
Efficient In-Pocket Detection with Mobile Phones

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Abstract

In this demonstration paper, we show a novel approach to detect the common placements of a mobile phone, such as “in pocket”, “in bag” or “out of pocket or bag”, from embedded proximity (IR) and light sensors. We use sensor data fusion and pattern recognition to extract distinct features from sensor signals and classify the boundaries among these three phone placement contexts. The detection results are demonstrated on a Samsung Tizen mobile phone.

Author Keywords

Context recognition, feature extraction, sensor fusion

ACM Classification Keywords

I.5.4 [Pattern Recognition]: Applications.

Introduction

More and more sensors are being embedded into mobile devices such as smartphones, and this is enabling a new generation of personal and environmental sensing applications. Because most continuous context aware applications running on mobile phones are resource intensive and power consuming in terms of sensing, computation and communication, there is a strong need to develop efficient recognition algorithms. Typical phone placement contexts include “in pocket” (*inPocket*), “in

bag" (*inBag*), or "out of pocket or bag" (*outOfPocket*) (i.e., "in hand" (*inHand*) or "on table" (*onTable*)). Efficient recognition of these low-level contexts on the phone is a fundamental building block for other new emerging sensing applications.

Recognizing these three placement contexts can improve the accuracy of recognizing other contexts. For example, if the phone is detected out of pocket or bag, the *onTable* context can be better detected by further estimating the gravity vector on a surface and signal magnitude variance from the accelerometer sensor. The *inHand* context can be better detected by further inspecting signal vibration signatures from accelerometer and gyroscope sensors.

Figure 1 shows examples of interesting applications that can be enabled by recognizing these three phone placement contexts. For example, in accelerometer-based physical activity recognition, the accelerometer sensor generates different signals when the phone is in a pocket, in a bag or out of them. If the placement context of the phone is known, a placement-dependent algorithm can be created to improve the recognition accuracy. Moreover, the *inPocket* context recognition can enable a new mode called "pocket mode" in which the phone screen can be automatically locked, the volume of an incoming call automatically increased and vibrations turned on. Similarly, if the phone is detected in a bag (bag mode), the ringtone time for an incoming call can be automatically increased to give users enough time to take the phone out and avoid entering voicemail. Also, recognizing that a phone is out of pocket or bag can be used to turn on and off power-consuming sensing components on the phone such as the camera photo taking, GPS location tracking or environmental sound sensing. Another interesting use case is to enter a

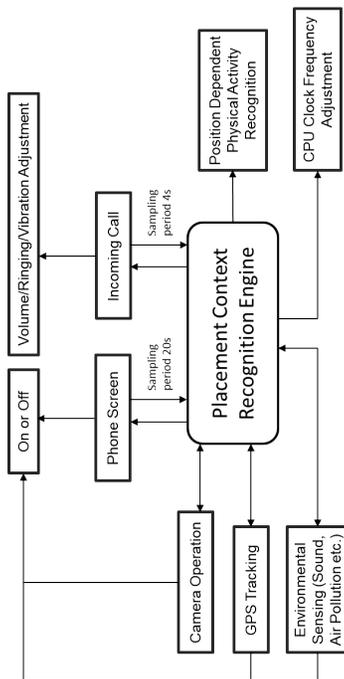


Figure 1: Applications Enabled by In-Pocket Detection

low-performance mode by lowering the CPU clock frequency of the phone automatically to save power whenever the phone is detected in pocket/bag or on table.

Related Works

Although there has been significant research efforts in the area of context awareness, there is little work on developing accurate, robust and energy-efficient recognition algorithms that automatically detect phone placement contexts. In [1], a context inference scheme is created to recognize phone placement from a single accelerometer. However, the approach has two limitations: (1) It is based on a single modality; (2) It only works when the user is walking. In [2], preliminary results from a microphone-based framework to automatically detect the phone placement contexts are presented. However, it is not a robust and energy-efficient algorithm because sound sensing requires more sampling and processing power than other inexpensive sensors like proximity and light. In [3], an analog hardware solution based on a reflective proximity and optical sensor is proposed for an electronic device to determine whether it is being placed inside a handbag or pocket. However, this method cannot be applied to smartphones due to space and cost constraints. In addition, this approach cannot discriminate whether the device is in a pocket or in a bag because there is no distance data available from the analog proximity sensor. [4] presents some typical measurements of illuminance intervals under different lighting conditions which could be used to recognize ambient lighting conditions surrounding the phone.

The main contributions of this paper over existing works can be summarized as follows: (1) It is more robust and accurate than accelerometer-based approach [1] due to sensor data fusion over proximity and light; (2) It is more

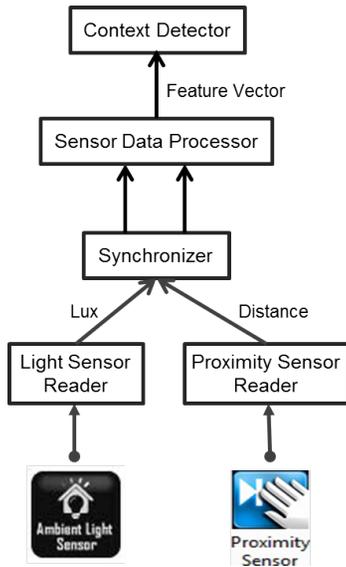


Figure 2: System Diagram of In-Pocket Detection

energy-efficient compared with the microphone-based sound sensing approach in [2]; (3) It requires less training data for pocket or bag detection as needed in [1, 2] because representative features of distance to nearby objects have been extracted from the proximity sensor; (4) It is a pure light-weight software solution compared to the hardware solution proposed in [3] that might increase cost and size of smartphones.

