Research of MEMS Accelerometers Features in Mobile Phone

Maxim Grankin, Elizaveta Khavkina, Alexander Ometov

Saint-Petersburg State University of Aerospace Instrumentation
Saint-Peterburg, Russia
m.grankin@vu.spb.ru, el.khavkina@gmail.com, axelbrains@mail.ru

Abstract

The purpose of this study is exploring the possibilities of MEMS accelerometer of mobile phone Nokia N900 to determine human gait or similar tasks. This study answers the question of whether you can use this sensor to solve these problems. Main emphasis is on accelerometer-based human gait identification. Previous studies proved that human gait contains very distinctive patterns that can be used for identification and verification purposes. There are different approaches for identification of a gait: accelerometers [1], sensors on the floor [2], motion analysis system, image registration. This means that person can be recognized by his walking style using MEMS accelerometers, which modern phones are equipped by.

Index Terms: Accelerometer, MEMS, Identification, Gait detection.

I. Introduction

There are a lot of various sensors in modern smartphones, such as accelerometer, gyroscope, pressure sensor, light sensor. Most of the sensors in smartphones are MEMS (Microelectromechanical systems**)** based. In this work we were studying potentialities of built-in MEMS-based accelerometers.

In a very simple sense MEMS are small chips equipped with one (or multiple) sensors utilized to detect a change and relay that data back into the system to cause some new reaction or adjustment. The common benefits afforded by these technologies are:

- low cost;
- miniaturization;
- low power consumption;
- mass distribution in mobile phones.

The accelerometer is component that is becoming a standard item in new devices. MEMS-based accelerometers include series of needle-like structures that detect motion, generating the readings, and then transmit them to the main circuit. The accelerometer in the Nokia N900, with which we worked, is a STMicroelectronics LIS302DL.

An accelerometer is a sensing element that measures acceleration as well as tilt, tilt angle, incline, rotation, vibration, collision and gravity. However MEMS-based accelerometers have one significant disadvantage – very low accuracy in comparison with more expensive sensors. This disadvantage wasn't very big problem while accelerometer in smartphones was used for very simple tasks, such as positioning of images on the phone, but it's not enough for complex tasks which require higher accuracy. In addition, this phone uses quantization output of accelerometer, which significantly reduces the accuracy of the measurements.

But now many scientists and developers search for new ways to use MEMS-based accelerometers: from more simple tasks such as pedometer and to very complex such as gesture recognition or tuning inertial navigation system.

Previous studies proved that human gait contains very distinctive patterns that can be used for identification and verification purposes. There are different approaches such as identification of human [1, 2, 3], health monitoring [4, 5, 6] and calculation of passed distance [7, 8]. Objective of this paper is to study the usability of MEMS accelerometer of mobile phone Nokia N900 to determine human gait and other similar tasks.

II. Our tasks

A. Patterns of movement

Our purpose is to calculate the rate of movement, but now it's very difficult task, so we use patterns. Movement is divided into three patterns: inactivity, walking and running. Depending on pattern we can, for instance, switch phone's modes, such as sound volume.

For pattern analysis accelerometer data were transferred to the frequency domain using the Fast Fourier transform (FFT). We have found that in the frequency domain when running frequency of the main peak is more than walking. In other words if peaks of the spectrum are located in the left frequency part with respect to vertical boundary, it means that person is walking, if in the right part – person is running (see Fig 1.).

