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Performance evaluation of graded precision localization with sensor networks in indoor spaces ☆

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ABSTRACT

Modalities other than GPS need to be employed to localize mobile sensor-node-enabled subjects in indoor conditions. The location of some mobile nodes needs to be computed precisely while this may not be essential for the remaining nodes. We have proposed the concept of graded precision localization which allows mobile nodes to localize themselves to heterogeneous precision levels in a common framework. With graded precision localization, we define a modular node for the subjects, specify deployment strategies customizable for each site, and propose a framework for evaluating site-specific localization performance. We comprehensively evaluate graded precision localization with experiments and simulation for indoor conditions, and highlight its advantages over similar systems.

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1. Introduction

In sensor networks with mobile nodes, the mobile nodes often need to periodically know their location with the help of other nodes in the network in the absence of GPS. However, all nodes do not need to know their location to the same degree of precision. Some nodes need to be localized precisely while for others, an approximate knowledge of their location might be sufficient. We have used such requirements to introduce the concept of Graded Precision Localization (GPL) [1] for fixed-grid setups. GPL refers to the ability to localize mobile nodes to different precision levels using a common infrastructure with a combination of coarse-grained localization, fine-grained localization and inertial navigation.

GPL uses a combination of coarse-grained localization involving calculating the centroid of location information received in radio beacons, fine-grained localization by Time Difference of Arrival (TDOA) techniques, and inertial navigation. Range-based methods involve computation of RSSI [2] or other techniques such as Angle of Arrival (AOA) [3], Time of Arrival (TOA) [2], or Time Difference of Arrival (TDOA) [4,5]. RSSI has been shown to be unsuitable for ranging applications [6]. Motetrack [7] tries to address this limitation by creating a repository of location and RSSI signature of radio beacons. With TDOA, location of a node is computed by calculating its distance to (at least) three non-collinear reference nodes. For distance calculation with TDOA based trilateration, Cricket [4] uses combination of ultrasound and radio messages while Thunder [8] uses an acoustic wave—generated for 100 ms with a 73 dB (street noise level) microphone—and a radio signal to achieve a ranging distance of 137 m with a 25 cm distance estimation error. Dead Reckoning (DR) systems have been proposed for robot navigation [9,10]. By computing steps, strides and heading, an accuracy of up to 95% has be achieved [11].

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Helmet-mounted inertial navigation systems have also been proposed [12]. GPL is a modular technique which is suitable for both localization and tracking applications.

In this paper, we present a rigorous performance evaluation of GPL for indoor conditions [13]. We first present the operation of GPL highlighting the interaction between the GPL user module and the infrastructure. This is followed by the performance evaluation of the user module and the infrastructure with experiments, analysis and simulation. An analytical model based on Markov chains is developed to evaluate the performance of GPL infrastructure for customized indoor deployments. We conclude by highlighting the advantages of GPL over related systems.

2. Graded precision localization

The operation of GPL is briefly outlined to support the discussion on performance evaluation. Every mobile subject in a GPL deployment carries a user module or a trimmed version of it called the restricted user module. Fig. 1 shows the different phases of localization of a user module *U* with GPL. As *U* moves through a GPL deployment, it uses the messages from radio nodes to compute its centroid and advertises the changing centroid as its coarse location. When the computed coarse location indicates that *U* is inside a hotspot, *U* requests the hotspot to compute its precise position by trilateration. Thereafter, *U* uses inertial navigation to localize itself till it reaches the next hotspot. If the accumulated errors due to inertial navigation cross a threshold before *U* reaches a hotspot, it goes back to computing its coarse location. The restricted user module RU, in comparison, computes only its coarse location all throughout. Any GPL deployment permits the co-existence of both kinds of modules and inter-conversion between the two is only a matter of plugging the right hardware into a generic architecture. We note that GRADELOC [1] and IGRADELOC [14] discuss grid-based deployment of GPL with the help of pseudo-code.

The user module is envisioned as a cap-mountable sensor node, for precise positioning, and a phone for inertial navigation. The infrastructure consists of beacon nodes and radio nodes. Beacon nodes have both radio and ultrasonic transmission capabilities, and they are used for TDOA based trilateration of the user module. Therefore, wearing a sensor node on the cap helps achieve Line-Of-Sight (LOS) communication with the beacon nodes. We have configured a prototype user module for evaluation, which consists of a Cricket sensor node [4] as a beacon-listener, an Android phone, and a laptop as shown in Fig. 2. Since hotspots are correction points for a user module's INS, strategic hotspot placement would depend on the architectural floor plan indicating places frequented by people. Skeletonizing the top-view image of a deployment area creates quench-lines. Branch-points of quench-lines at path-interconnects are effective hotspot placement choices which is illustrated in Section 4.

3. Performance evaluation of user module

Fig. 3 shows the functional architecture of the prototype given by Fig. 2(a). It consists of a laptop connected to a Cricket node (beacon listener) and an Android phone which communicates with the laptop over Wi-Fi. The Cricket node runs TinyOS 1.x [15]. The laptop runs a Decision Support System (DSS) consisting of the RAPIDSNAP [16] Gateway, DBMS and User Application. We note that GPL Subsystem is an *Event Source* for the RAPIDSNAP Gateway. The *Cricket Interface Subsystem* sends the trilaterated position (i.e. fine-grained location) of this user module to the GPL Subsystem when the user module is in a hotspot. The DSS is responsible for logging and visualization of all incoming data. A node ID is assigned to the user

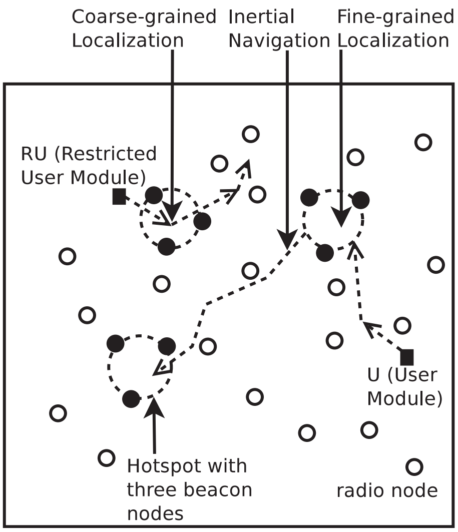

Fig. 1. User module *U* and restricted user module RU in a typical graded precision localization setup.

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