Design Approach

Most smartphones have embedded proximity (IR) and light sensors. Normally, the proximity (IR) sensor is widely used to turn off the screen when the phone is detected close to the ear during a phone call. However, proximity sensor data can also be used to measure the presence of nearby objects at different distance levels. The light sensor is normally used to sample ambient lighting conditions around the device and automatically adjust the brightness of the phone screen.

In Figure 2, there is a proximity sensing module and a light sensing module, which are combined to detect the surrounding placement environment of the mobile device. The proximity sensing module consists of a sensor reader that invokes the Samsung Tizen device API to obtain 8 discretized proximity levels. The Galaxy S3 Android device API allows binary or detailed analog-to-digital proximity measurements, which can be used to detect different surrounding placement environments. Similar to the proximity sensing module, the light sensing module consists of a sensor reader that invokes the Samsung Tizen device API to obtain illuminance measurements from 0 to 65535 lux. The Galaxy S3 Android device API allows for illuminance measurements from 0 to 85745 lux. From practical experimentation, we found that a sampling rate of 10Hz is sufficient to obtain continuous sensor

readings with regular intervals from both sensors. Specifically, the sensor reader operates over a four-second sliding window with 50% overlapping between adjacent windows. Each window contains about 40 evenly distributed samples. After sensor reading processing, there is a synchronizer to synchronize the data streams from both sensors based on a fixed timer. It is useful when one data stream has a different number of samples than the other one during a timing period.

After data synchronization, there is a sensor data processor to perform feature extraction. Since the proximity sensor data has only one-dimensional discrete values, it is simple to extract basic statistical features such as the mean over each window, denoted by $M_{proximity}$. Based on the observation that distance measures at different proximity levels are nonlinear, we compute the binned distribution of sensor readings $\{d_i, i = 1, 2, \dots, N\}$ as a feature over a window. If the proximity sensor readings are discrete distance levels from 1 to L as converted from continuous ADC outputs, we normalized them by L to be between 0 and 1. Specifically, we compute the percentage below a small distance threshold $P_{close} = \frac{|\{i|d_i < D_{Th1}\}|}{N}$, percentage between a small distance threshold and a medium distance threshold $P_{near} = \frac{|\{i|D_{Th1} \leq d_i < D_{Th2}\}|}{N}$, and percentage above a large distance threshold $P_{far} = \frac{|\{i|d_i \geq D_{Th2}\}|}{N}$. D_{Th1} and D_{Th2} are experimentally set thresholds obtained by putting the phone into the placement environments of interest (in pocket or bag). For a Tizen device, $D_{Th1} = \frac{1}{4}$ and $D_{Th2} = \frac{1}{2}$ are good choices based on the non-linearity of proximity distance readings.

Similarly, we compute the mean value of light sensor readings over each window denoted by M_{light} to measure the light condition where the mobile device is placed. A

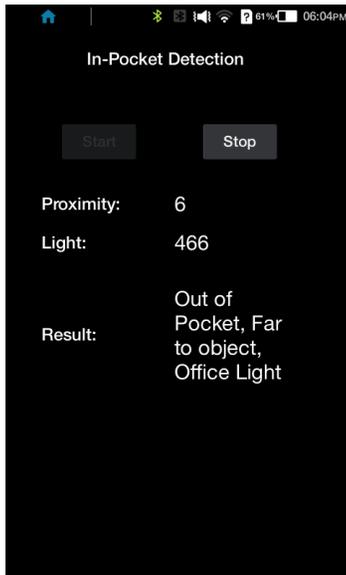


Figure 3: Screenshot of In-Pocket Detection Demo

threshold-based clustering model can be used to detect the light conditions around the device, such that for darkness detection, the threshold I_{dark} can be set to an empirical value below 50.

To detect whether a phone is “in pocket or bag” or not, we design a joint rule-based classifier using combined features from proximity distance levels and light lux values. For example, if the proximity distance level to nearby objects is close and light condition is dark, the phone is likely “in pocket or bag”; otherwise, it is likely “out of a pocket or bag”. When the phone is detected “in pocket or bag”, we can use the proximity pattern distribution to decide whether it is exactly in a pocket or bag. There are a couple of unusual cases however that may cause false alarms such as when a user makes a phone call in a dark environment and the phone is close to his ear, or both proximity and light sensors are accidentally blocked by fingers. The previous cases seldom occur, so they don’t affect the overall performance of our system significantly. The core algorithm can be described as the following pseudo code:

```

If  $M_{proximity} < D_{th2}$  and  $M_{light} < I_{dark}$ ,
    calculate the distance between
     $f = [P_{close}, P_{near}, P_{far}]$  and
     $(1, 0, 0)$ ,  $(0, 1, 0)$  respectively
    if  $f$  is close to  $(1, 0, 0)$ ,
        outputs "in pocket";
    else
        outputs "in bag".
Else
    outputs "out of pocket or bag".
  
```

Demonstration

We implement the previously described in-pocket detection method on a Tizen device as shown in Figure 3. Our demo prototype leverages the proximity (IR) and light sensors available on most Samsung smartphones. The demo prototype reads data streams continuously from both proximity and light sensors at a sampling frequency of 10Hz, process them on over a 4-second 50% overlapping sliding window, and performs proposed sensor fusion and classification method. The demo prototype outputs two placement inference results: “in pocket” and “out of pocket” by a voice announcement whenever there is a context event change. The overall accuracy of our in-pocket detection demo prototype is above 98% as evaluated in practice over several days. The average power consumption for sensor reading is less than 6mW and CPU processing power is negligible. The demonstration also indicates closeness to nearby objects and current environmental lightning condition such as office lighting vs full daylight.

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