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Floor and Motion Classifying Scheme Exploiting Smart-phone for Indoor Movements

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Abstract

In these days, smart-phone becomes a major personal communication device and more and more hardware including various sensors as well as software including various applications tend to be mounted on it. In this paper, we propose a classification scheme that classifies ambulatory movements of the user and the floor where the user exists with a smart-phone. In the proposed scheme, ambulatory movements of the user are classified by exploiting the barometer and the accelerometer, while the GPS data is used to classifies the floor information. With the proposed scheme, various motions, such as walking, stop, up and down motions with elevator or stairs, are distinguished by utilizing the data from the barometer and the accelerometer. When the user enters a building, the building information is confirmed with the GPS information and the smart-phone can classify ambulatory movements and the floor information of the user. An Android application is developed for the performance evaluation of the proposed scheme. The proposed scheme is evaluated with experiments at general building in university and the accuracy of the proposed scheme is more than 94% for floor estimation, although there is still works to improve the estimation of movements.

Keywords: *Barometer, Accelerometer, Ambulatory movement, GPS, Rotation matrix*

1. Introduction

Lately, many kinds of smart-phones are released. More and more hardware including various sensors as well as software including various applications tend to be mounted on the newly released smart-phone [1]. Each smart-phone has various sensors for its own purpose, but the barometer, the accelerometer, and GPS receiver are commonly mounted. Especially, GPS is most popular navigation system in outdoor environments. However, it is hard for GPS to estimate exact locations and altitudes under non-line-of-sight (NLOS) conditions with satellites, likewise indoor environments [2]. Signal strength and accuracy of GPS also are significantly decreased in indoor and underground conditions. When GPS information is not reliable, other sensors such as the barometer and the accelerometer can replace the roll of GPS for indoor navigation [3-5].
In this paper, we propose a classification scheme that classifies ambulatory movements of the user and the floor where the user exists with a smart-phone. When the user with a smart-phone enters a building, the signal to noise ratio (SNR) of GPS is significantly decreased. When the SNR of GPS is decreased, the GPS information can be utilized to decide which building the user enters at that moment. With the information of building, the proposed scheme can classify ambulatory movements and floors of the user more accurate. In conventional classification scheme, ambulatory movements and floors can be classified with energy detection which needs calculations of high complexity [6]. In the proposed scheme, ambulatory movements of the user are classified by exploiting the barometer and the accelerometer. The sensor drift that causes errors, and compensate errors [7, 8] of barometer is also considered in the proposed scheme. With

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rotation matrix, it is possible to convert accelerometer datum into vertical components [9], [10]. By employing the rotation matrix scheme, the proposed scheme can detect ambulatory movements and floors regardless of smart-phone direction. An Android application is developed for the performance evaluation of the proposed scheme and the proposed scheme is evaluated with experiments at general building in university. The rest of paper is organized as follows. Section 2 represents the related works of proposed scheme and provides the detailed description of the proposed scheme. In Section 3, the performance of the proposed scheme is evaluated with experiments. Finally, concluding remarks are given in Section 4.

2. System Description

The flow chart of the proposed scheme is shown in Figure 1. Based on the received GPS information, firstly it detects the nearest building and gets the information of the building from the data base.

