Integrating Pressure Sensors and Accelerometers for Footwear-Based Human Probes

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ABSTRACT

Recent mobile devices are integrated with various kinds of sensors, thereby allowing people to capture what stationary sensing devices cannot easily acquire. We term the systems and practices that exploit the ubiquity of the users of such devices Human Probes. Human Probes, as they allow for the acquisition of a variety of contextual information, facilitate collaborative information sharing and community action as well as the provision of personalized services such as personal health management and context-aware advertisements. To realize a Human-Probe environment, our research group has examined the usefulness of pressure sensors embedded in shoes [1][2]. As accelerometers can be easily embedded in shoes as well, it is meaningful to examine the uses of not only pressure sensors but also accelerometers. In this paper, the close examination of the signals from both sensors reveals the strengths and the weaknesses of each, and suggests the possibility of their complimentary use to support Human Probes.

Author Keywords

Pressure sensors, Accelerometer, Human Probes.

INTRODUCTION

Recent advances in the MEMS technology made it possible to integrate small inexpensive sensors in mobile devices. Since users can take sensor-enabled mobile devices to wherever they go, they can capture and analyze the kind of sensor data that cannot be easily captured by using stationary sensors. In particular, mobile sensing allows users to capture their biological information as well as the information about their physical environments. Indeed, mobile sensing is already used in some dedicated medical and fitness devices [3]. Sensors can be integrated in a belt, wristwatch, mobile phone, bicycle, or umbrella, and therefore users can carry sensors in different ways. Existing research projects exploit various sensors such as gyro, pressure, temperature, and sound sensors as well as accelerometers [4][5]. In general, these sensors are selectively utilized to capture different types of information. Walking is a ubiquitous activity in our everyday lives, and therefore estimation of walking-relevant context is an important challenge. There is a variety of contextual information in our everyday spaces, including the information about the weather, crowding, and sidewalk surface condition. If pedestrians can capture such contextual information, we can visualize the information on a map, or use it to trigger actions in interactive applications. We can also provide navigation aids for pedestrians considering walkability, if sidewalk surface condition can be captured by using sensors. One of the most important issues in mobile sensing and context estimation is the selection of the right kind of sensors. It is important to consider the limitations to the resources of mobile devices, equipping a mobile device with too many sensors can reduce the lifespan of the device and make computational processing unnecessarily complex. In addition, users may not be comfortable wearing a number of sensing devices, and therefore too many sensors can negatively impact system adoption. It is desirable to use the minimum number of sensors that can support the intended application.

SYSTEM IMPLEMENTATION AND EXPERIMENTS

We designed and implemented a system that captures data from accelerometers and pressure sensors embedded in shoes. We then collected data from a pedestrian who put on the sensor-enabled shoes and walked in a city.

Sampling rate

In this work, we used the sampling frequency of 50 Hz, which is the maximum frequency in this prototype system, and allows for a detailed analysis of the data from the two types of sensors. When actually building it in the system, it is necessary to use the best sampling rate based on the result of this study.

System Overview

Figure 1 shows the overview of the system that integrates pressure sensors and SunSPOTs [4]. The SunSPOTs, which are equipped with a three-axis accelerometer and a wireless communication interface (IEEE802.15.4), are attached at the heel portions of the shoes, with x, y, and z axes pointing to the directions shown in Figure 1. Two pressure sensors are embedded in a shoe, one at the toe and the other at the heel portion. The X axis corresponds to the right and left movement of feet, which we did not examine in this research. Using wireless communication, a mobile PC receives some data which are captured by two kinds of sensors.

Experimental Fields

Using the system, we carried out field experiments in four different walking conditions (see Table 1).

DATA ANALYSIS

We collected data in four different places in Tokyo, each of which corresponds to different walking conditions in Table 1. This section presents the analysis of the data.

Preliminary Analysis of Pressure Data

Figure 2 shows the pressure values measured by two pressure sensors in a shoe. The user walked on a flat pavement surface wearing this shoe. It is likely that the peak patterns could provide useful information for estimating the context of walking. Figure 3 shows the data when the user waked an a lawn surface. Compared to the data shown in Figure 2, the peak pressure values are much smaller in Figure 3. Similarly, walking on stairs generate unique peak pressure patterns at the heel and the toe. Moreover, When the user walked on a slope, the pressure signals at the toe increased at a different rate. Figure 4 shows the distribution of the peak values at the toe and the heel for each walking environment. The distribution suggests that we can estimate the ground-surface conditions using learned threshold values. In addition, pressure sensors could be useful for measuring the inclination of the user's body. Our preliminary analysis suggest that the pressure sensors embedded in shoes can provide information that is useful for understanding the context of walking such as ground-surface conditions.