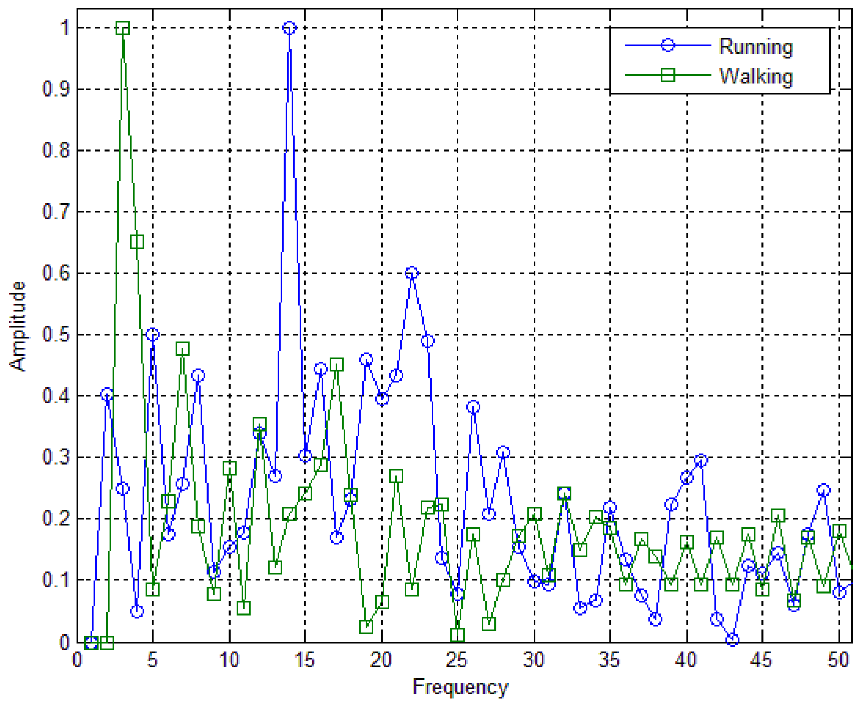

Fig. 1. Frequency domain of run and walking patterns

In the future we plan to study the change in the frequency domain of human gait, depending on the frequency of steps.

B. Inertial navigation system

An inertial navigation system (INS) uses motion sensors (accelerometers) and rotation sensors (gyroscopes) for continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references. It is used on vehicles such as ships, aircraft, submarines, guided missiles, and spacecraft. We conduct some simple experiments to determine the trajectory of motion. Unfortunately, these experiments show that the accuracy of MEMS sensors is not enough even to move small distances. This means that INS solutions do not work for this task today.

C. Identification

A number of biometric methods of identification have been introduced over the years, such as eye scans (retina or iris), fingerprint recognition, hand or palm geometry, voice recognition, facial recognition, heartbeat biometrics and others. But most of them either require expensive and specialized hardware or are inefficient as often inexpensive systems are prone to errors of the second kind (for instance, built-in laptops fingerprint readers).

Therefore we've decided to study the ability to identify human using his gait. It is inexpensive because of using built-in MEMS-based accelerometers and also requires no specific actions from the user except just walking.

However, we have some problems with this system that we want to eliminate during this project. These problems connected with both the inaccuracy of device and some domestic reasons, for instance, other clothes and footwear can change the gait. The problems with device lie in the low accuracy of the MEMS-based accelerometer. Furthermore, we were confronted by problems with value quantization of the accelerometer data by the device itself that can't be changed.

Our algorithm is based on FFT. But since FFT calculations are very complex for smartphone's processors we perform calculations on the server: smartphone transmits accelerometer's data to server via Wi-Fi.

1) Scenarios: A certain organization wants to check paths of employees in its territory. The organization has server, which stores gate data of every employee. When employee enters the territory his smartphone connects to server and transmits accelerometer's data. The server performs the calculations and defines this person as one of the employee so it's possible to check where he is going and compare his current path with his path's pattern.

Another scenario is theft detection. The smartphone performs the calculations uninterruptedly and if it is stolen, it will block and, for example, send warning message with location coordinates to police.

2) Algorithm: One of the problems is to recognize a moment when a person is walking via accelerometer indications. We propose a solution which is based on a similarity of accelerometer signal spectrums via different axes (X, Y, Z) and a low variance of accelerometer's signals during human walking (gait detection). This can be done by applying Fast Fourier Transform to the signals obtained from the different axes of accelerometer.

The advantages of the solution are:

- spectrum of accelerometer data allows identification of a human gait;
- FFT can be efficiently implemented in hardware.

The main idea is that certain identifier, called the Gate Data (GD), is calculated for every walking person. Then the GD of this person is compared with database of other GD and the system makes a decision on further actions. The principal calculations of getting GD are performed in the frequency domain.

