PDR with Head Swing Detection Only Using Hearable Device

Koki Tamura
College of Information Science and Engineering, Ritsumeikan University
Shiga, Japan
tamuchin@ubi.cs.ritsumei.ac.jp

Hiroto Asai
College of Information Science and Engineering, Ritsumeikan University
Shiga, Japan
arthur@ubi.cs.ritsumei.ac.jp

Nobuhiko Nishio
College of Information Science and Engineering, Ritsumeikan University
Shiga, Japan
nishio@is.ritsumei.ac.jp

ABSTRACT

PDR is a method of estimating the relative position from initial position using only an accelerometer and gyroscope. In recent years, hearable devices are becoming increasingly popular, and there are many researches on head pose estimation with them. In this paper, we aim to realize PDR considering head pose using only sensor data obtained with hearable devices. However, horizontal head swing affects the estimation of the traveling direction of PDR when wearing the sensor on ear. Using the difference of acceleration applied to both ears to detect head swing. For evaluation, we created the device with accelerometer and gyroscope attached to the left and right speaker of the headphone. As a result of the evaluation, the accuracy of swing motion estimation is 88.0%. F-measure of head swing is 0.87. In conclusion, the detection result of swing is adopted to PDR, and realized PDR that use sensor data obtained by hearable device.

KEYWORDS

hearable; wearable; activity recognition; PDR; indoor positioning

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1 INTRODUCTION

Spreading of mobile devices available GNSS (Global Navigation Satellite System), it has become easy to obtain locational information of the device. Many services with GNSS have appeared and continuing to develop. Using satellite radio waves makes it difficult to reach indoors, resulting in large positioning errors. In order to compensate for such defects, a self-position estimation method without GNSS has been proposed. There are Wi-Fi positioning and BLE positioning that use the difference in received signal strength from the access point[1][2]. These methods can estimate the absolute position, but they require maintenance costs such as creating fingerprint and installing beacon. An another example is PDR (Pedestrian Dead Reckoning). It uses accelerometer and gyroscope equipped with the devices[3][4][5]. PDR is a method of putting a device in the waist or chest pocket, estimating the number of steps with an accelerometer and the traveling direction with a gyroscope, and accumulating them to estimate the current position. Although it is possible to estimate the relative position from the initial position only, they don't need special equipments and maintenance costs.

In recent years, spreading of wearable devices, many wearable devices that are worn on the ear are available in market. Some of them are equipped with accelerometer and proximity sensors for each of the left and right devices. Using the sensors installed in the wearable device, acquire physical information easily. Researches on services using physical information is actively conducted. People have the property of turning their face to an object of interest, therefore using this information it is possible to estimate the direction and object the user is interested. In particular, hearable devices allow user to obtain information without seeing a screen. Using it, it seems to be possible to eliminate using smart phone while walking which was a problem in the conventional navigation application. The device attached to the head can estimate the movement of the head and the direction of the face. However, it cannot estimate the direction of travel correctly if the direction of the face and the traveling direction are different. The differece was caused by horizontal head swing. Therefore in this research, we estimate the correct traveling direction by detecting the head swing. We aim to realize PDR using only the sensor data obtained by the hearable device. The difference between the accelerations applied to both ears is used to detect the head swing. We created a device with accelerometer and gyroscope attached to the left and right speaker parts of headphones. We extract the head swing section, and adopt it on the estimation of the traveling direction of PDR.

2 RELATED WORK

2.1 Research using head-mounted devices and waist-mounted devices

Takahashi et al. [6] proposed a wearable sensor device that estimates head posture relative to body posture in real time. They has two types of devices, head-mounted device and body-mounted device. A gyroscope and IR marker are mounted on head-mounted device. and a gyroscope and marker tracker are equipped on the body-mounted device. The direction of movement is estimated using a gyroscope on the body-mounted device. IR marker and marker tracker are used to correct drift error of gyroscope. However, this method requires mounting devices on the body and head respectively.