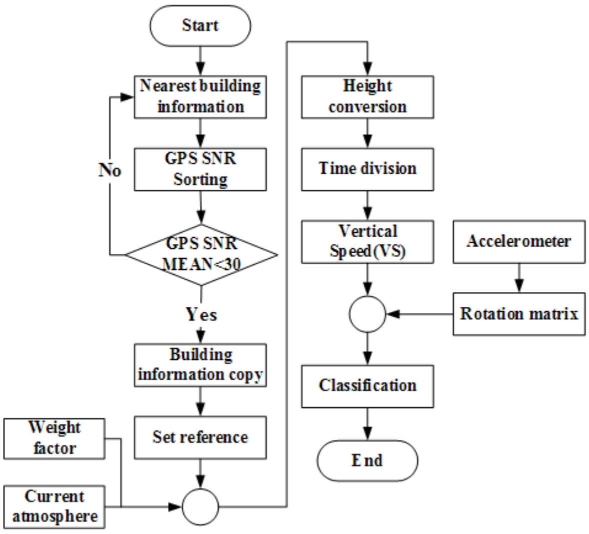

Figure 1. Flow Chart of the Proposed Scheme

When many satellites are detected, it is necessary to sort SNRs of GPS signals from satellites. In the proposed scheme, the 5 largest SNRs from the sorted GPS-SNR are utilized. The mean value of 5 largest SNRs is used to distinguish whether the user is located in outdoor and indoor conditions. If the mean value is over the threshold of GPS-SNR, the user is considered to be located in outdoor conditions and the smart-phone detects the information of building. Since high value of GPS-SNR is more reliable than low value of GPS-SNR, the device updates the information of the nearest building in high SNR. In case of low GPS-SNR, it copies the latest information that contains the height of a floor for the nearest building. Meanwhile, it sets last atmosphere value that is detected before entering into the indoor condition as a reference atmosphere. When the current height is calculated by the current atmosphere and the reference atmosphere, weight factor is multiplied because of the sensor drift for the barometer. The smart-phone used in the experiments saves 40 samples and detects sensor values at the rate of 20Hz. Vertical speed (VS) is derived from the saved samples of the current height and the sensor rate. Acceleration variance (AV) can be derived from the rotated sensor data of the accelerometer. The AV detects the vibrations of vertical direction. By applying the threshold to the VS and the AV, ambulatory movements can be classified with the proposed algorithm.

2.1. Rotation Matrix

A rotation matrix is utilized to obtain the vertical components among each axes of the accelerometer. In Euclidean space, the rotation matrix can be used as rotation. Actually, orientation operating in earth centered inertial coordinate system can be calculated by the gravity direction in the body frame. Therefore, the rotation matrix, R, can be defined as follows:

$$R = \times \begin{bmatrix} \cos\psi\cos\theta & \sin\psi\cos\theta & -\sin\theta \\ -\sin\psi\cos\theta + \cos\psi\sin\theta\sin\phi & \cos\psi\cos\phi + \sin\psi\sin\theta\sin\phi & \cos\theta\sin\phi \\ \sin\psi\sin\phi + \cos\psi\sin\theta\cos\phi & \sin\psi\sin\theta\cos\phi - \cos\psi\sin\phi & \cos\theta\cos\phi \end{bmatrix} \quad (1)$$

where ϕ , θ , ψ represent three rotation angles, which are shown in Figure 2. The transformed accelerometer data can be obtained by multiplying the rotation matrix and the accelerometer data. The sum of the transformed three axes component means the vertical component. In the proposed scheme, it also is regarded as the vertical component.

2.2. Height Conversion

The height conversion can be derived from the equation that calculates absolute altitude by both atmospheres of sea level and current location, and it can be expressed as follows:

$$h_c = h_b - \frac{R \cdot T_b \cdot \ln(P_c / P_b)}{g_0 \cdot M} \quad (2)$$

$$h = h_c - h_r = -\frac{R \cdot T_r \cdot \ln(P_c / P_r)}{g_0 \cdot M} \quad (3)$$

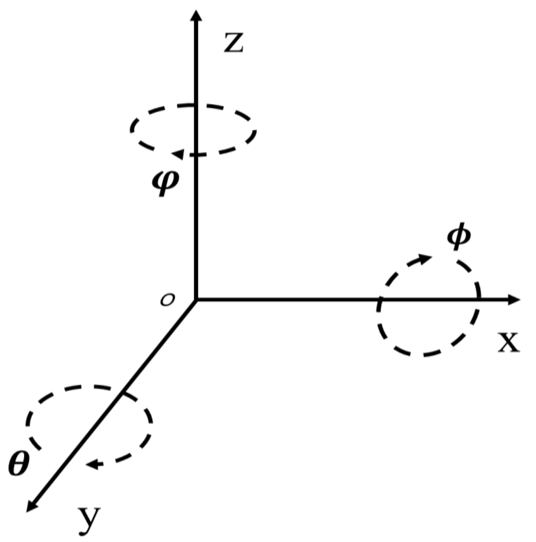

Figure 2. Rotation Angles

where h_c is height at current location, h_b is height at the sea level, h_r is height at reference location, h is the difference of height between the current and the reference location, R (=

