Poster Abstract: MapSentinel: Map-Aided Non-intrusive Indoor Tracking in Sensor-Rich Environments

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ABSTRACT

Estimating an occupant's location is arguably the most fundamental sensing task in smart buildings. Existing indoor tracking systems require occupants to carry specialized devices or install programs on their smartphones to collect inertial sensing data. In this paper, we propose MapSentinel, which performs non-intrusive location sensing based on WiFi access points and ultrasonic sensors. MapSentinel also combines the noisy sensor readings with the floormap information. Instead of using floormap merely to conduct sanity check of walking trajectories, we exploit the motion characteristics of occupants available from the floormap to enhance our location estimation. The fusion of heterogeneous information is theoretically formulated within the Factor Graph framework and the inference algorithm based on Particle Filtering is developed to efficiently solve real-time walking trajectories. Our evaluation in a large office space shows that the MapSentinel can achieve significant accuracy improvements compared with the purely WiFi-based tracking system.

Keywords

Indoor Tracking Systems, Non-intrusive, Map-aided, WiFi, Ultrasonic Sensor Network, Particle Filters

1. INTRODUCTION

The indoor location sensing technology has emerged as an inherent part of the "smart buildings" as it provides great potential for building operation improvement and energy saving. The applications for fine-grained, responsive building operations require the location sensing systems to provide location estimates in real time, also known as indoor tracking. Most indoor tracking systems necessitate each occupant to carry or wear a powered device such as infrared, ultrasonic, or RF transceiver. Even if the transceiver is miniaturized into a convenient form, occupants are not willing or likely to carry it at all times. Another subset of tracking systems alleviate the need for carrying specialized devices by using the inertial sensors on smartphones to perform dead reckoning However, specialized programs are required to be installed on smartphones to continuously collect inertial sensing data, and thereby the associated energy issues or occupants' engagement become the main impediment.

On the contrary, we enable non-intrusive indoor tracking by developing an information fusion system that takes advantage of noisy measurements from various sensors, namely, WiFi access points and ultrasonic sensors. There is no need for specialized devices or programs for location inference. In addition to the sensor measurements, another key input for our system is the floormap of the indoor space of interest. Floormap information has been used to refine walking trajectory estimates by eliminating wall-crossings or unfeasible locations. In effect, we can also acquire some prior knowledge of occupants' dynamic motion from the floormap. For example, when located at his/her office or cubicle, the occupant is very likely to keep static; the occupant walking on a particular corridor tends to continue the motion constrained along the corridor, while an occupant in an open space are free to move in any direction. Such information is useful to track occupants' movement; notwithstanding, it is less considered in previous work. It is, therefore, the objective of this paper to propose MapSentinel, a non-intrusive location sensing system via information fusion, which combines the various sensor measurements with the floormap information, not only as sanity check of estimated trajectories but as an input for occupants' kinematic models.

2. SYSTEM DESIGN

Figure 1 presents the overall architecture of MapSentinel. There are three key components in MapSentinel: the non-intrusive sensing networks, the floormap processing engine, and the information fusion algorithm. The non-intrusive sensing networks, as the name suggests, generate location-related measurements without the need for computation on the smartphone end. Our sensing networks consist of WiFi access points (APs) and ultrasonic calibration stations, which

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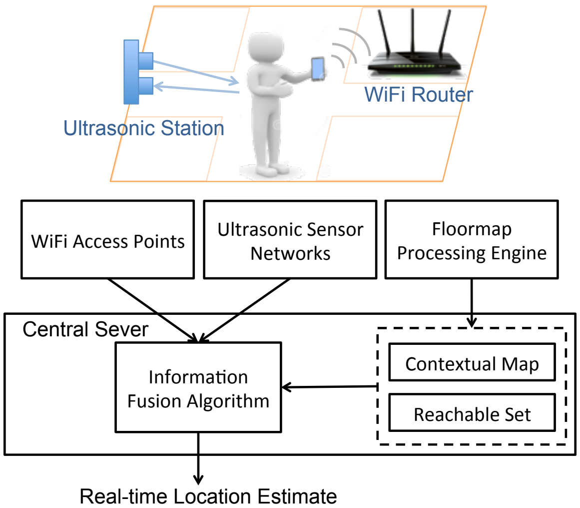

Figure 1: MapSentinel architecture.

track locations by relating the WiFi signal strength or the sound time-of-flight to the distance. Based on different motion capabilities, we categorize the indoor space into several "*contexts*", namely, open space, constrained space and static space. And the floormap processing engine is designed to convert the original floormap into the *contextual floormap* that indicates the context of each point in the original floormap. Another function of the floormap processing engine is to compute the reachable set containing all the points visited with admissible speed from a given starting point. The output of the floormap processing engine represents the prior knowledge obtained from the map, and can be computed in the offline phase. Then, the information fusion algorithm combines the sensor measurements and the floormap information to generate real-time location estimates.

