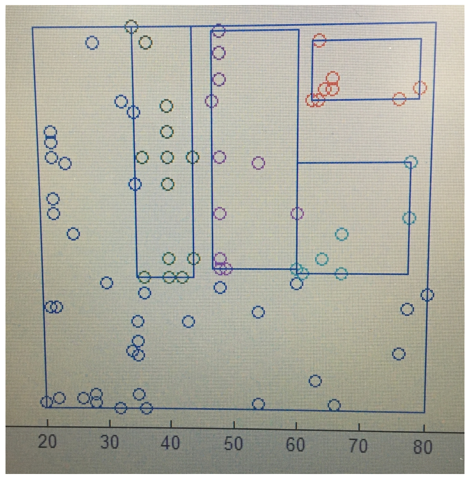

Figure 9: scatter diagram

As shown in figure 10,we can see the rough outline of the five rooms,and if more positions are added to the situation,the margins will be more clearly.

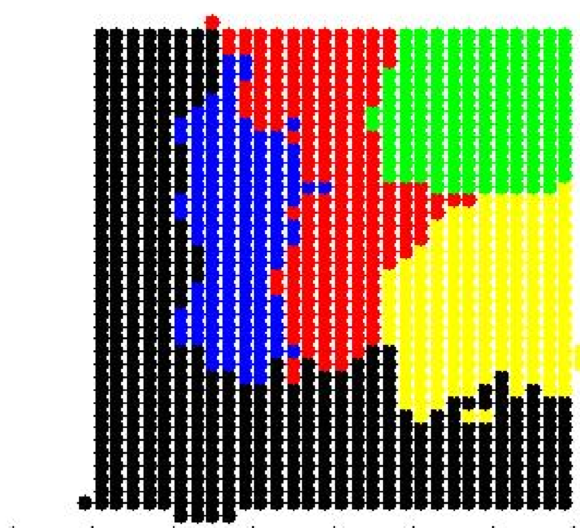

Figure 10: reconstructed rooms

4 Reference

[1] Wonho Kang,Youngnam Han,"SmartPDR:Smartphone-Based Pedestrian Dead Reckoning for Indoor Localization,"in IEEE SENSORS JOURNAL,VOL.15,NO.5,MAY 2015.