Parasitic Mobility in Dynamically Distributed Sensor Networks

Mathew Laibowitz and Joseph A. Paradiso
Responsive Environments Group
MIT Media Laboratory
Cambridge, MA 02139 USA
mat@media.mit.edu

ABSTRACT

Distributed sensor networks offer many new capabilities for monitoring environments with applicability to medical, industrial, military, environmental, and experiential fields. By making the system mobile, we increase the application space for the distributed sensor network mainly by providing context-dependent deployment, continual relocatability, automatic node recovery, and a larger area of coverage. In existing models, the addition of actuation to sensor network nodes has exacerbated three of the main problems with these types of systems: power usage, node size, and node complexity. This paper introduces a proposed solution to these problems in the form of parasitically actuated nodes that gain their mobility and local navigational intelligence by selectively engaging and disengaging from mobile hosts in their environment. This paper also illustrates the work that has begun to design, implement, evaluate, and demonstrate a parasitically actuated wireless sensor network as a solution to these problems and to explore new applications and features of a system with this type of mobility..

Categories and Subject Descriptors

B.m [**Hardware**]: Miscellaneous

General Terms

Experimentation

Keywords

Mobile Sensor Networks, Parasitic Actuation

1. INTRODUCTION

We are at a point in time where advances in technology have enabled production of extremely small, inexpensive, and wirelessly networkable sensor clusters. We can thus implant large quantities of sensors into an environment, creating a distributed sensor network. Each individual node in the network can monitor its local space and communicate with other nodes to collaboratively produce a high-level representation of the overall environment. By using distributed sensor networks, we can sculpt the sensor density to cluster around areas of interest, cover large areas, and work more efficiently by filtering local data at the node level before it is transmitted or relayed peer-to-peer [1].

Furthermore, by adding autonomous mobility to the nodes, the system becomes more able to dynamically localize around areas of interest, allowing it to cover a larger total area with fewer nodes by moving nodes away from uninteresting areas. Such approaches are well suited to sampling dynamic or poorly modeled phenomena. The addition of locomotion further provides the ability to deploy the sensor network at a distance away from the area of interest, useful in hostile environments. Cooperative micro-robots can reach places and perform tasks that their larger cousins cannot [2]. Mobility also allows the design of a system where nodes can seek out power sources, request the dispatch of other nodes to perform tasks that require more sensing capability, seek out repair, and locate data portals from which to report [3].

But the creation of mobile nodes is not without a price. Locomotion is costly in terms of node size and power consumption. In dense sensor systems, due to the large quantity of nodes and distributed coverage, it is difficult to manually replace batteries or maintain all nodes. Some researchers [4] have explored using robots to maintain distributed networks, but this is difficult to implement over large, unrestricted environments. Additionally, the added intelligence and processing power required for a node to successfully navigate in an arbitrary environment further increases the power and size requirements of each node. Large nodes, in physical size, complexity, cost, and power consumption, prevent the sensor network from being implanted in most environments [5, 6]. Although harvesting power from ambient sources of energy, such as sunlight, vibration, etc., is an active topic of research in the sensor network and mobile computing fields [7], the amount of energy that can be passively gleaned is usually insignificant when compared to that needed to physically move the network nodes.

This research is concerned with exploring a novel type of mobile distributed sensor network that achieves the benefits of mobility without the usual costs of size, power, and complexity. The innovation that allows this to happen is the design of nodes that harvest their actuation and local navigational intelligence from kinetic entities in their environment. The node will be equipped with the ability to selectively attach to or embed itself within an external mobile host. Examples of such hosts include people, animals, vehicles, fluids, forces (e.g,. selectively rolling down a hill), and cellular organisms. These hosts provide a source of translational energy, and in the animate cases, they know how

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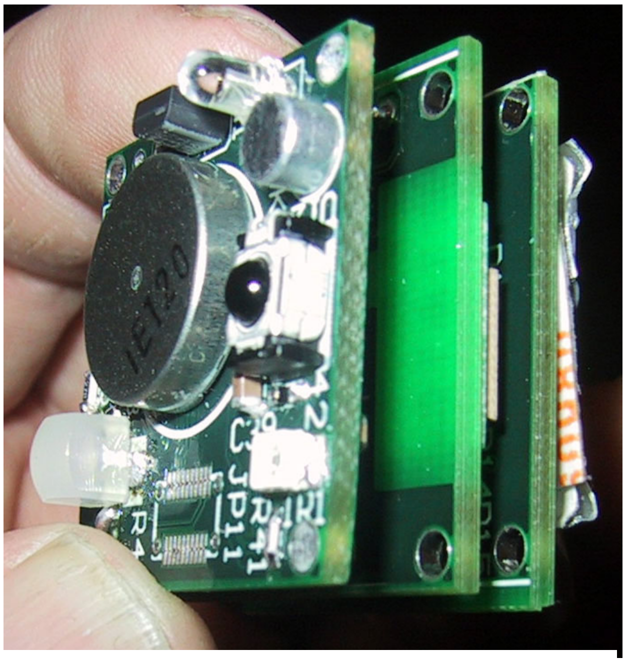