8.31432 $N \cdot m/(mol \cdot K)$) is universal gas constant, T_b (=288.15 K) is the standard temperature at sea level, T_r is the temperature at the reference location level, P_c is the pressure at the current location level, P_b is the pressure at the sea level, P_r is the pressure at the reference location level, g_0 (= 9.80665 m/s^2) is the gravitational acceleration constant , and M (= 0.0289644 kg/mol) is the molar mass of air of earth.

The equation (2) is used to convert from the current atmosphere to the current altitude. By replacing the sea level to the reference value, the difference of height, (3), between the current and the reference location can be derived from the ratio of reference atmosphere to current atmosphere. The current floor can be estimated roughly by the equation (3) if the height of a floor is known.

2.3. Drift Compensation

By subtracting the estimated heights from the real heights, the error can be calculated. To minimize the error, the appropriate value for compensation is defined through the experiments. Note that the weight for compensation should be considered whether the reference atmosphere is larger than the current atmosphere or not in general.

Figures 3 and 4 show the comparison between the estimated height and the real height. As shown in the figures, the sensor drift are detected. If the estimated value is less than real value in positive side, weight value should be larger than 1 to increase value. However, weight value should be less than 1 to increase value, when the estimated value is less than real value in negative side.

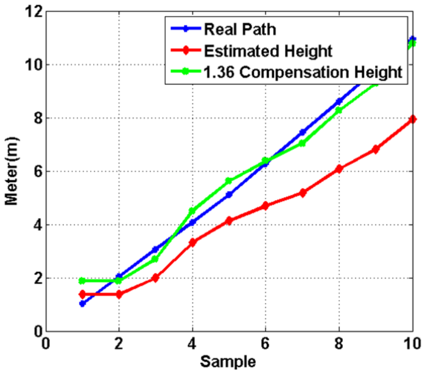

Figure 3. Comparison between the Estimated Height and the Real Height In Positive Side

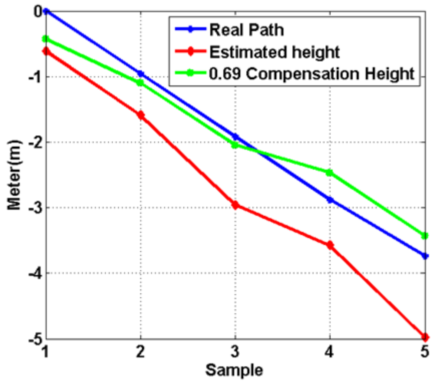

Figure 4. Comparison between the Estimated Height and the Real Height In Negative Side

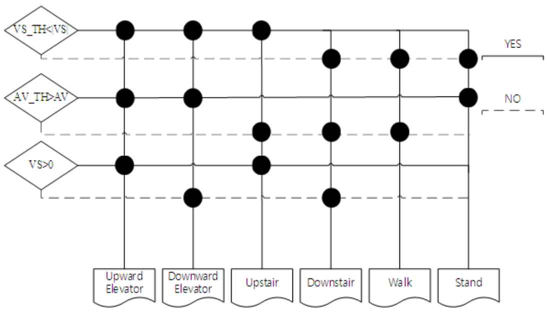

Figure 5. Classification Algorithm by Using the Thresholds, Where VS_TH Is the Threshold of Vs and AV_TH Is the Threshold of Av

When the reference atmosphere is larger than the current atmosphere, in the proposed scheme, the weight is defined as 1.36, while the weight is defined as 0.69 in the other case. Note that the value for each position is the averaged value of 100 samples at 20Hz sampling rates. The weighted heights are calculated as follows:

$$h_w = 1.36 \times h \tag{4}$$

$$h_w = 0.69 \times h \tag{5}$$

where *h* is the difference of height between the current and the reference location.

