Project Proposal:
Mobility, Navigation and Localization

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1 Introduction

We propose to study the symbiotic relationship between mobility, navigation, and localization in the context of wireless sensor networks and mobile objects. We observe that mobility can aid in network node localization and that once localized, the network nodes can localize and track a mobile object (robot) and guide its navigation. Our motivation, and the ultimate goal of this work, is to realize the following scenario. A set of sensor networks nodes are dropped onto a field at unknown locations. A friendly (or unfriendly) mobile object travels through the sensor network in a structured (or random) walk. The network nodes determine their own locations by estimating the range to this mobile object in a coordinated fashion and applying a transform to these range estimates to yield the node positions in some global coordinate frame. Once localized, the nodes may multilaterate the location of the mobile object and guide its motion to locations and events of interest within the sensor network.

2 Range Estimation

Robust range estimation is essential to localization of either the nodes or robots. Unfortunately, range estimation has proven to be difficult in sensor networks and affordable/precise general solutions do not yet exist. Hence, we view range estimation as high risk and critical path, and propose to invest our early efforts in this area. As a risk mitigation strategy, we will investigate two different techniques for range estimation: ultrasonic and magnetic.

Ultrasonic ranging would leverage work from the Calamari project and would involve integrating the Mica2Dot ultrasound boards used in the DARPA midterm demonstration and the CotsBots robots previously developed by one of the authors. Magnetic ranging would leverage concurrent work on creating an empirical sensor model being performed at Intel Research Berkeley by one of the authors. In either case, We would make some simplifying assumptions to make the ranging problem tractable in the available timeframe. For example, we assume that only one robot is present at a time and that the robot's size is negligible. In the general case, we could not make these assumptions.

3 Localization

There are two aspects of localization that are relevent for our research. The first case is the localization of the network nodes (sensors) such that nodes can determine their coordinates. Depending on the ranging techniques that are employed, the network node localization problem may be able to leverage earlier work like Calamari. On the other hand, a more interesting research problem may be to use a mobile object to localize the nodes. Hence, we describe below the mobile object based approach to localizing the nodes. We then assume the node positions are known and review localization of a mobile object via multilateration.

3.1 Network Nodes

Given a ranging technology that allows three independent sensor nodes to range the same mobile object simultaneously, we now propose our localization approach. Consider a single mobile object or *target*[1] traversing through a sensor network as shown in Figure 1.

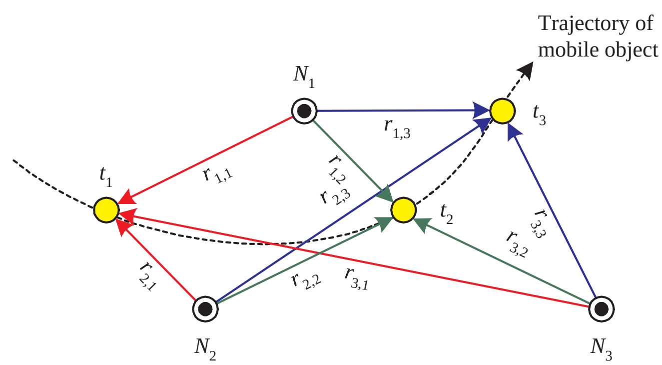

Fig. 1. The trajectory of a target (yellow dot) and its distance $r_{n,t}$ from three sensor nodes at three points in time, where n is one of N_1, N_2, N_3, and t is one of t_1, t_2, t_3.

The positions of the three nodes N_1, N_2, and N_3 are initially unknown and we refer to these nodes as the *unknown* nodes. Each of these unknown nodes is able to determine the distance to the target at three distinct times t_1, t_2, and t_3. Let the three nodes and the location of the target at the three times be the six vertices of a 2-dimensional geometric structure with nine edges given by the ranges $r_{n,t}$. Our algorithm would determine the distance $d_{i,j}$ between any pair of nodes N_i and N_j that satify our initial assumption. Once the set of inter-node distances are calculated, multidimensional scaling or some similar transform can be used

[1] We refer to the mobile object as the *target* since it is the target of the ranging.

to convert the distance estimates to a coordinate system. We are uncertain about the specifics of the proposed algorithm and the development of the algorithm is itself an important component of the project effort. There are two key anticipated challenges. The first challenge is proving that the planar geometric structure whose six vertices are defined by the location of the three unknown nodes and of the target at the three times, and whose edges are the nine range estimates is rigid, non-deformable, and unique. Integrating error from the range estimates into this algorithm will also be crucial. The second challenge is devising the algorithms that allow inter-node distances to be computed from the set of range estimates.

3.2 Mobile Robots

Localizing the position of a mobile robot based on distance or range measurements from three or more spatially-distributed sensors is a familiar multilateration problem. We will restrict our analysis to two dimensions although the approach can be generalized easily to three dimensions. A single range measurement, r, restricts the target's location to a circle of radius r centered at the sensor. Similarly, if a second sensor can provide a range measurement as well, then the target's position is restricted to one of the two points where the two circles intersect, unless of course the circles do not intersect or the target falls on the line connecting the two sensors. If a third sensor can provide a range measurement, then the target's position can be narrowed to just one position. With only two dimensions, three range estimates will exactly determine the target's location and four or more range estimates will overdetermine the solution. However, given the error inherent in the sensors, more range estimates will likely improve robot localization.

4 Navigation

Once the problems of node and robot localization are solved, we can turn our attention to the problem of navigation. By navigation, we mean the guidance of a robot from one location to another. In one view of navigation, we may envision that a robot has notions of its current and future locations, and can compute and follow a trajectory that will allow it to get from "here" to "there." A simpler robot might navigate towards a source by following a gradient. Unlike these examples in which robots navigate on their own, we propose to view robots as simple automatons that are an extension of the sensor network. As a result, the robots benefit from a spatially-distributed network of sensors.

Consider a scenario in which the robot must navigate to the darkest location in a room. As described earlier, one way of accomplishing this task might be to use sensors on the robot to follow a gradient to the darkest point. However, gradient-descent algorithms are susceptible to local maxima. To compensate for this shortcoming, the robot might keep track of the darkest point it has seen so far and keep wandering around until either some time has passed or a darker spot has been found. If no darker spot is found, the robot would need to backtrack to last location it found. However, since shadows can change with the time of day and there are likely many local maxima, the robot's motion may be haphazard and it might expend significant energy searching.

Contrast the above method with an approach in which a spatially-distributed sensor network can simply measure the darkest spot in a room, or at least identify the darkest regions. Since the sensor network nodes locations are known, and the position of the robot can be determined via multilateration, the network simply needs to determine the darkest spot in the room and the robot's current location, and relay this information to the robot. Note that in this case, the robot only requires communication with the sensor network and no specialized sensors for light detection or odometry are necessary. The robot can then begin moving toward the target location.

5 Annotated Bibliography

In this section, we List background reading/papers on various approaches to localization. Eventually, we may expand this list to include navigation and mobile robots.

In [1], the author, a member of the Mathematics Department at Syracuse University, provides an introduction to a relatively new area of applied mathematics called *rigidity theory*. In [2], and overview and taxonomy of localization systems is presented. In [3], an angle of arrival (AOA) algorithm is developed to derive node orientations and positions. In [4], a range-free algorithm for network localization using hop counts and a small number of location-equiipped anchors is presented. In [5], Bulusu presents a doctoral dissertation on beacon-based localization. In [6], a mobile beacon based bayesian approach to localizing network nodes is presented. This approach is similar to our proposal but the authors assume the mobile beacon knows its own dynamically changing position but we do not require this information.

References

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