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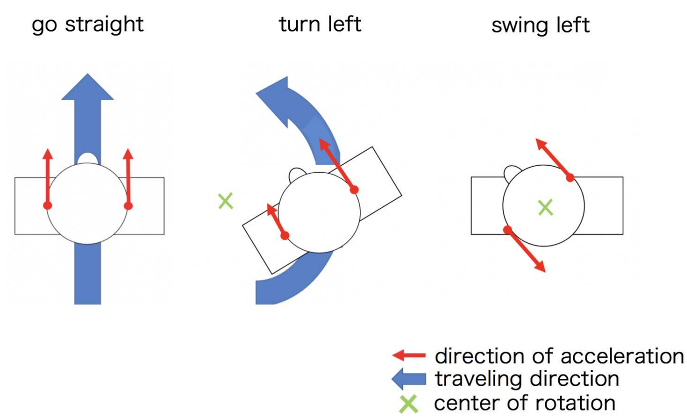

Figure 1: Direction of acceleration of ears in walking phase

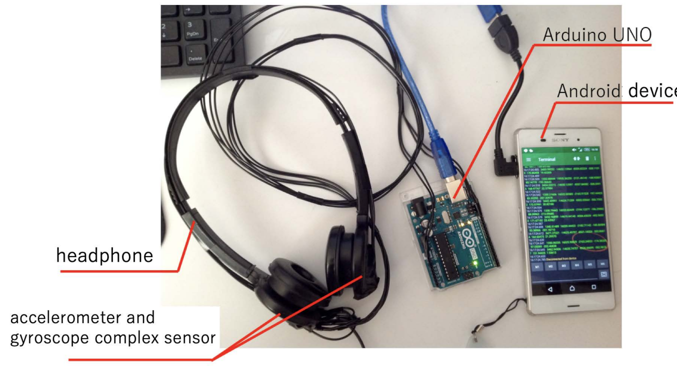

Figure 2: System overview

2.2 Research using only head-mounted devices

Sakamoto et al. [7] proposed a method for estimating the traveling direction in PDR using only a head-mounted device, and improved the accuracy of PDR. The amount of change in the horizontal component of the acceleration applied to the terminal before and after detecting the rotation while walking. The amount of change in the horizontal component of acceleration applied to a device before and after detecting the rotation of the terminal during walking is compared. If the amount of change is large, it is discriminated as turning. If it is discriminated as turning, the traveling direction is corrected. In this method, the accuracy of the identification of the swing and turn was as low as about 50%, which did not lead to a reduction in the accuracy of PDR positioning with a head mounted device.

3 HEAD SWING DETECTING SYSTEM AND METHOD

3.1 Principle of detecting head swing

This system uses the difference in acceleration applied to both ears during walking to detect horizontal swing motion. The direction of the acceleration of both ears in walking motion is shown in figure1. Figure1 is a top view of a pedestrian. In this figure, the direction of acceleration at both ears in walking motion is indicated by red arrows. The directions of acceleration applied to both ears are same when going straight and turning, but they are reversed when swing. The difference is used to detect head swing.

This method requires 2 kinds of sensor data, one for PDR and the other for detecting head swing. For swing detection, use a copy of sensor data obtained for the PDR processed according to the following procedure.

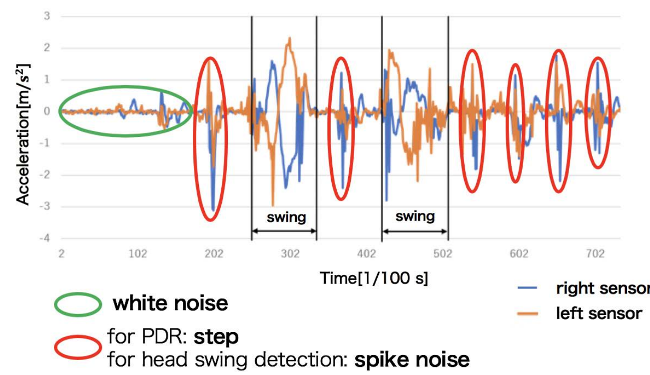

Figure 3: Acceleration of both sensors

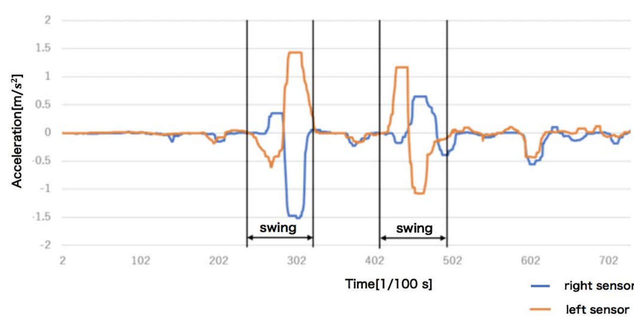

Figure 4: Acceleration of both sensors(after noise removal)