2.4. Vertical Speed

Vertical speed can be used to distinguish vertical movements from other movements. A ratio of h_w to time is defined as the vertical speed and is expressed as follows:

$$V = \frac{h_w}{t} \tag{6}$$

where v is velocity in period of h_w, t is time in period of h_w. Time of collecting data can be calculated by dividing total samples by sampling rates. The device saves the 40 samples of sensor data at sampling rate, which is 20Hz. Equation (6) indicates sign of speed that determined direction of upwards and downwards. The Equation (6) also can be used to distinguish vertical movements via stairs or elevator from horizontal movements, walking, and standing motion. If the equation (6) is positive, it means that the user moves upward direction. In contrast of upward direction, downward direction has negative sign of (6). Details of proposed classification scheme in Figure 1 are shown in Figure 5. With the velocity threshold and the AV threshold, as shown in the Figure 6 kinds of ambulatory movements can be distinguished. Movements of walk and stand are independent with the sign of estimated height and the VS, because those are horizon movements.

2.5. Variance of Vertical Accelerometer Component

As a result of rotation matrix, vertical component can be calculated. In the proposed scheme, 40samples are saved at 20Hz rates and the variance is obtained with the saved samples. The AV can be expressed as the result of calculating vertical component of accelerometer. Since the AV indicates the variance of vertical movements, the AV can detect how the user vibrates to the vertical direction. Therefore, it can figure out two different types of movements. The one is for walking, movements via stairs, the other is for standing, movements via elevator.

3. Experiment Results

The proposed scheme is evaluated with experiments at general building in university and a general smart-phone of G series of S company was used. Figure 6 shows the top view of Haw do building of our university and its entrance as a starting point of experiments. When the user enters the building, the value of GPS-SNR is decreased rapidly. Thus the starting point based on the GPS signal is regarded as the starting position of the experiments. Note that the starting point is obtained from GPS signal and it was averaged with 500 samples. For convenience and realistic results of experiments, an Android application is developed to detect the motions of the user and the floor where the user is located. Figure 7 shows a screen shot of the developed Android application program. As shown in the Figure, 6 different movements and the estimated floor information are displayed in the screen.

Figure 6. Top View of Hwado Building and its Entrance as a Starting Point of Experiments

Figure 7. Screen Shot of the Developed Android Application Program

3.1. GPS-SNR Decision

In Table 1, the 5 largest values of GPS-SNR for various situations, such as outdoor, indoor, and under a tree, are detected and compared. Note that the value of SNR is a mean of 500 samples and is ordered in terms of larger value. As shown in the table, the values of GPS-SNR are rapidly decreased by moving from outdoor to inside of the building. Since the mean of the 5 largest values of GPS-SNR is used in the proposed scheme, 30 is determined as the threshold of GPS-SNR, although there is a degradation of SNR under a tree condition.

Table 1. 5 Largest Values of GPS-SNR for Various Situations

Location		SNR1	SNR2	SNR3	SNR4	SNR5	Mean
Outside		38.7594	36.7392	35.1160	33.8068	32.2600	35.3363
Hwado	10cm in	34.5322	27.9026	25.0758	21.4280	18.5328	25.4942
	50cm in	30.3934	23.2982	21.1508	21.2920	20.7548	23.3778
Under a tree		35.0198	34.0774	33.3154	31.1708	30.1696	32.7506

3.2. Threshold Decision

Table 2 shows the variance of each motion in terms of the VS and the AV over 800 samples. As shown in the table, the VS of elevator is the largest and the VS of stairs is second one, while the AV of stairs is the largest and the AV of walking is second one. It is natural when the motions of real life are considered. Since the signs of upwards direction and downwards direction are different, the absolute value of speed components was used. Through the extensive experiments, the thresholds of VS and AV are defined as: 0.31 in AV, 0.32 in VS of stair, and 0.82 in VS of elevator. Note that they are the half of sum between standing and walking in AV, walking and stairs in VS, stairs and elevator in VS.