Figure 1: Photograph of an operational parasitic sensor node, showing the sensor-actuator layer (top), radio-processor layer (middle), and battery-power layer (bottom). A GPS layer (not shown) is presently nearing completion.

to navigate within their environment, allowing the node to simply decide if the host will take it closer to a point of interest. If so, the node will remain attached; when the host begins to take the node farther away from a point of interest the node will disengage and wait for a new host.

This area of research aims to develop and understand a potential method for the combination of mobile sensor agents, dense distributed sensor networks, and energy harvesting. These areas have been active and fruitful over past years, now that node size has decreased while node capability has increased. The combination of these interests can be addressed as parasitic mobility. Moreover, research in parasitically actuated sensor nodes may reveal novel applications only achievable with systems of this type.

2. Current Research

Some of the behaviors we are investigating involve trying to get to a specific geographic location, finding and analyzing an area of interest according to its sensor suite, locating a power source for recharging, attempting to maximize sensor coverage of an area, and seeking out other nodes to perform distributed tasks. We are currently building three systems to address these research goals [8].

The first system is a software simulator (Fig. 2). This allows us to design environments of a particular geometry with varying degrees of navigational difficulty. We can then populate the environment with environmental attributes and mobile hosts that behave in a particular, pseudo-random, or completely random way. We can then add parasitically actuated devices and give them behaviors and goals. This simulator allows us to quickly evaluate behaviors and control

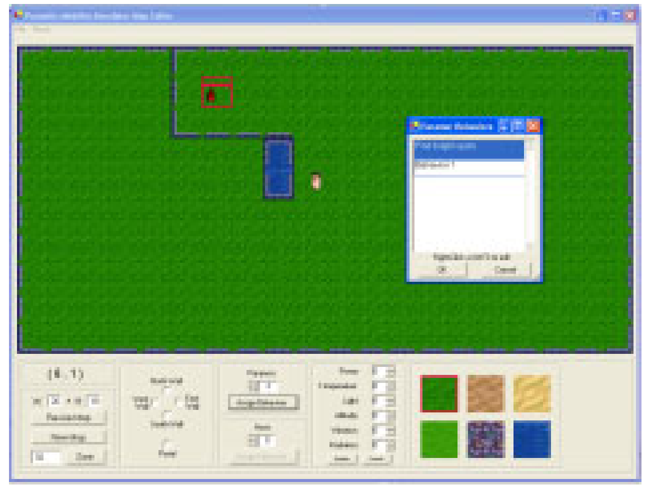

Figure 2: At right is a screenshot of the simulation's editor that allows you to define geographic boundaries, assign environmental behaviors and set initial positions of hosts and parasitic nodes

schemes, compare the energy cost and performance of parasitic mobility to other forms of mobility, identify which behaviors are valid for which environmental situations, and also to provide us with a starting point of expected results.

The second two testbed systems we are designing are actual sensor network hardware systems that have the ability to become mobile parasitically. These two systems are based around the same sensors, communications, and processing, but differ in their mechanical structure and parasitic modality.

Each node is equipped with a GPS module, in-field rechargeable battery system (145 mA-hr) with gas gauge, Bluetooth communication module supporting a self-configuring scatternet topology, 16 megabytes of flash data memory, and a suite of sensors including temperature, inertial motion, proximity to solid objects, light, audio, and temperature. A prototype node including all of the above components (excepting GPS, which is now being integrated) is shown in Figure 1; it forms a roughly 1-inch cube when fully assembled.

The first of these two systems is built into a sphere and has the ability to stick to objects that it comes in contact with. It can then shake itself loose with a vibrating pager-style motor when its behavior dictates.

The second device is similar, but instead of a pager motor, it is equipped with a hopping actuator that allows it to selectively jump on and attach to a host body that it detects within its target range. It can then hop off at a specific locations or when it detects a new host that is potentially more useful. The weight of the complete module with hopping actuator attached is 40 grams.

The current hardware nodes are small enough to innocuously hop onto vehicles, perhaps attaching and releasing with a permanent magnet shutter. As electronics continue to shrink [9], invisibly engaging animate hosts becomes more feasible. Tests [8] are now underway that use a "Trojan Horse" approach, where nodes perhaps confer some kind of benefit and look interesting enough for people to pick up and carry willingly. When it wants to be released, a node vibrates, buzzes, and flashes annoyingly.

3. ACKNOWLEDGMENTS

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