3.2 System overview

This system consists of two accelerometer and gyroscope complex sensors (MPU-6050 manufactured by InvenSense), headphone, Arduino UNO, and an Android device (Xperia Z3 manufactured by Sony Mobile Communications). In order to obtain the acceleration and angular velocity applied to both ears, a headphone type sensor device was created. The system configuration is shown in Figure2. Connect complex sensors to Arduino UNO by I2C communication, and connect Arduino UNO to Android device via USB, and receive and save sensor output by serial communication. The estimation

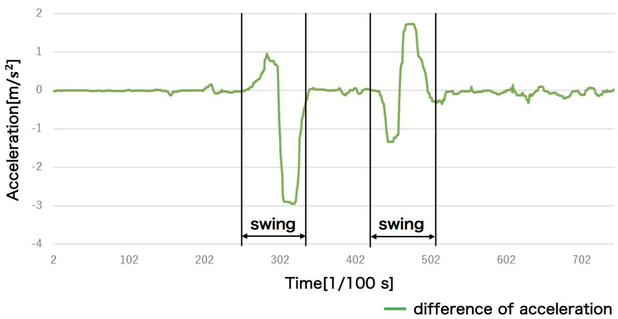

Figure 5: Difference of acceleration between both sensors

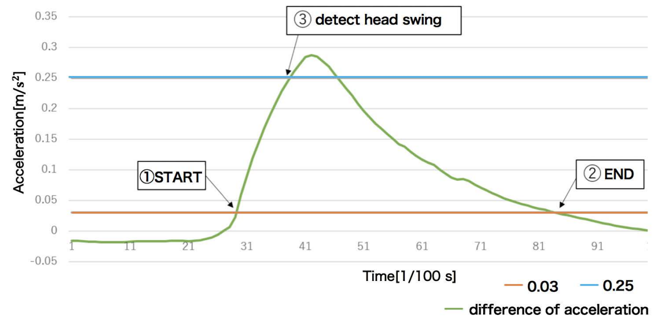

Figure 6: Extraction of head swing section

is executed on a PC using sensor data. The sampling rate of the sensor data is 100 Hz.

3.3 Axis definition

For the right and left sensors, the user's horizontal and frontal directions are Y_r and Y_l axis, and horizontal and left directions are X_r and X_l axis, and vertical upward direction are difined as the Z_r and Z_l axis respectively.

3.4 Detecting method of head swing

To detect the head swing, the change of the difference of the acceleration sensor installed in both ears is used. The data of Y_r, Y_l axis is acquired from two accelerometers. The flow of data processing is shown in the Figure3 ~ Figure 5.

3.4.1 Coordinate transformation.

In the proposed method, it is necessary to estimate the posture of the sensor device. Since the combined acceleration of 3-axis acceleration cannot be approximated to the gravitational acceleration, it is impossible to estimate the pose with the direction of gravity. Therefore, we need to use the method of Madgwick [8], which controls the posture during walking by combining acceleration and angular velocity, etc. Madgwick et al. use angular velocity to complement when gravity direction cannot be determined from acceleration. In this way, posture estimation is realized with the influence of walking motion minimized. Acceleration and angular velocity of a plane horizontal to the ground are obtained by rotating acceleration and angular velocity with respect to the horizontal plane from this posture estimation method.

3.4.2 Noise removing.

The raw acceleration data of Y_r and Y_l axes obtained from the left and right sensors are shown in Figure3. The data have in addition to the acceleration at the time of swinging and turning, white noise and spike noise. White noise is occured the sensitivity of the sensor itself, spike noise is caused by vibration of walking. These two noise are removed using a low-pass filter and a median filter. Figure4 shows the result of filtering each acceleration data.