Preliminary Analysis of Acceleration Data

We can also estimate the context of walking by examining acceleration patterns. Figure 5 shows the acceleration data along the y and z axes, which were captured from a pedestrian walking on a flat surface as he pulls his foot up and moves it forward and down. Figure 6 shows the data that corresponds to an upward step on stairs. As shown in Figures 5 and 6, the extent of the movement along the Y axis is different in A and B. This difference can be used to estimate the condition of the ground surface. Also, the acceleration along the Z axis varies differently in different ground surface conditions. Some ground surface conditions prevent the user to make a big stride, and the acceleration along the Z axis would reflect the limited stride length. Figure 7 shows the maximum extent of the movement of the acceleration values along the Y axis, for each type of walking. This shows that it is difficult to precisely classify ground surface conditions by using the Y-axis data. The data however can be used to classify the level of limitations that are imposed on the up and down movements of a foot. Overall, our result suggests that Y axis data is useful for obtaining information about the up and down motion of a foot. As for the data along the Z axis, we have observed the repetitive wave patterns in Figures 5 and 6. Also, the wave patterns were affected by the level of limitations imposed on stride lengths. Therefore, our result suggests that the data along the Z axis are useful for obtaining information about stride lengths. Overall, these results reinforce the intuition that acceleration sensors are useful for acquiring contextual information about walking, in particular, the information about the movement of a pedestrian.

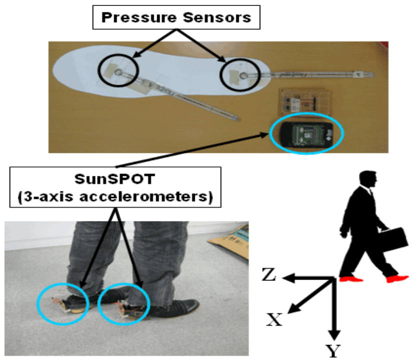

Figure 1. Sensor-enabled shoes.

Walking conditions	Details
Flat surface	Asphalt pavement
Stair	18cm-high, 28cm-wide steps
Slope	25-degree slope
Lawn	15cm-high grass

Table 1. Walking conditions.

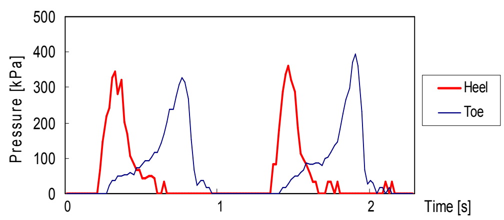

Figure 2. Pressure values when walking on a flat surface.

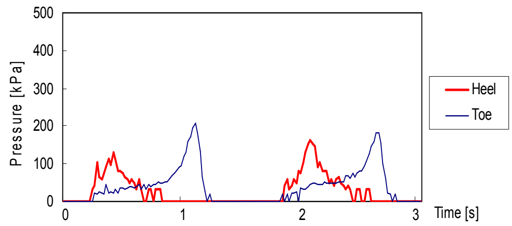

Figure 3. Pressure values when walking on a lawn surface.

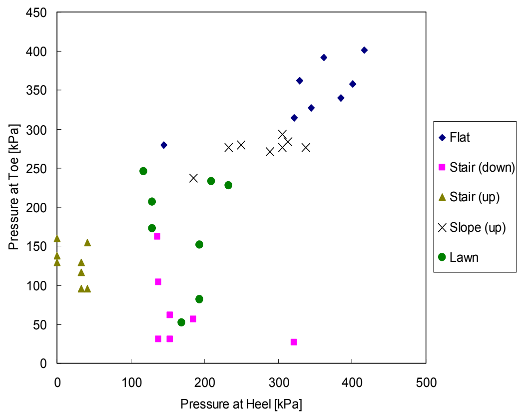

Figure 4. A distribution of peak values of pressure sensors.

Complimentary Usage of Sensors

Based on the results discussed above, we can say that acceleration sensors are useful for detecting dynamic context such as walking behaviors and pressure sensors for detecting postures and ground surface conditions. That is, these two kinds of sensors can complement with each other to capture dynamic as well as static information about walking. Figure 8 shows the acceleration and pressure data that were measured at the same time. It is apparent that when the data from one sensor do not seem to show any interesting patterns, the data from the other sensor show a more complex, seemingly interesting patterns. By carrying out sensing using both of these complimentary sensors, we can capture the information that we might miss when using only one of these sensors. Additionally, the combination of these sensors can be useful for improving the accuracy of sensing, and for capturing the contextual information that we cannot capture by using one of these sensors. Figure 9 shows the case in which such complementary sensing is useful for improving sensing accuracy. In this case, the use ran down on a steep slope, making irregular movements as if he was stumbling along. As shown here, the acceleration data along the Y and Z axes look very 'messy' and therefore it is difficult to segment the data into short time frames, each of which corresponds to a footstep. However, using the pressure data, we can trace the transition of peak pressure values at the heel and the toe to extract some important information about walking. The system can use the encircled values in Figure 9 to detect a time frame that corresponds to a footstep. And we can use pressure sensors to segment the acceleration data, and then estimate stride lengths and up and down foot movements using the segmented data. When we analyze walking, it is necessary to detect the delimitation of one step. In this way, the measurement can be supplemented with both sensors.