Table 2. Variance of each Motion in Terms of the VS and the AV

	Standing	Walking	Stairs	Elevator
VS	0.1584	0.2218	0.4114	1.2282
AV	0.0316	0.5891	0.9043	0.0278

3.3. Experiment Path

Figure 8 shows the front view of Hawdo building and the path of experiment. As shown in the figure, the user starts at the start point of the 1st floor, moves via 6th floor, and arrives at the end point of the other side of 1st floor. In detail, the user steps up via stairs to 3rd floor, and then the user moves from 3rd floor to 4th floor by the elevator. After getting out at 4th floor, the user gets in the elevator again and moves to 6th floor. In 6th floor, the user walks to the opposite side and then steps down via stairs to 5th floor. From 5th floor, the user moves to 3rd floor by the elevator and steps down via stairs to 2nd floor and then walks for a while in 2nd floor. Finally, the user steps down via stairs to 1st floor and the user stops at the end point.

3.4. Results

The experiments are performed with 6 different users and repeated 22 times. Experimental results are divided into each motion and are expressed as conditional probability. Abbreviation of each motion is defined as: UP is to move upwards via elevator, DO is to move downwards via elevator, US is upstairs, DS is downstairs, W is walking, S is standing.

Figure 8. Front View of Hawdo Building and the Path of Experiment

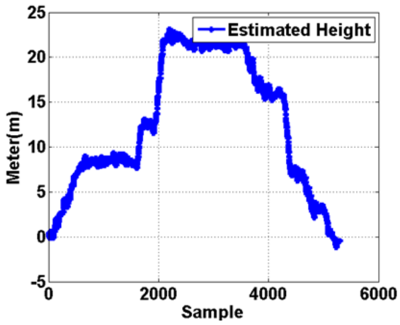

Figure 9. Estimated Height, HW

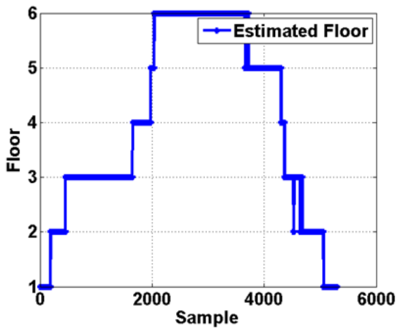

Figure 10. Estimated Floor based on Estimated Height, HW

3.4.1. Floor Detection

The floor where the user is located is determined by using the estimated heights, h_w, which can be obtained from the equations (4) and (5). Figure 9 shows the estimated height. As shown in the figure, fluctuation of barometer occurs and it can cause errors [11]. Figure 10 shows the estimated floor. As shown in the figure, the proposed scheme can classify the floor clearly without fluctuation.

3.4.2. Motion Detection

Motions are classified by the proposed algorithm, which is shown in Figure 5. In the experiments, as shown in Figure 7, the motions are classified as numbers. In the Figure 1 is to move upwards via elevator, 2 is to move downwards via elevator, 3 is upstairs, 4 is downstairs, 5 is walking, 6 is stand, respectively. The results of motion estimation are shown in Figure 11. As shown in the figure, the real motions are well matched by the proposed scheme.

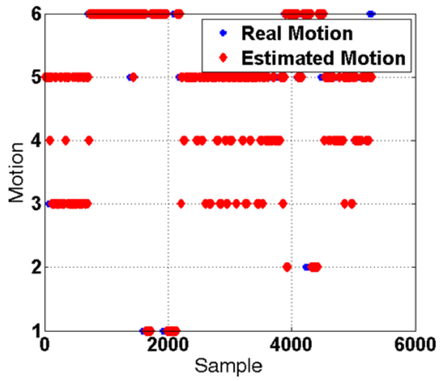

Figure 11. Comparison between Real Motions and Estimated Motions

3.4.3. Performance Evaluation

Performance evaluation is expressed as conditional probability in Tables 3 and 4. As shown in the table 3, the floor estimation is accurate as high as 94%. However, the motion estimation is not good as the floor estimation because there is alternative motion, which causes the error. By investigating the results in table 4, for example, it is noticed that the conditional probability P (UP|UP) is slightly higher than P (S|UP), while the conditional probability of other motions is negligible. Note that similar situations occurs for P (DO|DO), P (US|US), P (DS|DS), P(W|W) cases.