3.4.3 Detecting of head swing.

The difference between the accelerations of the two sensors is used to detect the head swing. The waveform obtained by subtracting Y_l from Y_r can be shown in Figure5. For detection of the start and end point of the head swing, in order to extract the swing motion section from this waveform. In this system, we defined the start and end point of swing as follows. The difference means a difference of accelerations of both sensors.

- START: when the difference becomes 0.03m/s^2 or more, or -0.03m/s^2 or less
- END: when the difference becomes -0.03m/s^2 or more, and 0.03m/s^2 or less

If the value that is included in the section is 0.25m/s^2 or more, or -0.25 m/s^2 or less, the section is estimated to be the swing motion section.

3.5 Integration estimated result with PDR

In this study, we use the basic PDR algorithm which consists of step detection by 3-axis combined acceleration and direction estimation by angle calculated from integration of angular velocity. Combining it with the head swing detection, the accurate travel direction estimation is realized in the case of using a hearable devise. The rotation is eliminated by not adoping the value of the gyroscope when head swing is detected. Erros in s traveling direction due to head swing are corrected as described above.

4 EVALUATION

4.1 Experiments

In order to collect acceleration and angular velocity data of swing motion during walking, experiments were conducted with the device which we created. We conducted an experiment at the corridor of Ritsumeikan University's Learning Facility Campus Creation Core 5F, as shown in Figure7 on the way starting at point1. The correct route is a route to go straight ahead from the start point, to make a turn in the left direction, and then to go straight ahead. In addition, two swing movements were performed between the start point and the turn. Walks were performed 10 times, and 142 seconds of data (14,286 samples) were collected.

4.2 Estimated accuracy of head swing

Estimation results of head swing in time series are shown in Figure8, Figure9. Figure8 is in case of fast speed at start and end of swing motion. The estimation accuracy is lower in the slow case than in

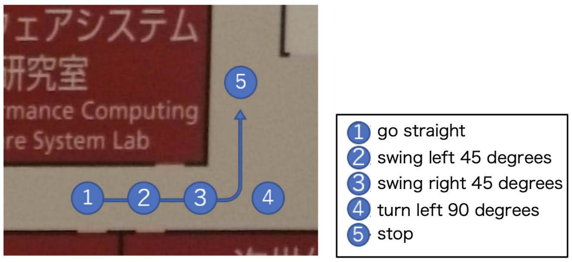

Figure 7: Experimental environment and procedure

Table 1: Estimated result

	swing (correct)	non-swing (correct)
swing (estimated)	1325	54
non-swing (estimated)	344	1615

Table 2: Estimation accuracy of head swing

	value
precision	0.96
recall	0.79
F-measure	0.87
accuracy	0.88

the fast case. In figure9, the estimated section of the swing motion is much narrower than the correct label, which is considered to be low rotational speed and no difference in the acceleration of the left and right sensors. In both figures, mis-estimation occurs in the section apart from the correct answer. This is considered to be caused by the judgment error due to the noise which could not be removed at the part of noise correction. For instance, the vibration of stepping on a ground and body shakes. In addition there are differece in the right and left sides of the sensor value, so could not complete removal of the median filter. Next, the estimation result of the swing motion is shown in the Table1. The number of samples is 3338. The estimation accuracy is 88.0%. For non-swing movements, the correct answer is 1615, and the incorrect answer is 344. The estimation error is noticeable. As described above, it is considered that the noise removal failure and the rotation speed at the start and end of the head swing are slow. The F-measure for each label is shown in the Table2. The estimated F-measure of the swing motion was 0.87, which resulted in high estimation rates.

