Demo Abstract: Sensor Network Navigation without Locations

Mo Li, Jiliang Wang, Zheng Yang and Jingyao Dai
Computer Science and Engineering Department, HKUST
{limo, aliang, yangzh, daijy}@cse.ust.hk

Categories and Subject Descriptors
C.2.4 [**Distributed Systems**]: Distributed Applications

General Terms
Design, Algorithms, Experimentation

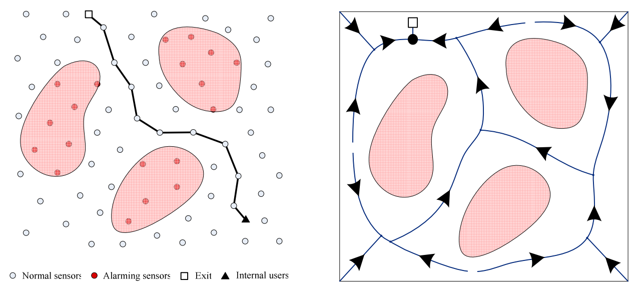
Keywords
Wireless Sensor Networks, Navigation, Location-Free

1. Introduction

This work proposes to utilize the wireless sensor network as an infrastructure system for navigating internal users under emergencies. The users are equipped with communicating devices like 802.15.4 compatible PDAs that talk with sensors. Under emergencies, the sensor network explores the dangerous areas and provides necessary guiding information to safely navigate the users out of the field.

Many efforts have been made towards guiding navigation using wireless sensor networks. As a natural intuition, most existing approaches assume the availability of locations on each sensor node. Based on the awareness of the locations of dangerous areas, the sensor network incurs easy and efficient route calculations to navigate internal users out of the emergent field. The location information may not be always available in many practical situations, such as underground tunnel or coal mine environment, complicated indoor area, etc. As reported in our recent work for the coal mine surveillance sensor network [1], it is essential to navigate miners to retreat from the coal mine tunnels after emergency happens, yet obtaining accurate location for each sensor is quite difficult in the GPS-less underground environment. Indeed, the requirement of location information largely limits the applicability of existing approaches on location-free environment. Besides, existing approaches do not specifically consider the impact of the variations on dangerous areas, e.g., the emerging, expanding, shrinking or diminishing of dangerous areas. In reality, such variations might significantly degrade the effectiveness or even overwhelm existing navigation protocols.

Oppositely, in this work, we release the necessity of utilizing location information to guide navigation. Neither the sensor network system nor users need to know their instant locations to achieve successful navigation. We further make efforts to address emergency dynamics, which lead to variations of dangerous areas. Nevertheless, to successfully design such a versatile navigation protocol with nearly the least information, we have to address challenges not yet faced by previous approaches as follows. Without location information, how should we guide people to the destination exits across the field, bypassing potential dangerous areas that we cannot even locate? How should we maintain the safety and efficiency of the selected navigation routes? Under emergency dynamics, the dangerous areas vary quickly. How should we design our protocol, which provides timely and efficient replan and update of the safe routes for users?



(a) (b)

Figure 1. (a) Sensor network navigation principle; (b) The directional road map built by the navigation system.

2. Design Principles

We characterize this navigation problem as a path planning problem. We assume an emergent field containing several areas of dangers, as the red areas shown in Figure 1 (a). The dangerous areas might emerge, disappear, expand or shrink as the time passes and the number of different dangerous areas at any time instance t is a constant L_t, independent of any other factors like field size. A wireless sensor network is deployed on the field, where each sensor is able to detect the dangers distributed over the field. The objective of a successful navigation is planning a path for the user to one or more pre-known exit spots on the field which leads to safe departure, bypassing all dangerous areas. Each user carries a communicating device like 802.15.4 compatible PDA that can talk with sensors. By measuring the strength and direction of the wireless signals [2], the user is able to track any targeted sensor node. Thus the navigating route can be interpreted as a sequence of sensor nodes. In Figure 1 (a), we depict such an example route that leads the internal user to the exit.

The main idea is that we embed a distributed road map system in the sensor network. This road map system is built according to the distribution of dangerous areas and thus characterizes the features of the field safety. The navigation system maintains the road map as a public infrastructure and guide different users across the

SenSys'08, November 4-7, 2008, Raleigh, North Carolina, USA.
ACM 978-1-59593-990-6/08/11.

field through the same road map, saving unnecessary overhead of individually planning routes for different users. The road map is updated in an event-driven manner when the dangerous areas vary.