3. INFORMATION FUSION FRAMEWORK

We we use factor graph to model the dependencies among the variables involved in the tracking problem (Figure 2), where z_k is the state vector consisting of location and velocity, m_k is the context, and y_k denotes the sensor observations received at time k. $\mathcal{T}_k(\mathbf{z}_k, \mathbf{z}_{k-1}, m_k, m_{k-1}) = p(\mathbf{z}_k|\mathbf{z}_{k-1}, m_k, m_{k-1})$ represents transition model, which is able to capture context-dependent characteristics of occupants' motion in the indoor space by applying different state noise models to distinctive contexts. $\mathcal{O}_k(\mathbf{z}_k, y_k) = p(y_k|\mathbf{z}_k)$ stands for observation model, where we use certain conditional probabilities to characterize the sensor observations, and multiple sensor observations are combined via Bayes' theorem. $\mathcal{C}_k(\mathbf{z}_k, m_k)$ is the characteristic function that checks the validity of the correspondence between $\mathbf{z}_k$ and m_k using the contextual floormap. Online estimation of the states is done by extending the classical particle filtering algorithm to incorporate the auxiliary context variables.

4. PERFORMANCE EVALUATION

Our experiment was carried out in a large typical office environment consisting of cubicles, individual offices, corridors and obstacles like walls, desks, etc. Four contexts are used to describe the motion characteristics of the space, namely, free

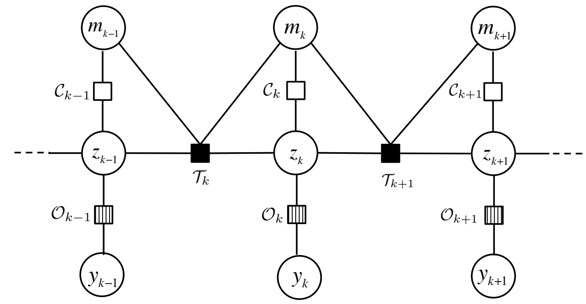

Figure 2: A factor graph model representation of the dependencies among location, velocity, context and observation.

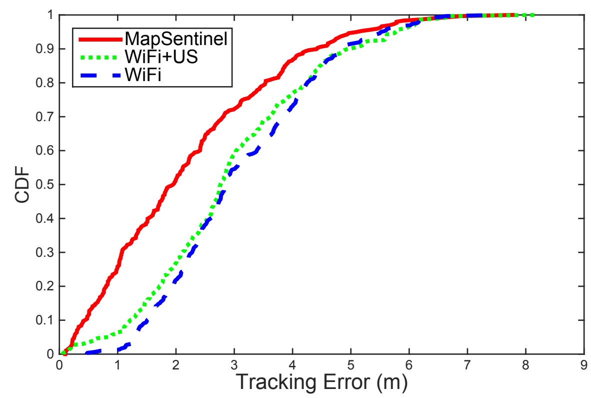

Figure 3: Tracking performance of MapSentinel, the fusion system of WiFi and ultrasound sensor, the pure WiFi system. The median tracking accuracy of the MapSentinel is 1.96m.

space, vertical and horizontal constrained space, and static space. We compare the performance of MapSentinel against the fusion system of WiFi and ultrasonic station without leveraging the floormap information, as well as the purely WiFi-based tracking system. The tracking error distributions are depicted in Figure 3. As can be seen, the MapSentinel achieves an essential performance improvement, 31.3% over the WiFi tracking system and 29.1% over the fusion scheme. Note that adding the ultrasonic calibration into the WiFi system is able to realize a small amount of accuracy increment. Due to the high degree of uncertainty of WiFi signals, the effect of ultrasonic calibration will not last for long. The map information elongates the effect of the ultrasonic calibration via imposing additional constraints to the motion, and that's why MapSentinel greatly enhances the tracking performance compared with the purely WiFi-based system.

5. CONCLUSION

We develop a non-intrusive location sensing network and propose the information fusion framework that combines multi-sensor observations as well as the occupants' motion information available from the floormap. It is shown that our system can achieve significant accuracy improvements over the purely WiFi-based tracking system.