Extended Abstract for FSR'03
Japan, July 2003

An Experimental Study of Localization Using Wireless Ethernet (Extended Abstract)

Andrew Howard, Maja J Matarić and Gaurav S. Sukhatme
ahoward@usc.edu, gaurav@usc.edu, mataric@usc.edu

Introduction

This paper presents an experimental study exploring the use of wireless Ethernet as a localization sensor. Briefly, we assume that one or more wireless Ethernet devices have been placed in the environment to act as beacons, and use signal strength information from these beacons to localize the robot. The beacons may be wireless access points or other embedded devices that already exist in the environment, or they may be robots that have been deployed specifically to serve as radio beacons.

Our interest in wireless Ethernet as a localization sensor derives from two applications: service robots intended for tasks such as cleaning, delivery and security, and heterogeneous robot teams designed for reconnaissance and monitoring tasks. For service robots, the cost, weight and power consumption of laser range-finders and cameras may prohibit their use as localization sensors. In contrast, wireless Ethernet devices are cheap, light-weight and have relatively low power consumption. Similar considerations apply to heterogeneous robot teams, which mix small numbers of very capable robots with large numbers of very simple robots. For such teams, one can imagine a scenario in which a few of the simple robots are deployed into an unknown environment to serve as beacons for the remainder of the team.

This paper extends similar work conducted by a number of previous of authors [1, 3]; our key contributions are the embedding of the problem within the context of Monte-Carlo Localization (MCL), and the inclusion of much more comprehensive experimental results.

Approach

Our approach to localization is as follows. Each robot is equipped with three sensors: odometry, a contact sensor and a wireless network card. Robots are also given two maps: an occupancy grid and a signal strength map containing the measured signal strength for one or more beacons. The occupancy grid is used in conjunction with the contact sensor to bound the set of possible robot poses; from the *absence* of contact, for example, we can infer that the robot cannot be adjacent to any cell that is marked as occupied. In a similar fashion, the signal strength map is used in conjunction with the wireless network sensor to infer the set of probable robot poses. The actual localization is performed using a standard Monte-Carlo Localization (MCL) approach [5]. That is, we maintain a probability distribution over the space of all possible robot poses, using data from all three sensors to update the distribution. This continuous distribution is approximated using a *particle filter*, in which each particle effectively represents a single hypothesis for the robot pose. Given that the contact sensor is relatively uninformative, and the signal-strength measurements are extremely noisy, the MCL approach appears to be a very good fit.

The two maps that are required for localization can be built using a more capable robot equipped with a scanning laser range-finder. The techniques for building occupancy grids from odometry and laser range scans are well understood [4]; the construction of signal strength maps, however, is not so well understood. It is important to note that radio propagation in indoor environments can be extremely complex, with reflections, refractions and multi-path effects (see [2], for example). Therefore, rather than attempting to model such effects explicitly, we adopt a sampling/interpolation strategy. As the robot builds the occupancy grid, it simultaneously makes local signal strength measurements; the signal strength map is then generated from these measurements via interpolation (see Figure 1).

Preliminary Results

Figure 2 shows preliminary results obtained for a robot whose initial pose is entirely unknown. Three pose distributions are shown: the distribution obtained using odometry and contact sensing alone (blue), the distribution obtained after adding signal strength information (green), and the distribution obtained after adding both signal strength and laser range information (red). Comparing the three distributions, it is apparent that convergence speed and accuracy are both improved by the addition of signal strength information.

The experiments included in the full paper will address several key questions:

- Spatial variation. How does signal strength vary on both large and small scales? Large variations over small scales (perhaps due to multi-path effects) could greatly reduce the utility of this sensor.

- Temporal variation. How does signal strength vary over time? Variation may arise either from changes in the properties of the transmitters/receivers, or from changes in the radio propagation characteristics of the environment (such as heating/cooling during the course of the day).

- Heterogeneity among robots. The robots that construct the signal strength map will almost certainly be of different construction from the robots *using* the map. To compensate for such variations, it may be necessary to use signal strength *ratios* rather than absolute values.

- Non-static environments. How does the movement of large dielectric elements (people, doors) affect radio signal strength, and hence localization accuracy? This question is particularly relevant for service robotics applications.

Through this empirical study, we aim to assess both the accuracy and reliability of wireless Ethernet-based localization for practical robotics applications.

