THE GNATS –
LOW-COST EMBEDDED NETWORKS FOR SUPPORTING MOBILE ROBOTS

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Abstract We provide an overview of the GNATs project. This project is aimed at using tens to thousands of inexpensive networked devices embedded in the environment to support mobile robot applications. We provide motivation for building these types of systems, introduce a development platform we have developed, review some of our and others' previous work on using embedded networks to support robots, and outline directions for this line of research.

Keywords: Pervasive Computing, Sensor Networks, Multi-Robot Systems

1. Introduction

Pervasive networks of computing, communicating, and sensing devices will be embedded in future environments. These devices will include the likes of RFIDs, active badges, and sensor networks. For the most part, these devices are framed in the context of enabling and supporting human activities. We posit that these networks can also support robot systems, and particularly, mobile robot systems. In fact, we believe these networks will be so useful for mobile robots, that even when this infrastructure is not already available (e.g. space exploration) robots should expend the resources to deploy them as an early part of the mission.

Embedded networks can aid robots in completing their tasks, primarily by providing communication and coordination services, and possibly computation and sensing services. We feel this heterogeneous system of embedded devices and mobile robots puts a natural constraint on the design space of multi-robot systems. The embedded network serves as a pervasive communication, computation, and coordination fabric, while the mobile robots provide sensing and actuation.

Additionally, not only can pervasive networks support mobile robots, they can also be supported by mobile robots. The tedious tasks of deployment and maintenance of a thousand node network is a perfect application of autonomous robot technology.

One possible criticism of using embedded networks to support mobile robots is that of “engineering the environment”. Roboticists have worked tirelessly to make robots truly autonomous, often meaning the robots act intelligently in unknown and unpredictable environments. By creating infrastructure to support mobile robots, it may seem as though we are sidestepping this aspect of autonomy. We believe that almost all natural autonomous creatures build and use artifacts to support them in their daily tasks. As examples, ants lay pheromone trails and humans create traffic light systems. We feel that mobile robots can do the same. And if we must use the term “engineer the environment” – rather than the roboticist engineering the environment, we do believe it is useful for the robots to engineer the environment. The robots and the embedded network should have a symbiotic relationship by supporting each other, often in an autonomous manner.

In previous simulation work we investigated the use of embedded networks to facilitate mobile robot activities (O’Hara and Balch, 2004b). We have implemented a hardware platform to realize these types of applications. The platform, the GNATs[1], are low cost devices, allowing us to build a large number of them, and are highly configurable. The GNATs are intended to be used as a massively parallel system for computation, communication, and coordination in supporting mobile robots. The simplicity of the GNATs due to their specialization for mobile robot applications allows us to build them for a price an order of magnitude less than the Motes. This allows us to experiment with very large-scale systems.

2. The Hardware Platform

We have implemented a hardware platform, called the GNATs, for building embedded networks to support mobile robots. The hardware design choices were made explicitly to enable them to support mobile robots. The GNATs consist of four infrared (IR) emitters, four IR receivers, two visible light LEDs, a button, a Microchip PIC16F87 microcontroller, and a 3V battery. The platform is pictured in Figure 1.

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[1] **G**eorgia Tech **N**etwork/**N**ode(s) for **A**utonomous **T**asks

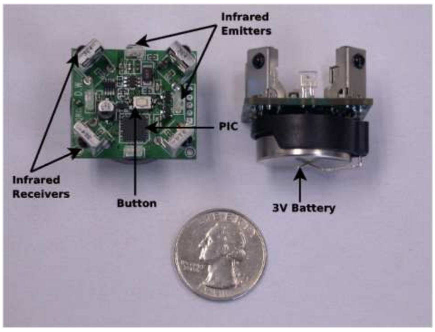

Figure 1. Two GNATs

The simplicity of the platform makes it very inexpensive, allowing us to build, and experiment with, a large number of devices.

Using infrared as the communication medium has multiple advantages and some disadvantages. Infrared is short-range and line-of-sight, these characteristics make is useful for storing environmentally sensitive information, often the most useful to mobile robots. Because environmental information is often local, we need a communication medium that respects this and keeps the information in context. This was the idea behind using infrared communication for "World-Embedded Computation" (Payton et al., 2001). Also, infrared is less power hungry than radio.

One disadvantage of infrared, as compared to radio, is its sensitivity to ambient, interfering, light sources. Many fluorescent lights (like the variety in our lab!) radiate infrared light that interferes with the infrared communication. Another disadvantage of infrared, as compared to radio, is its low data-rate. In general this is an disadvantage of infrared, but we don't feel this really impacts our applications since we don't imagine the network needing very high data-rates.