Getting identifier (GD)

Signal of length N obtained from one accelerometer axis is divided into overlapped windows of length L, i.e. every next window overlaps previous window by $L-1$ samples. Thus there are $N-L$ windows for every axis. For every triplet of windows a_x, a_y, a_z, from the axes X, Y and Z correspondingly, the following steps are performed:

Step 1. Calculate FFT of a_x, a_y and a_z. Let us denote results as FFT_x, FFT_y, FFT_z (here and below if superscript isn't specified, it is a vector of a length L, otherwise if superscript is specified, it is a component of the vector).

Step 2. Remove constant (DC) component from a_x, a_y and a_z by applying the following formula:

$$FFT_j^{(0)} = 0,$$

where $j \in [x, y, z]$.

Step 3. Calculate normalized spectrums (let us denote them as $AFFT_x, AFFT_y, AFFT_z$), by applying the following formula:

$$AFFT_j = |FFT_j| / \max_{i=1,L} |FFT_j^{(i)}|,$$

where $j \in [x, y, z]$.

Step 4. Calculate sum of pairwise squared differences by the following formula:

$$SSD = \sum_{i=0}^{L-1} (AFFT_x^{(i)} - AFFT_y^{(i)})^2 + (AFFT_x^{(i)} - AFFT_z^{(i)})^2 + (AFFT_y^{(i)} - AFFT_z^{(i)})^2 .$$

After completing these steps for every window we'll get vector SSD of length $N-L$. In this vector we find the minimal point. Then we take the window of length L starting with this point from axis with highest average acceleration. This window will be the GD:

$$AFFT = AFFT_j;\ j : \left|\overline{a_j}\right| = \max([\left|\overline{a_x}\right|, \left|\overline{a_y}\right|, \left|\overline{a_z}\right|]).$$

Collect gait data algorithm shown in Fig. 2.

Comparison of identifiers:

Compare obtained identifier GD with every identifier from the database (GDb). Shift GD regarding GDb to j samples, where $j = 0 \ldots L-1$. Calculate Dif_j at every step:

$$Dif_j = \sum_{i=0}^{L-1} \left(GD^i - GDb^i\right)^2 .$$

As a result we get vector Dif. In this vector we find the minimal value and this value is divergence between two identifiers.

Perform the same actions for other identifiers from the database and find minimal divergence among all identifiers. It's required identifier that belongs to one person. If divergence is too big for all identifiers in the database we can say that there is no such person in the database.

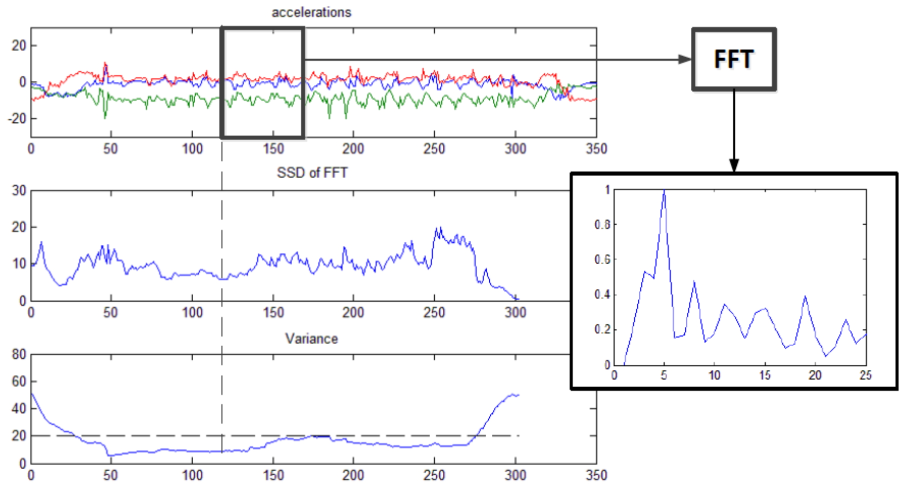

Fig. 2. Collect gait data algorithm

This algorithm has been tested for five people with accelerometers data taken from a mobile phone Nokia N900. The test gate of each of person was compared with his GDb (see Table I).