2.1 Building the Road Map

We build the basic framework of the road map by concatenating the medial axis of region *R*. Under the continuous settings, the medial axis is a set of points, each of which is closest to at least two different points on the boundaries of dangerous areas. In the discrete network in practice, we approximate the distance by the network hop counts. As proven in [3], the medial axis of region *R* is a finite set of continuous curves and it retains the topological features of this region. It is shown that any bounded open subset in the Euclidean space is homotopy equivalent to its medial axis [3]. For any continuous path in region R, we can find a homotopy transformation which maps the path into a segment of the medial axis. Thus our road map framework is expressive, which captures the topological features of the safe region *R*, representing the possible safe corridors among dangerous areas with curve segments on the medial axis. The road map is also compact, which represents the topological and geometric features of region *R* by a simple curve graph, the size of which is proportional to the complexity of large geometric and topological features on *R* [3]. We utilize the road map as a backbone for navigating different users inside the field. On the road map, we accordingly assign directions for each "road" segment, indicating a safe path towards this gateway for each point on the road map backbone. Figure 1 (b) depicts the maintained directional road map. Each user is first guided to the road map backbone and then navigated through the road to the exit.

We prove that the selected navigation route provides global safety as well as local safety for each user. First, the selected navigation route maximizes the minimum distance of all possible routes to the dangerous areas, i.e., the route is a Max-Min route in terms of the distance to the dangerous areas. On the other hand, for any given path segment on the selected navigation route, any substitute path will not be farther to the dangerous areas, which guarantees that any intermediate local path segment on the selected route yields the largest distance to the dangerous areas.

2.2 Reacting to Emergency Dynamics

Due to the emergency dynamics, the dangerous areas might vary during the navigation process. We introduce an updating principle which additively rebuilds the road map according to the emergency dynamics and affects only a local district.

We treat any targeted area or curve as a set of points and the variation of dangerous areas is considered as a continuous process of switching a series of points into or out of dangerous areas. We let each point in the field maintain a status recording the closest dangerous points to it and the distance between them. Each time a point is switched into a dangerous area, we only need to update those points which will have it as their closest dangerous point. Similarly, each time a point is switched out of a dangerous area, we only need to update those points which record it as their previously closest dangerous point. We prove that the impact of the emergency dynamics in the field is local, and the amortized overhead incurred by emergency dynamics is $O(\sqrt{n})$.

Figure 2. The prototype system

3. Demonstration Setups

We implement and demonstrate our protocol through a prototype system consisting of 36 TelosB motes deployed into 6 × 6 grids (see Figure 2). We design a black box challenging game to testify the effectiveness of this protocol in practical scenarios.

One participant within the sensor network field carries a laptop or PDA that talks with the sensor nodes. Our navigation system builds the road map infrastructure across the monitoring field and provides navigating route to guide the user out safely. The route is represented by a sequence of sensor nodes and the user is directed along those sensor nodes. At each step the user is provided the direction pointing from his current stop towards his next stop. At present, we do not equip the laptop with the antenna array that can detect the direction of received signals. Alternatively, we pre-load the positions of the sensor nodes in the laptop to facilitate the calculation of directions. Nevertheless, such information will not be revealed to the user so that the experiment can demonstrate the effectiveness of our system for its real usage in the location free environment. On the other hand, the other participant uses a PC connecting to the sensor network and behaves as a challenger to this navigation system. He manages the dangers within the field by setting certain areas from safe to dangerous and vice versa, simulating the emergency dynamics including danger emergence, disappearance, expanding and shrinking. The frequency and intensity of the updating on the dangers represent the extent of the emergency dynamics.

Neither of the two participants is aware of the other's operations. The person in the field simply moves according to the indications received from the navigation system. The challenging person freely sets the dangers without the knowledge of the navigation progress. Such a demo experiment validates the effectiveness of our navigation system under different emergent situations.

References

[1] M. Li and Y. Liu, "Underground Structure Monitoring with Wireless Sensor Networks," in proceedings of IEEE/ACM IPSN, 2007.

[2] D. Niculescu and B. Nath, "Ad Hoc Positioning System (APS) using AOA," in proceedings of IEEE INFOCOM, 2003.

[3] J. Bruck, J. Gao, and A. A. Jiang, "MAP: Medial Axis Based Geometric Routing in Sensor Network," in proceedings of ACM MobiCom, 2005.