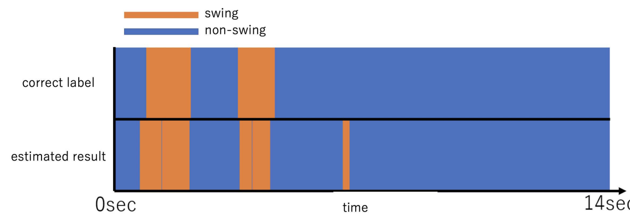

Figure 8: Estimated result in time-series order (fast rotational speed)

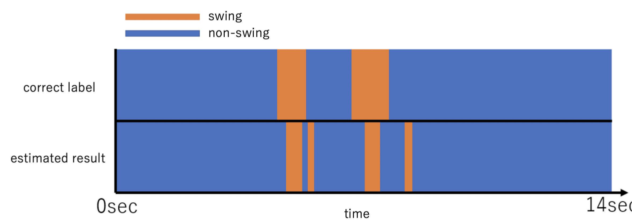

Figure 9: Estimated result in time-series order (slow rotational speed)

4.3 PDR trajectory

Positioning results of the basic PDR which is descriand in chapter 3 and the PDR which proposed method is applied are shown in Figure10. In basic PDR, the change in angular velocity due to the head swing is reflected in the direction of movement estimation. In contrast, the PDR adopted our method not reflected it, so the progress direction does not change during the head swing, and the result closer to the correct route. However, in the PDR positioning results using data with low detectional accuracy of swing, it is considered that part of the turning is misestimated as head swing, and the rotation is not reflected. Although, it is considered that there is no problem for the adaptation of map matching, etc., because the trajectory in going straight is output with straight line and the trajectory in turning is output with curve. Using this method, we obtained positioning results that were almost similar to the correct route compared to the basic PDR.

4.4 Detectionable head swing speed

In this method, head swing is detected using the difference in acceleration applied to both ears. Since the difference in acceleration decreases as the speed of swing the head slows down, and thus it can not be estimated correctly. The time taken to rotate the neck by 90 degrees was measured, and the F-measure of the estimation result for each rotation speed is shown in the Table3 ~ Table8. In the case of 128.6 deg/s, the F-measure of the swing is 0.85. Next, at 90 deg/s, the F-measure of the swing is 0.48, and the F-measure of the swing is less than 0.5. Finally, at 69.2 deg/s, the F-measure of the swing is 0.30. Although the estimation accuracy of 128.6 deg/s

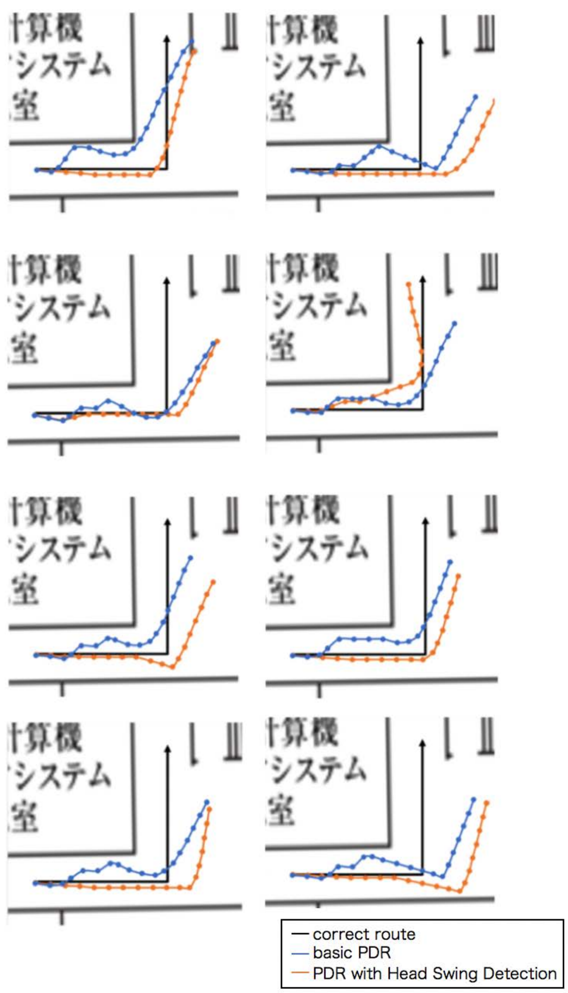

Figure 10: PDR trajectory

Table 3: Estimated result (128.6deg/s)

	swing(correct)	non-swing(correct)
swing (estimated)	528	11
non-swing (estimated)	163	639

Table 4: F-measure/accuracy of estimated result(128.6deg/s)

F-measure	0.85
accuracy	0.87

or more can maintain sufficient estimation accuracy, the estimation accuracy gradually increases between 128.6 deg/s ~ 90 deg/s. In the case of 90 deg/s or less, the estimation accuracy of the head movement is less than 0.5, resulting in unreliable estimation accuracy. The limit speed that can be handled by this method is 90 deg/s.