TABLE I
TEST OF GAIT IDENTIFICATION ALGORITHM

	Test walking person 1	Test walking person 2	Test walking person 3	Test walking person 4	Test walking person 5
GDb person 1	**1,07**	2,08	**0,97**	2,39	1,8
GDb person 2	1,3	**1,25**	1,42	2,17	1,87
GDb person 3	1,37	1,34	**0,99**	2,14	1,58
GDb person 4	1,82	1,76	1,25	**0,71**	1,67
GDb person 5	1,33	1,69	1,1	1,03	**0,38**

The gait of each of person was compared with his *GDb*. Only one of five identifications was a mistake (person 3). This is due to low accuracy readings phone, which we have mentioned above.

D. Health monitoring

This task is our future research direction. It also will be connected with human gait, since we want to study the potentialities of using smartphone to diagnose injuries and diseases of the lower extremities. Similar research has already been carried out [5]. Authors of this article used the smartphone accelerometers to diagnose physical and psychological state of health, such as sickness, stress and fatigue. However, we want to lay emphasis exactly on diagnostics of diseases of the lower extremities.

In recent years the biomechanical and electro-physiological methods of gait analysis increasingly develop [6]. It was found that patient's gait changes if he has diseases of the lower extremities: walking pace slows down, phases of step expand in time. These biomechanical studies provide an opportunity to recognize some of the diseases at the earliest stages. But this diagnostic methods use expensive and bulky equipment and if you want to be diagnosed it is necessary to visit medical institution. Therefore, we'll try to port the existing biomechanical diagnostic methods to portable devices that use MEMS-based sensors. Of course, this development will be aimed just at addition to already existing diagnostic methods, because MEMS-based sensors don't have sufficient accuracy yet. However, this technology is able to detect anomalies in gait and notify the owner of the necessity to pass the diagnostics.

Other possible direction is to detect if the person is drunk. It can be done by using a set of methods that were described above. Although the accuracy of MEMS is insufficient for INS the same approach can be used to check if the person is walking straight or not. It can be useful to detect e.g. intoxicated drivers.

III. Conclusion

These studies have shown that the MEMS accelerometer can be used to solve complex problems such as the identification and determination of human movement patterns. It was shown that frequency analysis of acceleration allows us to identify the person. Unfortunately, experiments show that the accuracy of Nokia N900 sensor is not enough for faultless applications work.

In the future, we plan to focus on the problem of health monitoring and will use other mobile devices to test the proposed methods.

Acknowledgment

The authors would like to thank Sergey Balandin for providing telephone Nokia N900.

References

[1] Mohammad O. Derawi, Patrick Bours, Kjetil Holien, "Improved Cycle Detection for Accelerometer Based Gait Authentication," in *Int. Conf. on Intelligent Inform. Hiding and Multimedia Signal Process.*, Harbin, China, 2010, pp. 312-317.

[2] Murat Ekinci, "A New Approach for Human Identification Using Gait Recognition," in *Int. Conf. on Computational Sci. and Its Applicat.*, vol. part III, 2006, pp. 1216-1225.

[3] Mostayed A., Mynuddin M., Mazumder G., Sikyung Kim, Se Jin Park, "Abnormal Gait Detection Using Discrete Fourier Transform," in *Int. Conf. on Multimedia and Ubiquitous Eng.*, 2010, pp. 36-40.

[4] Yu-Jin Hong, Ig-Jae Kim, Sang Chul Ahn, Hyoung-Gon Kim, "Mobile health monitoring system based on activity recognition using accelerometer," *Simulation Modelling Practice and Theory J.*, vol. 18, issue 4, pp. 446–455, 2010.

[5] Joshua Juen, Bruce Schatz, "Health Monitoring using Gait Analysis from Smart Phone Accelerometers," in *AMIA Annu. Symp. on Biomedical and Health Informatics*, Washington, DC, USA, 2011.

[6] Alexey Zhilyaev, "Biomechanical and electro-physiological criteria of estimation of the functional state of the musculoskeletal system of the lower extremities," Ph.D. dissertation, Moscow, Russia, 2003, (in Russian).

[7] Ryan Libby. (2008). *A simple method for reliable footstep detection on embedded sensor platforms* [Online]. Available: http://ubicomp.cs.washington.edu/uwar/libby_peak_detection.pdf

[8] Neil Zhao, "Full-Featured Pedometer Design Realized with 3-Axis Digital Accelerometer," *Analogue Dialog*, 44–06, 2010.