References

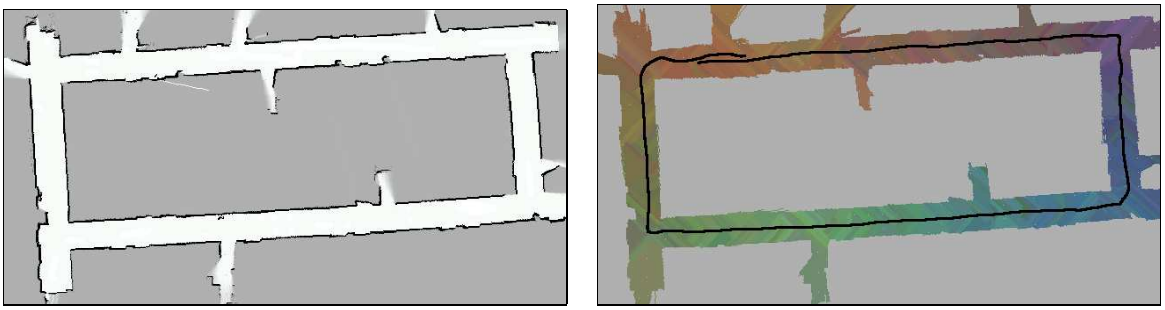
[1] P. Bahl and V. N. Padmanabhan. RADAR: An in-building RF-based user location and tracking system. In *INFOCOM (2)*, pages 775–784, 2000.

[2] M. Hassan-Ali and K. Pahlavan. A new statistical model for site-specific indoor radio propagation prediction based on geometric optics and geometric probability. *IEEE Transactions on Wireless Communication*, 1(1):112–124, Jan 2002.

[3] A. M. Ladd, K. E. Bekris, G. Marceau, A. Rudys, D. S. Wallach, and L. E. Kavraki. Using wireless Ethernet for localization. In *Proceedings of the 2002 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Lausanne, Switzerland, Sept 2002.

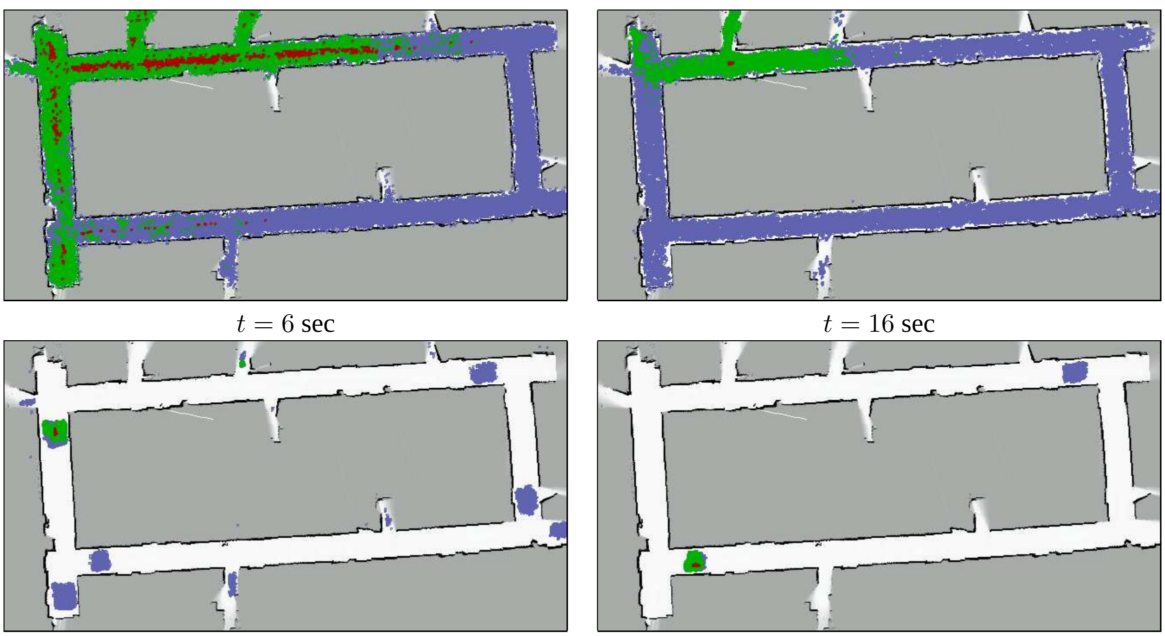
[4] S. Thrun, D. Fox, and W. Burgard. A probabilistic approach to concurrent mapping and localisation for mobile robots. *Machine Learning*, 31(5):29–55, 1998. Joint issue with Autonomous Robots.

[5] S. Thrun, D. Fox, W. Burgard, and F. Dellaert. Robust Monte Carlo localization for mobile robots. *Artificial Intelligence Journal*, 128(1–2):99–141, 2001.



(a) (b)

Figure 1: (a) Occupancy grid generated using odometry and a laser range-finder. (b) Combined signal strength map for three beacons, as indicated by the intensity in the red, green and blue color channels. Note that most of the values in this map are interpolated; the heavy line indicates the path of the robot that made the actual measurements.



$t = 6$ sec $t = 16$ sec

$t = 38$ sec $t = 69$ sec

Figure 2: Localization results. The blue distribution shows the result obtained using odometry and contact sensing only; the green and red distributions show the results obtained after adding signal-strength and laser range data, respectively. Note the persistent ambiguity in the pose when using contact sensing only.