Table 5: Estimated result(90deg/s)

	swing (correct)	non-swing (correct)
swing (estimated)	256	0
non-swing (estimated)	536	759

Table 6: F-measure/accuracy of estimated result(90deg/s)

F-measure	0.48
accuracy	0.65

Table 7: Estimated result (69.2deg/s)

	swing (correct)	non-swing (correct)
swing (estimated)	110	1
non-swing (estimated)	472	581

Table 8: F-measure/accuracy of estimated result(69.2deg/s)

F-measure	0.30
accuracy	0.59

4.5 Delay of detecting head swing

In this method, a delay occurs at the time of noise removal of acceleration data or estimation of swing motion. A median filter is used to remove noise. Since the filter width is 21 data, the future value of 10 data is required, and the delay time is 100 ms. The swing operation starts and ends the timing when the differece of acceleration crosses 0.03m/s^2 or -0.03m/s^2. If the value contained in the section exceeds the threshold, it is detected head swing. The time from start to the crossing of the threshold is a delay time. The maximum delay time is the time from start of the head swing to the time when the speed exceeds the threshold when rotating at 90 deg/s, sinse the limit speed which can be dealt with by proposed method is 90 deg/s. The difference in acceleration when rotating at 90 deg/s is shown in the Figure11. In this case, since the delay between the starting point and detecting the head swing is 9, the delay is estimated 90 ms. From the above, it is necessary to have a delay time of 190 ms after collecting data by this method and outputting the estimation result.

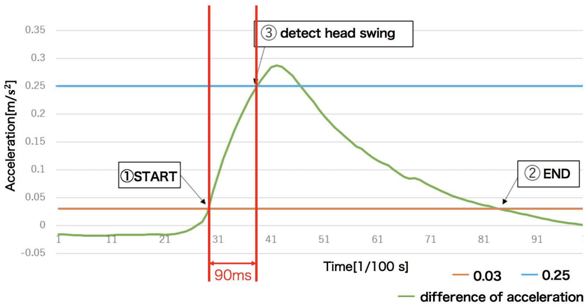

Figure 11: Delay of detecting swing when rotating 90deg/s

5 CONCLUSION

5.1 Summary

In this paper, we proposed a method of estimating swing motion using a hearable device. In previous researches for estimating head swing, there are research which use a head-mounted device and a body-mounted device, or a head-mounted type only. When PDR is used in combination with head pose estimation, the conventional PDR method can not be applied because it does not correspond to the swing motion. It is necessary to consider the swing motion in the estimation of the traveling direction of PDR with hearable device. Therefore we created a device with an acceleration gyroscope on both ears. The swing motion was estimated by using the difference of acceleration applied to both ears at the time of swing. Also, the correction was made to the estimation of the traveling direction at PDR positioning. As a result of the evaluation, the F-measure of the swing was 0.87, and the overall estimation accuracy was 88.0%. From these facts, it was confirmed that it was possible to identify swing using data obtained from the hearable device. Based on that, the PDR positioning result that has been corrected is closer to the correct route than when it is done with the conventional method.

5.2 Future work

5.2.1 Noise removing.

In this method, a median filter is used to remove the acceleration due to the vibration by landing. Median filter is suitable for the removal of sudden noise. However, some of the vibration caused of landing has a long duration, so this method cannot remove them completely. It is necessary to re-examine the filtering algorithm that can eliminate the vibration other than the median filter.

5.2.2 Estimation of traveling direction.

In the direction estimation of PDR in this method, the rotation is eliminated when head swing was detected, and the direction is corrected using the previous direction. However, an error occurs in estimation of traveling direction when turning and swing occurs in same time. Also, the positioning accuracy is decreased. Instead of not adopting the value of the angular velocity when head swing is detected, by substituting the angular velocity just before the time of swing motion detection as a constant, There is a possibility that the direction estimation can be corrected.

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