An Inexpensive Bluetooth-Based Indoor Positioning Hack

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ABSTRACT
A Bluetooth-based indoor positioning system using off-the-shelf low-cost stationary beacons and mobile host devices is described. The system permits low-cost, rapid prototyping of applications where room-level location detection is sufficient. The technical details required to make such a system work in practice are described.

Keywords
Bluetooth, indoor, positioning, ubiquitous, computing

INTRODUCTION

Many applications that have been proposed by ubiquitous computing researchers depend upon automatic detection of indoor location. Although some applications would require high-resolution position information (e.g., cm or mm accuracy), many require only room-level accuracy.

We are interested in building ubiquitous computing applications for the workplace and therefore need a low-cost indoor position system that can be rapidly deployed and easily maintained in an office setting for studies that may last months or longer. The system should work robustly, determine location at the scale of rooms and workspaces (i.e. 2-3m), and update quickly enough to capture movement trajectories of people. For these applications, it is acceptable to require that the user carry a "tag," such as an infrared transceiver or a mobile phone. Our criteria preclude our use of conventional Satellite Global Positioning Systems (poor signal reception indoors) and cellular tower triangulation (large spatial resolution). Other options that we considered were systems explicitly created for indoor tracking tasks, but are (IR, RF, and ultrasound tag systems) either not commercially available or are quite costly (e.g., costing hundreds of dollars per beacon or tag). Further, many of these systems require additional hardware to communicate with mobile devices.

We wanted something simple and robust; other researchers had frequently suggested using Bluetooth. Nearly everyone we talked with assumed that it would be straightforward, except those researchers who had actually tried it. The consensus in published work on Bluetooth positioning implies that the standards and intrinsic characteristics of the protocol do not favor conventional signal time-of-flight based positioning methods [e.g., 3].

Passive Beacons

To produce our system, we built upon the work of Albert Huang and Larry Rudolph at MIT CSAIL [4]. Huang and Rudolph proposed using a low cost address discovery system, with existing Bluetooth protocol characteristics and off-the-shelf dongle hardware. Using a USB Bluetooth dongle, self powering hub, and aluminum cooking foil, they produced a stand-alone beacon with 9m range (vs. standard 30m for Bluetooth devices). With all beacons continuously broadcasting an address and device name (discovery mode); position is determined based on which beacons can be "seen" by a host device.

We implemented this address discovery system, but encountered two significant problems. Firstly, the presence of many other devices (that are not part of the system) increases the time needed per positioning event. Secondly, the address discovery system requires each beacon to be initialized and then wrapped, which represents significant on-site time commitment, and does not withstand power outages. These are overcome with the use of off-the-shelf phone headsets with a standby mode that allows a host device to determine presence, and by utilizing the self initializing ability of these headsets.

KNOWN DEVICE CHECK SYSTEM

Researchers who need a low-cost indoor positioning system can follow the steps below to obtain a system that we have found sufficient for prototyping.

Hardware

Each of our beacons consisted of the following parts, for a total purchase cost of about $20.00 : {1: SCALA 500 Bluetooth Mobile Phone Headset; $19.00; 1: Cardboard Carton 2.5"x3"x1"; $0.42; 1: Foil Tape, 2"x15'; $0.65}. Assembly of the beacon begins with ensuring that the device will remain powered on, whenever it is plugged in. For our devices, this simply entails removal of the headset battery (leaving the AC power connection), to bypass the charging cycle. After the initial power up, the device remains in a standby mode, where it does not broadcast an address, but will respond to specific inquiries to its own address. To finish the beacon, the headset is placed inside the cardboard carton, and this is wrapped with the foil tape, covering the surface of the carton twice. It was found, by trial and error, that the foil tape (Nashua brand, 322) was important for attaining a 2-3m beacon range. Two layers ensured gap free coverage. Other wrapping methods and parameters, such as shape of the carton, did not show a significant effect on the performance of the beacon.

Implementation on Windows Mobile Smartphone

Using Audiovox SMT5600 phones and C#.NET development tools, supplemented by Windows Bluetooth libraries [5], we developed test applications that continuously scan only for the addresses of known beacons. Using the results of attempted socket connections [6], initial methods take between 1.5 and 6 seconds to determine if each beacon is within range.

System Performance

Open field tests of the beacons revealed a symmetrical range; see Figure 1.

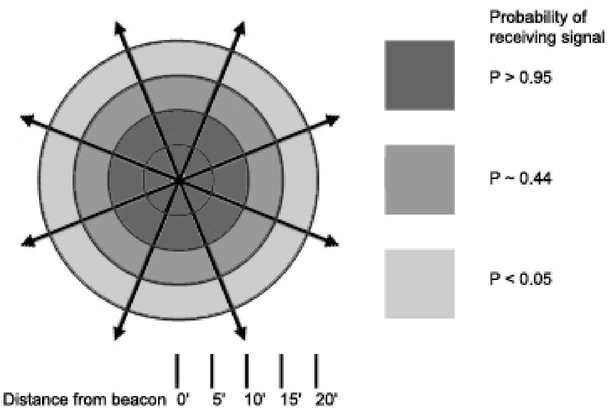

Figure 1. reception field in open field

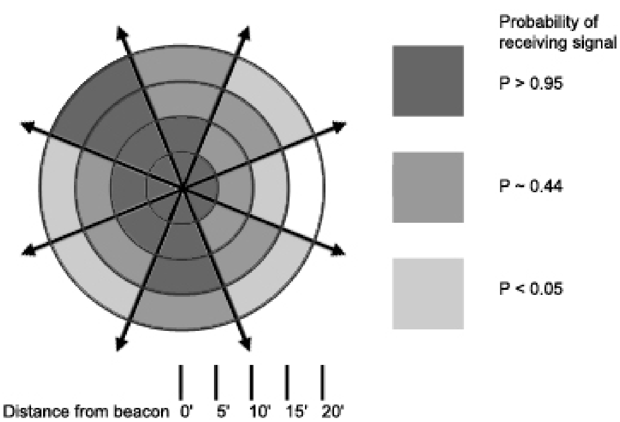

Figure 2. example of reception field, in office environment

However, when placed within a conventional office environment (in our case, steel and reinforced concrete building construction, and an abundance of ceiling and wall embedded data and power lines), the reception field tends away from radial symmetry, due to the presence of building infrastructure, as well as metal furniture and electronic equipment. Importantly, these fields do not change significantly with the movement of people, typical office chairs, and doors (ours are wood). Prior tests, with beacon reception field attenuated to approximately nine meters, showed that this variation in field shape is more significant, and makes it very difficult to set up a system that relies on overlapping fields for position determination.

DISCUSSION

We have described a strategy that employs Bluetooth for positioning with mobile devices, that is effective indoors, at a spatial resolution of two to three meters, and requires only low cost off-the-shelf hardware. Our methods of using presence of beacon signals as positioning information have shown to be reliable in a real world setting with greater than normal expected noise, in terms of electronic equipment, etc. Given the properties of the shape of the reception field in such an environment, we have found that using beacons with a range that is approximately equal to the desired spatial resolution (i.e. 2-3m) to be desirable.

A self initializing Bluetooth beacon can be created with an off-the-shelf Bluetooth headset, as described in our "known address check system." The associated positioning scheme is ideal for applications that require only several beacons, or that can tolerate slightly longer positioning determination times. Further development of this (known device check) scheme is under way (significant speed improvements are expected), as well as studies utilizing the system at the scale of a thirty person workplace.

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