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Context-supported local crowd mapping via collaborative sensing with mobile phones

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ABSTRACT

Positioning and tracking of mobile devices have been a fundamental building block of people-centric mobile applications. As well as global (or absolute) positioning, recognizing one's current position with respect to surrounding crowd of people at a busy station or in an event place is increasingly needed for emerging services like mobile social navigation. In this paper, we propose a novel positioning system that provides a *local map of surrounding people* based on sensing data gathered from smartphones in the crowd, without relying on any infrastructure or exhaustive fingerprinting. To cope with large position errors due to sensor noise and other environmental factors, we introduce a heuristic error correction algorithm based on collective activity context of mobile phone users. Analyzing recent history of the sensing data, it detects "groups" of people who move together and then corrects deviation of estimated traces of individual users by harmonizing with the traces of other group members. Through a field experiment using Android smartphones, we have shown that our error correction mechanism successfully enhances positioning accuracy by 28% (from 4.16m to 3.01m). Furthermore, we have analyzed the performance of our method in detail through extensive simulations.

1. Introduction

Recent advances in personal sensing technology have opened up a new stage of mobile applications. With a variety of sensors being available in off-the-shelf mobile phones, mobile systems can capture the situation that a user is currently involved (e.g., location, activity and social context) to provide various people-centric services. Since human activity is closely dependent on one's location, positioning faculty is usually an essential building block of such applications. When the application requires only district-level granularity allowing a typical error of a few hundred meters, cellular-based localization [1–3] would serve the purpose. If necessary, GPS provides finer accuracy that can identify the building where the user is located.

While most of the mobile applications have typically focused on location and situation of individual users, some emerging services aim to support interaction with other people who have social relationship with the user. For instance, let us think of a party place as shown in Fig. 1. Since the place is highly crowded with those present, our view is often obstructed by the surrounding people as Fig. 2. Thus we can hardly find a particular person in such a crowd even if we know that he/she is nearby. Mobile social navigation would help us in such situations by guiding the user to the friend she is looking for. These applications require fine-grained position information of the users themselves and/or relative position to the surrounding people with a few meters accuracy in indoor environments where GPS rarely works.

Despite considerable research effort to develop universal indoor positioning systems, unfortunately, it is still an open problem. A major difficulty in spreading indoor localization system arises from the tradeoff between accuracy and scalability. Infrastructure-based location systems using ultrasound, infra-red or RF have achieved high position resolution, but usually

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Fig. 1. A scene of a party.

Fig. 2. Finding a person in a crowd.

need a huge number of embedded sensors on the walls or ceilings as well as dedicated receivers at client side. Although fingerprint-based localization techniques may partially address such hardware-related problems using environmental signatures at each location [4–8], they incur considerable initial effort for collecting reference signatures over the whole building.

Now that smartphones are becoming pervasive and many people participate in some location-dependent services (while they may run different sets of applications), they would share a common demand for finer-grained positioning. It motivates us toward another potential solution; collaborating with other users to achieve better accuracy without relying on special equipment, infrastructure, or time-consuming calibration. In this paper, we propose a novel positioning system that embodies this idea. Our system, called *PCN* (the acronym of people-centric navigation), provides relative positions of surrounding people to create a *local map of surrounding crowd*. It employs pedestrian dead reckoning (PDR) to estimate user traces and received signal strength (RSS) of Bluetooth radio for proximity sensing, both of which can be accomplished by off-the-shelf mobile phones. By overlapping the estimated traces at the points where the users seem to have encountered, PCN derives the relative position between the users. A challenge for this approach is dealing with large position errors due to sensor noise, variance of Bluetooth RSS and other environmental factors. As demonstrated in our preliminary experiment being presented in Section 3, position errors in PDR may grow up to tens of meters, which may seriously degrade the relative position accuracy. Furthermore, different Bluetooth RSS values can be observed at the same distance due to multipath effect and human presence, which confuses proximity sensing. PCN copes with the problems by focusing on *collective activity* of the people in the crowd. In crowded situations like exhibitions and parties, people often move together with some others, forming a "group". These groups may be formed by friends, families, colleagues, or even strangers who are just moving toward the same direction. PCN dynamically detects similarity of their activities by gathering mobile phone's acceleration, direction and Bluetooth RSS, and then corrects deviation of the estimated traces by harmonizing with the traces of other group members. Such group-based error correction alleviates the impact of unstableness in the heading estimation, misdetection of user's steps and variance of Bluetooth RSS, which may affect the relative position accuracy. Through a field experiment in a public trade fair, we have shown that PCN achieves median relative position accuracy of 3.01 m, which would be sufficient for mobile social navigation or similar emerging applications.

2. Related work and contribution

A number of methods have been investigated to estimate location of mobile devices. The most fundamental, but robust approach would be infrastructure-based localization. Cricket [9] and Active Bat [10] are well-known systems that employ

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