Pervasive and Mobile Computing 17 (2015) 23–42

Contents lists available at ScienceDirect

Pervasive and Mobile Computing

journal homepage: www.elsevier.com/locate/pmc

# Towards a position and orientation independent approach for pervasive observation of user direction with mobile phones

Seyed Amir Hoseinitabatabaei *, Alexander Gluhak, Rahim Tafazolli

*Center for Communication Systems Research (CCSR), University of Surrey, Guildford, Gu27XH, Surrey, United Kingdom*

ARTICLE INFO

*Article history:*
Received 7 June 2012
Received in revised form 7 November 2013
Accepted 13 February 2014
Available online 24 February 2014

*Keywords:*
Orientation
Direction
Estimation
Magnetometer
Accelerometer
Smartphone
Classification
Machine learning
Position

ABSTRACT

This paper presents a novel approach for mobile phone centric observation of a user's facing direction, relying solely on built-in accelerometer and magnetometer. Our approach achieves greater accuracy and independence by an automatic detection of the wearing position of the mobile device on the user's body and subsequent selection of an optimum strategy for estimating the user direction. We report on a detailed analysis of various features sets and classifiers in order to determine an optimum selection of those for recognizing the wearing position and evaluate the accuracy and reliability of our overall implementation through an extensive measurement campaign.



## 1. Introduction

The increasing maturity of pervasive sensing technologies during the last decade has seen the emergence of novel human centric applications exploiting these. One such application is the pervasive observation of user direction, which has attracted interest from researchers in various research fields, ranging from localization in wireless networks and robotics to recent social and behavioral analysis with wearable computing technologies and smart environments. In order to observe a user's directionality current approaches typically make use of the ambient sensors [1–3], Body Sensor Networks (BSN) [4–6] and localization with wireless transceivers (e.g. GSM or Wi-Fi) or GPS sensors. However, most of these approaches are faced with limitations to either the location or the duration of the observation. These limitations are either down to dependency of ambient sensors and wireless technologies on infrastructures deployed in an environment, the intrusiveness of BSNs or the effect of the environment (e.g. indoor signal blockage for GPS) on the utilized techniques.

Recent approaches have therefore started to exploit the availability of sensors in today's smart phones to overcome some these limitations. The wide scale use of mobile phones in today's life and ubiquitous connectivity for data communication makes mobile phones ideal candidates to act as ubiquitous observers. Among various emerging user direction observation techniques for mobile phones, the PCA based approach [1] and uDirect methodology seem more practical for pervasive observation [2]. By utilizing built-in inertial sensors, they allow the device to be placed in a more natural wearing position (e.g. trousers pocket), in contrast to approaches that rely mobile phone camera [3]. In addition, these systems are able to adapt to an arbitrary orientation of the device making the system more acceptable for users as they chose the orientation

* Corresponding author. Tel.: +44 0 7793459214; fax: +44 0 1483 686011.
*E-mail addresses:* s.hoseinitabatabaei@surrey.ac.uk, s.amir.h.tabatabaei@gmail.com (S.A. Hoseinitabatabaei).

http://dx.doi.org/10.1016/j.pmcj.2014.02.002
1574-1192/

of the device that is of most comfort to the wearer. Despite the potential of mobile phone based solution for user direction estimation, several shortcomings remain in the current solutions that hinder their applicability to everyday life situations.

Firstly, the current techniques are constraint to a particular wearing position, in this case the trouser pocket. Recent studies about the most popular wearing positions of the mobile phones [4] show a strong gender bias in selecting the wearing position. While the trouser pocket is the most popular position for male users, female users prefer shoulder bags, leaving trouser pockets to be only the third best choice. Both positions however only account for roughly half of the cases. Therefore both uDirect and PCA based approaches are biased towards male users and currently miss a significant amount of data when the device is worn in another positions.

Secondly, so far it is not clear whether PCA is applicable to other positions on user body. Regard to the fact that different segments of the body are experiencing different magnitude of accelerations and rotating pattern during the walking locomotion, it seems that the performance of the PCA would changed based upon wearing position. However, still such analysis has not been performed.

Thirdly, even if the approaches would be applicable to a different wearing position, they require a prior knowledge about exact device position(s). Requiring a user to provide manually such information (or to adhere to predefined positions in daily life) leads to an increased burden on user, which in turn makes the system more intrusive.

In this work, we present a novel mobile phone based system that automatically detects the direction of the user when the user is walking. Our approach is independent of the any prior knowledge of device position and orientation and makes use of two major phases to achieve its goals. The first phase determines automatically the wearing position of a mobile phone on a user's body. Based on the determined position a second phase selects the most suitable estimation technique to perform direction estimation. Utilizing such system fills the gap for detecting the position of the device, allowing a long term operations without being intrusive. It also allows a more accurate estimation as position specific direction estimation approaches instead of a generic one can be adapted.

The position estimation makes use of built-in accelerometer and magnetic field sensors measurements readily available in many off-the-shelf mobile phones. Using novel features and pre-processing we are now able to accurately detect the position of the mobile between a number of most popular positions including trouser pockets, shoulder bags, belt enhancements and also the user hand which has not been available before. According to [4], these accounts for more than 80% of the mobile phones wearing positions in public places which in turn suggests 46% improvement with respect to situations when only trousers pockets are considered. The direction estimation process then selects the most promising algorithm between a set of direction estimation algorithm specified for each position. For the trouser pocket position we are taking advantage of the uDirect based algorithm developed in our previous work. We propose a new variation of uDirect approach optimized for belt enhancement position and a novel approach for direction estimation for shoulder bag position. For the in-hand position a conventional PCA based approach is adapted.

During evaluation of a proof-of-concept implementation with 8 participants on a smart phone we were able to verify our system performance and show that our algorithm performs more accurately than existing standard GPS and PCA based approaches and provides several advantages compared to those. In summary we make the following contributions:

- We present a system for direction estimation which performs independent of device orientation and position.
- As part of the system we developed a position recognition technique that performs fast, reliable and accurate using the low power accelerometer and magnetic field sensors on mobile phones.
- We propose a novel pre-processing techniques such as PCA based transformation and the use of features from magnetic field for realizing our position recognition unit.
- We propose novel algorithms for direction estimation for the shoulder bags and belt enhancement positions.
- We further examine the application of the conventional PCA based approach for three new positions including the shoulder bags, belt enhancements and user hand.
- We report on the evaluation of the proposed algorithms for direction estimation along with the proposed position recognition technique based on more than 1000 data samples collected from 8 participants validating our underlying theoretical models and comparing the performance of our system to the existing approaches.

The remaining paper will first introduce the related works in Section 2, before describing a holistic overview of the proposed system in Section 3. In Section 4 the position recognition technique is described. Section 5 describes the direction estimation techniques and Section 6 reports on the experimental evaluation of an implemented prototype. Concluding remarks are provided in Section 7.

## 2. Related works

In this section, we survey related work and highlight how our approach differs from existing approaches for direction estimation. As the available work for mobile phone based sensing systems is rather limited, we also include in our discussion available techniques from the wearable sensor community, that can be adapted with minor modifications to mobile phone based sensing systems.

One of the most widely used approaches in wearable community is to take advantage of the inertial sensors such as accelerometers and gyroscopes along with magnetometers. Such sensors are particularly preferred to other techniques based on wearable cameras e.g. [5] or IR transceivers e.g. [6,7] as they can be attached to a wider range of positions and