A Shoes-Integrated Sensing System for Context-Aware Human Probes

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Abstract. *Human Probes*, which are human integrated or embedded with sensors, allow 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. Recently, we have examined the usefulness of pressure sensors embedded in shoes [2]. In this demonstration, we extend our previous research on embedded pressure sensors by considering complimentary uses of accelerometers so as to capture precise and meaningful context in our daily lives. Pressure sensors and accelerometers are similarly useful for capturing the motion of pedestrians; however, 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.

1 A Human-Probe System

We designed and implemented a Human-Probe system that captures data from accelerometers and pressure sensors embedded in shoes. Figure 1 shows the overview of the system that integrates pressure sensors and Sun SPOTs [1]. The Sun SPOTs, which are equipped with a three-axis accelerometer and a wireless communication interface, are attached at the heel portions of the shoes, with x, y, and z axes pointing to the directions shown in Fig. 1. Two pressure sensors are embedded in a shoe, one at the toe and the other at the heel portion.

Using the system, we carried out field experiments and collected data from a pedestrian who put on the sensor-enabled shoes and walked in four different walking conditions (see Table 1).

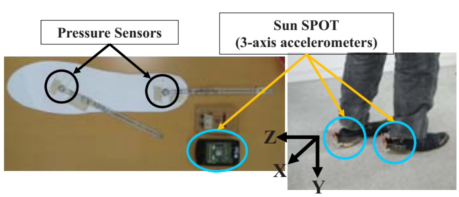

Fig. 1. Sensor-enabled shoes

H. Kitagawa et al. (Eds.): DASFAA 2010, Part II, LNCS 5982, pp. 424–427, 2010.
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Table 1. Walking conditions

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

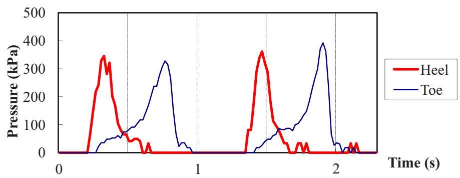

Fig. 2. Pressure values when walking on a flat surface

2 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.

2.1 Analysis of Pressure Data

Figure 2 shows the pressure values measured by two pressure sensors in a shoe. It is likely that the peak patterns could provide useful information for estimating the context of walking. Figure 3 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. We conclude that the pressure sensors embedded in shoes can provide information that is useful for understanding the context of walking such as ground-surface conditions.

2.2 Analysis of Acceleration Data

We can also estimate the context of walking by examining acceleration patterns. Figure 4 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. We found that fluctuation patterns of y-axis acceleration data in A and B shaded periods in the figure are different for each walking condition, thereby allowing us to capture information related to up-down motion of a foot. The acceleration data along the z-axis show a repeating waveform (see Figure 4). We also verified that the waveform of z axis changes when we impose restrictions on step length. This suggests that the acceleration data along the z-axis is useful for acquiring information about step length. We conclude that the accelerometers embedded in shoes can provide information that is useful for understanding the motion of walking.

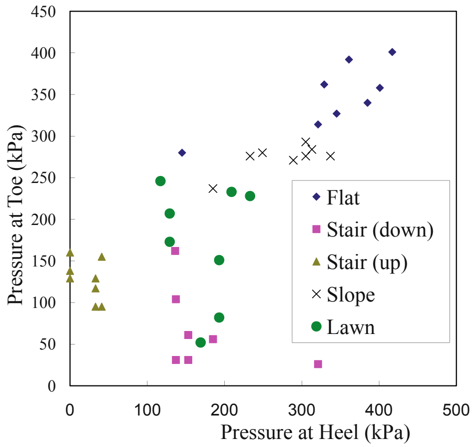

Fig. 3. A distribution of peak values of pressure sensors

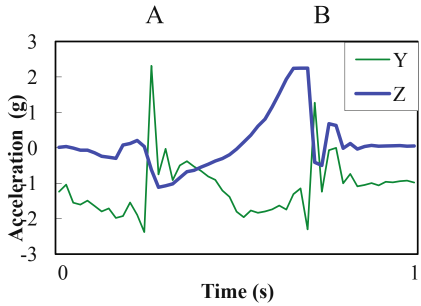

Fig. 4. Acceleration values when walking on a flat surface

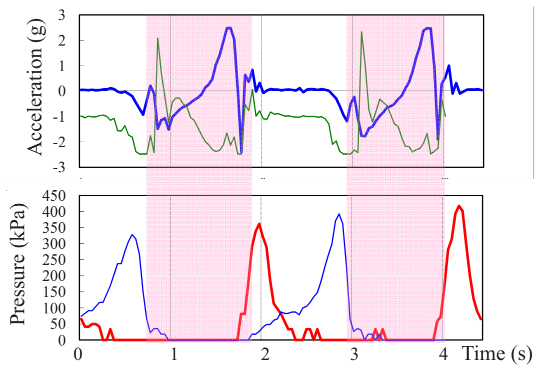

Fig. 5. Complimentary use of accelerometers and pressure sensor.

2.3 Complimentary Usage of Sensors

According to the above discussion, accelerometers are able to capture dynamic context such as walking patterns, on the other hand, pressure sensors are able to capture static context such as ground-surface conditions. This suggests complimentary sensing functions of both sensors. Figure 5 supports this conclusion by showing a situation that only one kind of sensor is able to capture changes of the sensing value (the shaded periods in the figure), while the value captured by the other sensor does not change during the periods. Figure 6 shows a complicated case of walking data. Acceleration data do not show any significant patterns; thus a high-level, high-cost technique is required to analyze and understand the data. However, we can extract each walking step easily by applying a simple recognition algorithm on pressure data.

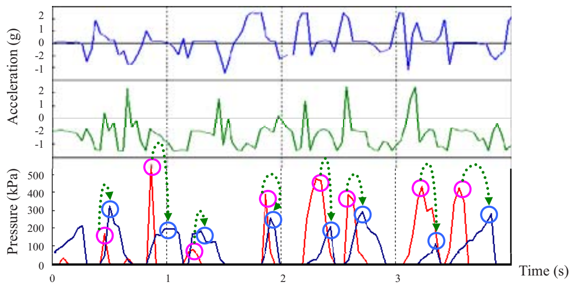

Fig. 6. Detection of complicated walking data

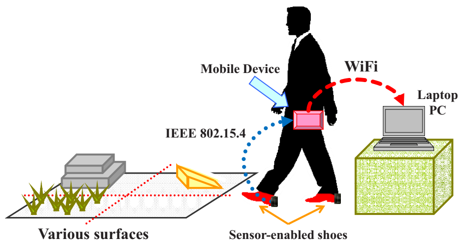

Fig. 7. Illustration of demonstration

3 Demonstration

Although we are using mobile phones to validate participatory sensing, we use WiFi in this demonstration to avoid possible troubles. Subjects can try to put on shoes, which are equipped with accelerometers and pressure sensors, and walk on four kinds of surfaces (as shown in Table 1). Figure 7 illustrates the structure and components of demonstration. As described in Sect. 1, we integrate Sun SPOTs and pressure sensors in shoes. The Sun SPOTs use IEEE 802.15.4 to transmit sensor data to a mobile PC, which in turn forwards the data to a laptop PC through WiFi interface. Upon receiving sensor data, the laptop PC analyzes and shows current ground-surface condition as well as other walking information such as walking patterns of subjects.

References

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