A Rotation Based Method for Detecting On-body Positions of Mobile Devices

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ABSTRACT
We present a novel rotation based method for detecting where a mobile device is worn on a user's body that utilizes the fusion of the data from accelerometer and gyroscope. Detecting the position of a mobile device could improve the performance of on-body sensor based human activity recognition and the adaptability of many mobile applications. In our method, the radius and angular velocity for a position is calculated based on the data read from the sensors integrated in a mobile device. We have evaluated our method with an experiment to detect four commonly used positions: breast pocket, trouser pocket, hip pocket and hand.

Author Keywords On-body Position Detection, Mobile Device Sensing, Rotation Distribution.

ACM Classification Keywords H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms Algorithms, Experimentation, Measurement

INTRODUCTION
In recent years, the integration of various sensors and strong computing power enables recognizing user activities by mobile devices. Being placed to different parts of the body, mobile devices can gather data through motion sensors such as accelerometers, gyroscopes and cameras. Then various human activities (e.g. walking, running and sitting, etc.) can be recognized. Since most of the methods depend on where the mobile device is worn on the body, the prediction model or the parameter is different from each position. Therefore, to achieve completely automatic recognition, the on-body position of a mobile device, as an input parameter of activity recognition algorithm, should also be detected automatically rather than inputted manually.

Mobile device on-body position detection method could also be valuable to improve the adaptability of other mobile applications. The replacement of a mobile device may be caused by the state transition of a user. Then the running application may adapt to the transition and change the working mode correspondently. For example, when a mobile device is put into a pocket, the brightness of the screen could be turned down to save energy. The ring mode (e.g. volume and vibration) could also be flexible according to the position in case the incoming call is missed.

In this poster, we propose a novel method for recognizing mobile device positions on a user's body. Our method is based on the assumption that different positions will have distinct rotation angular velocity and radius distribution during the movement due to the difference of the limb structure. The angular velocity can be read directly from the gyroscope equipped in the device and the radius can be calculated from the fusion of acceleration and angular velocity by employing both of accelerometer and gyroscope. After that, feature vectors describing the distribution are extracted to train a classifier. To satisfy the daily use requirement, the places to put the mobile device include the breast pocket, trouser pocket, hip pocket as well as user's hand.

ROTATION BASED METHOD
The rotation based method makes use of the characteristic of rotation component in the motion. When a mobile device is put somewhere on a user's body, its motion sensors will sense the composited motion which is caused by several forces. These include the integral movement of the user, the change of the direction to the gravity and the relative motion of the limb to the whole body, etc. For the motion of the limb, it can be simplified as the rotation around a joint by the rigid body model. For example, if a mobile phone is put in a trouser pocket, part of its movement is caused by the rotation of the thigh around the hip joint. As limbs will perform differently during an activity, their rotation mode relative to the joint will also be diverse.

Quantities of Circular Motion
In physical circular motion model, there are two independent quantities determining how to rotate, which are rotation radius and angular velocity. When a device is in certain pocket, the distance from it to the joint is related to the rotation radius and the speed of the limb's motion is described by the angular velocity. Therefore, the distribution features of radius and angular velocity in a time window should be characteristic for each position. Figure 1 shows the distribution of rotation radius r and regular velocity ω from a subject's data in four positions when he is walking. The x-axis presents the data magnitude range

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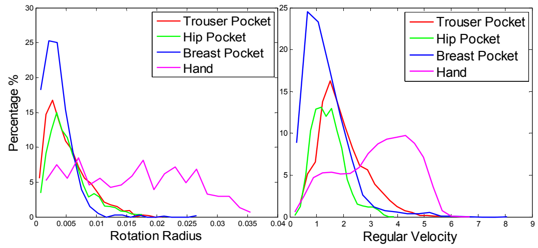

Figure 1. The distribution of rotation radius and regular velocity in four positions. The data points are from a 60s time window and partitioned into 20 bins.

while the y-axis presents the percentage of data points in each bin. The original angular velocity data from gyroscope is 3-dimensional. To make it invariant to the orientation, we use the magnitude of the three elements in the calculation. From the figure we can see that when the device is in hand, the distribution spreads widely in an upper range, while in other positions the peaks are narrower and concentrate in a lower range.

From the model of circular motion, when rotation is dominant, the rotation radius r can be calculated approximately as

$$r = a / \sqrt{\omega^4 + (\frac{d\omega}{dt})^2}$$

where a is read from the accelerometer and ω is from the gyroscope.

In each time window, the radius and angular velocity forms a distribution separately. For each quantity's distribution, seven features are chosen: mean, variance, kurtosis, skewness, and the three quartiles (25%, 50% and 75%). In the experiment, support vector machine (SVM) is used as the classifier.

EXPERIMENT

To evaluate our method, we conducted an initial experiment using iPod touch 4 [3]. An iOS application MotionLogger from our lab was installed to record the motion data. Each data point contained time in milliseconds, 3D acceleration without gravity component and angular velocity in 100Hz.

To make use of the diversity in the rotation mode, the corresponding component should be dominant in the composited motion, as data sensed cannot be completely divided. So a proper working scenario for the detection should be set. In this evaluation, we choose "walking" as the first scenario for the detection.

		Predicted Position			
		Trouser Pocket	Hip Pocket	Breast Pocket	Hand
Actual Position	Trouser Pocket	88.92%	8.17%	0.37%	2.54%
	Hip Pocket	3.25%	95.42%	0.50%	0.83%
	Breast Pocket	0%	1.08%	95.29%	3.62%
	Hand	6.5%	2.92%	3.46%	87.13%

Table 1.Confusion matrix for on-body position detection.

There were 4 users participated in our experiment: 2 males and 2 females. iPod touch was place in the four commonly used positions: left breast pocket, left trouser pocket, right hip pocket and left hand. Meanwhile, each user performed their normal walking with iPod touch in each position for 10 minutes and there was no special instruction about the orientation of the device.

Classification results based on Libsvm [2] show that setting the window length as 10s, our method with 14 features (7 features for each quantity) achieved average accuracy of 91.69% (5-fold cross validation). Table 1 shows the confusion matrix. We also get from the result that the fusion of the two quantity feature sets achieved better results than any one of them alone (76.04% for radius and 86.84% for angular velocity). This result gave the first evaluation for the effectiveness of our rotation based method to detect where a mobile device is.

CONCLUSION AND FUTURE WORK

We present a technique to detect the on-body position of a mobile device based on the calculation of two physical quantities in rotation: radius and regular velocity derived from acceleration and gyroscope. After getting the data points for each time window, 14 features that describe the distribution are extracted and inputted into a SVM classifier. An initial experiment with 4 users is conducted to evaluate our method. We are planning more evaluations and developing several position adaptive applications

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