In case of elevator and stairs, error rate is too high. First reason is the delay of determination. When device determines the motion, it uses 40 samples of saved sensor data. 40 samples mean 2seconds. Second reason is the mistake of experimenter. For example, in case of elevator, each experimenter decided elevator motion at different time. Some recorded the elevator motion while they are waiting for upwardness or downwardness in elevator. Others recorded the elevator motion when elevator starts to move. In case of stairs, stairs are not straight. It means that they should walk for a while when experimenter moves upstairs or downstairs. Time of stairs and elevator motion is shorter than walking and stand. The time delay and the mistake of experimenter can be critical for the estimation of motions during short time. According to the Figure 11, the smart-phone matches most of real motions, while it shows the errors of delay.

Table 3. Conditional Probability of Floor Estimation

P(1|1)	P(2|1)	P(3|1)	P(4|1)	P(5|1)	P(6|1)
1	0	0	0	0	0
P(1|2)	P(2|2)	P(3|2)	P(4|2)	P(5|2)	P(6|2)
0.0418	0.9582	0	0	0	0
P(1|3)	P(2|3)	P(3|3)	P(4|3)	P(5|3)	P(6|3)
0	0.05296	0.9470	0	0	0
P(1|4)	P(2|4)	P(3|4)	P(4|4)	P(5|4)	P(6|4)
0	0	0	1	0	0
P(1|5)	P(2|5)	P(3|5)	P(4|5)	P(5|5)	P(6|5)
0	0	0	0	1	0
P(1|6)	P(2|6)	P(3|6)	P(4|6)	P(5|6)	P(6|6)
0	0	0	0	0.02241	0.9775

Table 4. Conditional Probabilities of Each Motion

P(UP|UP)	P(DO|UP)	P(US|UP)	P(DS|UP)	P(W|UP)	P(S|UP)
0.5386308	0	0.00372655	0	0	0.45764262
P(UP|DO)	P(DO|DO)	P(US|DO)	P(DS|DO)	P(W|DO)	P(S|DO)
0	0.5449252	0	0	0	0.4550747
P(UP|US)	P(DO|US)	P(US|US)	P(DS|US)	P(W|US)	P(S|US)
0	0	0.5311224	0.03618153	0.4268493	0.00058466565
P(UP|DS)	P(DO|DS)	P(US|DS)	P(DS|DS)	P(W|DS)	P(S|DS)
0	0	0.02640108	0.5712162	0.4014447	0.0009379509
P(UP|W)	P(DO|W)	P(US|W)	P(DS|W)	P(W|W)	P(S|W)
0.00069903	0.00081479	0.1458343	0.1940476	0.5897526	0.068851579
P(UP|S)	P(DO|S)	P(US|S)	P(DS|U)	P(W|S)	P(S|S)
0.01912362	0.01593179	0.00925662	0.00454714	0.03630922	0.91483159

4. Conclusions

In this paper, we proposed a classification scheme that classifies ambulatory movements of the user and the floor where the user exists with a smart-phone. In the proposed scheme, ambulatory movements of the user are classified by exploiting the barometer and the accelerometer, while the GPS data is used to classifies the floor information. With the proposed scheme, various motions, such as walking, stop, up and down motions with elevator or stairs, are distinguished by utilizing the data from the barometer and the accelerometer. An Android application is developed for the performance evaluation of the proposed scheme. The proposed scheme is evaluated with experiments at general building in university and the accuracy of the proposed scheme is more than 94% for floor estimation, although there is still works to improve the estimation of movements. According to the experimental results, it is shown that the motion estimation is not good as the floor estimation because there is alternative motion, which causes the error. However, this alternative motion can be distinguished by considering the position information of the user whether the user is near the elevator, stair, or in the aisle. Therefore, we plan to combine the proposed scheme with a positioning scheme as a future work.

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