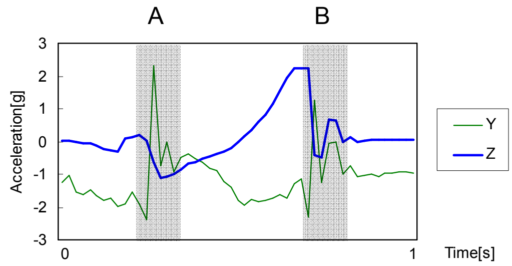

Figure 5. Acceleration values when walking on a flat surface.

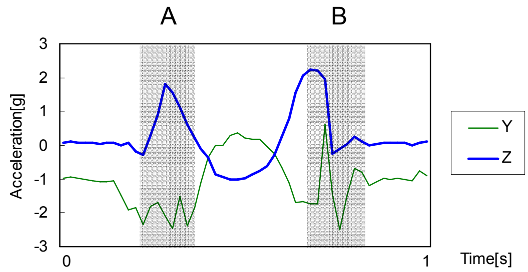

Figure 6. Acceleration values when walking on an up Stair.

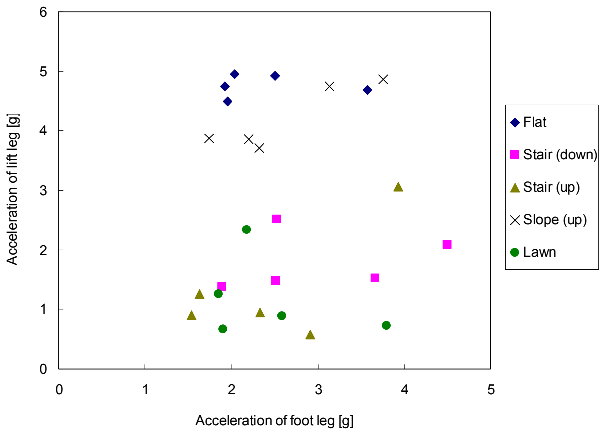

Figure 7. A distribution of peak values of Y-axis Accelerometers.

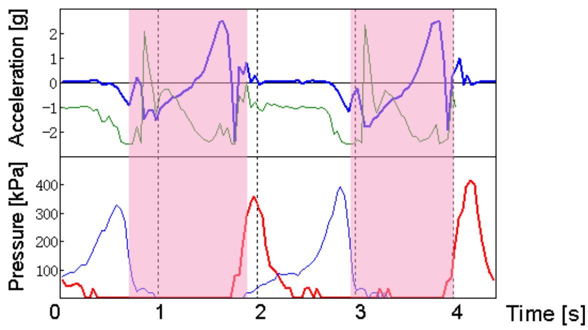

Figure 8. Complimentary use of accelerometers and pressure sensor.

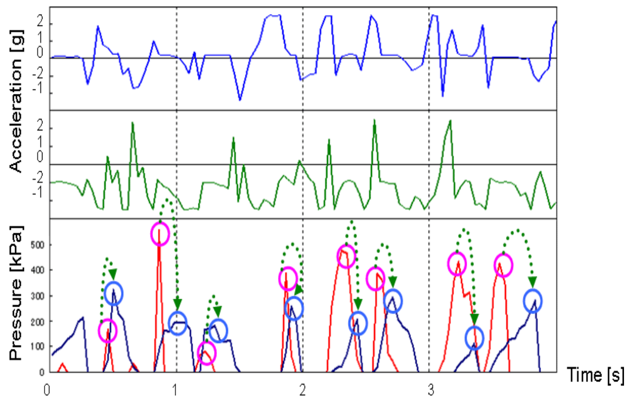

Figure 9. Detection of complicated walking data.

RELATED WORK

AoK [1] is a system that integrates pressure sensors in slippers so as to detect users' walking patterns. By integrating sensors in everyday objects such as slippers, users can sense their biological information without explicitly attaching sensor devices on their bodies. WINFO+ [2] combines pressure sensors and heart rate monitors, and also captures geographical information. Pressure sensors that are attached to shoes detect users' walking patterns, and heart rate monitors capture users' heart rates during the exercise of walking; and the system integrates the information from these sensors and relevant geographical information to generate map-based visual representations. K.Yonekawa et. al [7] use pressure sensors in shoes and measure fatigue levels.

CONCLUSION

The results of our analysis suggest that acceleration and pressure sensors are both useful for estimating the context of walking. However, if one is only interested in basic information about walking, pressure sensors may be the technology of choice as they allow for a simple approach to detection that focuses on the peak pressure values. Pressure sensors would allow us to accurately count the number of footsteps by taking a look at the peak values at the heel and the toe, even when users walk in an irregular manner that makes it difficult to extract useful information from acceleration data. Acceleration sensors also have strengths. They are useful for estimating the context that is related to foot motions, including stride lengths and up-down movements. Our results also suggest that pressure sensors and acceleration sensors can play complementary roles, as the former is advantageous in sensing static contexts of pedestrians and the latter dynamic contexts. We can improve sensing accuracy, and also capture information that we cannot obtain by using only one of the sensors. In our future work, we will carry out more experiments to examine if we can effectively detect various conditions of slopes, stairs and flat surfaces using this combination of sensors. We will also develop algorithms for classifying these conditions.

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