The GNATs can dynamically change their program code, their processor frequency, their communication output power and directionality, and turn off large parts of their circuitry when not in use for power-saving purposes. The GNATs also have a variety of sleep modes resulting in very long lifetimes. During these sleep-modes the GNATs can be configured to wake-up on timer or input (infrared activity, button) events.

Each device is less than $30 to build, enabling large-scale experimentation. The emitters' output power can be controlled with software allowing communication ranges of 1-5 meters. Also, the emitters can be individually addressed when sending messages, allowing the device to send messages in any combination of directions. Finally, the devices can write to their program memory permitting us to change the software on the devices on the fly, by a PC, or possibly a robot or other GNATs. The programming port can also be used for RS-232 serial communication. Using serial communication, one of the GNATs can be used as a communication device for a mobile robot. The mobile robot can carry a GNAT onboard to interact with other GNATs embedded throughout the environment.

3. Supporting Mobile Robots

Although, not explicitly directed at embedded networks, Parunak developed a technique for coordinating multiple unmanned air vehicles (UAVs) using synthetic pheromones and a multi-agent system (Parunak et al., 2002a; Parunak et al., 2002b). Inspired by pheromone communication in insects, they create potential fields for guiding the UAVs around threats to goal locations in a distributed manner. The technique they developed used uniformly placed (tiled as hexagons) "place" agents to store the pheromone and evaporate it over time, and "walker" agents to spread and react to the pheromone. The walker agents consisted of the UAV agents which physically move over the place agents and "ghost" agents which walk over the place agents virtually. The "place" agents could be implemented in the real world by using some kind of embedded network.

Several robotics researchers have proposed using embedded networks to support mobile robot applications. Both Batalin and Sukhatme (Batalin et al., 2004) and Li et al.(Li et al., 2003) have developed approaches to navigation using heterogeneous teams composed of mobile nodes and an embedded network. The network of embedded nodes, creates a "Navigation field" (Batalin and Sukhatme, 2003b), which mobile nodes can use to find the their way around. They differ in how they compute this navigation field. Batalin and Sukhatme use Distributed Value Iteration (Batalin and Sukhatme, 2003b). In their approach, the embedded nodes use estimated transition probabilities between nodes to compute the best direction to suggest to a mobile robot for moving between a start and goal node. These transition probabilities are established during deployment and both the robots and sensor nodes have synchronized direction sensors (e.g. digital compass). In addition to navigation, Batalin and Sukhatme have applied their technique to the multi-robot task allocation problem (Batalin and Sukhatme, 2003b).

Li et al. are able to generate an artificial potential field for navigation based on the obstacles and goals sensed by the network (Li et al., 2003). This potential field is guaranteed to deliver the mobile node to the goal location via an danger-free (obstacle-free) path. The field is created by the embedded nodes propagating goal-ness or danger to neighboring nodes. Both Batalin and Li used the Motes hardware platform for their physical experimentation.

In previous simulation studies we showed an embedded network supported effective cooperative multi-robot foraging by coordinating coverage patterns and by providing nearly optimal path planning without the network nodes having global knowledge or localization capabilities (O'Hara and Balch, 2004b). The embedded network created navigation networks for guiding mobile robots in various tasks such as coverage, recruitment, and path planning. Quantitative results illustrated the sensitivity of the approach to different network sizes, environmental complexities, and deployment configuration.

In addition, in previous work we developed and analyzed two different techniques for distributed path planning when the environment is dynamic (O'Hara and Balch, 2004a). One used global monitoring and the other focused communication. Both techniques were able to repair the plan when the environment changed and provided paths for a mobile robot to reach a goal. The first technique was able to respond to changes in the environment very quickly but did this at high communication cost. The second approach was able to respond to changes in the environment at the same speed, but with far fewer messages because it concentrated the messages along the path on which the robot currently resided.

A network of embedded nodes can also aid robots in coverage. Koenig (Koenig et al., 2001) and Wagner (Wagner et al., 1999) devise methods for doing parallel coverage using simple ant robots that communicate indirectly by leaving indicators in the environment. An embedded device can be used as this type of inexpensive indicator with the added advantage that they can communicate with each other. Batalin also uses communication nodes as "markers" in aiding mobile robots in the exploration problem (Batalin and Sukhatme, 2003a). The embedded nodes offer a suggested un-explored direction for the mobile robots to follow.

Mobile robots have also been used to support embedded networks. Lamarca et al. use mobile robots to continually calibrate a sensor network (LaMarca et al., 2002). Rahimi et al. present an approach for power harvesting in sensor networks by exploiting mobility (Rahimi et al., 2003). Corke et al. use a UAV to deploy and maintain the connectivity of a sensor network (Corke et al., 2004).

Acknowledgments We would like thank our collaborators on the GNATs project, Victor Bigio, Eric Dodson, and Arya Irani. Also, we would like to acknowledge the National Science Foundation for funding under award #0326396.

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