# A Demonstration of Tracking the Position of a Moving LEGO Train using the Cricket Indoor Location System*

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*Cricket* is an indoor location system that tracks the position of device and sensors with an error of a few centimeters. Two of the system's key features are its ease-of-deployment and tracking accuracy. In our demonstration, we plan to show how to deploy and configure Crickets quickly in a room-size environment and use the system to track the position of a moving LEGO train.

## 1 Background

The Cricket indoor location system [1] was motivated by the importance of mobile and context-aware applications in sensor networks and pervasive computing environments, and the poor indoor performance of the Global Positioning System (GPS). A compelling attribute of applications in pervasive environments is context-awareness, being able to discover the external context and adapting accordingly. An important example of context is location: the position in some coordinate system of a device or user, the geographic space in which a device or user is (e.g., the room or portion of a room), or the orientation of a device within some coordinate system. Knowledge of location in the form of coordinate position, spatial resolution, and orientation (a.k.a. "directionality" or "heading") enables a wide variety of pervasive computing applications such as resource discovery, pose-aware "point-and-use" interfaces, navigation, and augmented reality.

Although location information in outdoor environments may be obtained via the Global Positioning System or using the cellular infrastructure (with the emerging E-911 services) augmented with a magnetic compass, such capabilities are unavailable in indoor environments or in urban areas where line-of-sight to GPS satellites is usually unavailable. We assert that location-aware applications inside buildings, such as offices (and campuses), shopping malls, airports, homes, etc. have the potential to fundamentally change the way we interact with our immediate environment, in which computing elements will be "ubiquitous" or "pervasive."

Obtaining location information for applications in an indoor environment in an unobtrusive and private manner is a challenging task. Indoor environments are harsher than outdoor ones in their treatment of radio signals because of multipath effects and dead spots inside buildings. A traditional magnetic compass does not work well in many buildings because of electromagnetic interference from computers and monitors. User-privacy concerns are an important consideration in the successful deployment of these applications, especially if the users of the system are to extend beyond the researchers who develop the technology. The deployment of the hardware and software infrastructure used for this must be simple to reduce cost and the administration of them must be minimal because of the large number (potentially over several thousand in a typical building) of devices.

## 2 Technology

Cricket uses a combination of Radio Frequency (RF) and ultrasound technologies to provide distance ranging ability between a Cricket *beacon* and a Cricket *listener*. Wall- or ceiling-mounted Cricket beacons spread throughout a building and broadcast information on the RF channel. With each RF advertisement, the beacon transmits a concurrent ultrasonic pulse. Compact listeners attached to mobile or static devices listen for RF signals and, upon receipt of the first few bits, listen for the corresponding ultrasonic pulse. Because the ultrasonic pulse travels more slowly than the RF signal, there will be a time difference in the arrivals between the two signals. Using this time difference and the speed of sound, the listeners compute a distance estimate for the corresponding beacon. The listeners run an inference algorithm to correlate the RF

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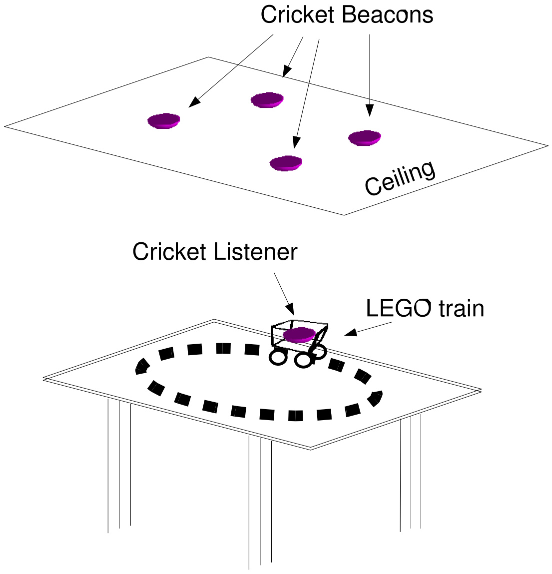
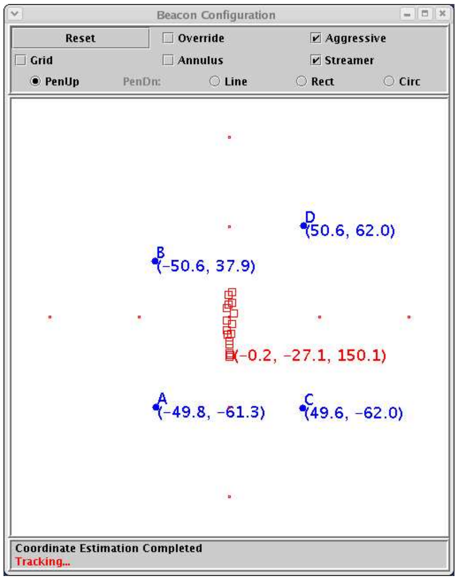


Figure 1: Cricket demonstration set up to track the position of of LEGO train.

and ultrasound signals (the latter are simple pulses with no data encoded on them) emitted from the same beacon. Even in the presence of several competing beacons, our goal is to accurately estimate the linear distances between a listener and all in-range beacons within a fraction of a second.

The Cricket beacons are programmed to advertised the beacon's space location (e.g., a room number) and an unique beacon identifier from which a $(x, y, z)$ coordinate representing the beacon's position in a predefined coordinate system can be derived. The advertised information and the listener's distance measurements are processed by a maximum likelihood estimator and a multi-lateration algorithm to pinpoint a listener's space location [1] and coordinate position [2]. We also developed localization algorithms that automate the process of configuring coordinates of each beacon deployed in the environment and have implemented an extended Kalman filter to track the position of moving devices to within a few centimeters of accuracy [3].

Cricket uses an architecture that employs active beacons that are mounted in the environment and passive listeners attached to mobile or static devices of interest. This architecture has three significant benefits. First, it is not a tracking system where a centralized controller or database receives transmissions from users and devices and tracks them. Second, it scales well as the number of locatable devices increases because the attached listeners are passive; in contrast, a system with active transmitters attached to locatable devices will increase the level of signal contention in the environment with increasing density of instrumented devices. Third, its decentralized architecture greatly simplifies the system and makes it inexpensive and easy to deploy.



Coordinate Estimation Completed
Tracking...

Figure 2: In tracking mode, the BeaconConfig application shows the current position and the trail of the moving train (red squares) relative to the beacons' positions on the ceiling (blue dots).

# 3 Status

At the time of writing, we are releasing a second version of the Cricket hardware (aka Cricket v2). In contrast to our first generation hardware, Cricket v2 has a smaller form factor, consumes less power and measures distances more accurately. Cricket v2 provides a connector that can attach to external sensor boards and is implemented on the TinyOS platform [4]. Crossbow Technology Inc.[1] is now offering the Cricket hardware for sale. The Cricket software can be downloaded from the Cricket Project website[2].

Various versions of Cricket have been used by several groups at MIT for applications including people location, multi-player physical/virtual games, human and robot navigation, location-aware access control, stream migration, and also for several student projects in an undergraduate pervasive computing course at MIT. We have also given Cricket units to researchers at other institutions, including the University of Washington, Intel Research, NTT Labs, Nokia Research, Delta Electronics, Acer group, Rutgers University, Philips Research, and HP Labs (the last two have also made their own versions).

# 4 Demo Description

We plan to show how to deploy and configure Crickets quickly in a room-size environment and use the system to

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[1] `http://xbow.com`
[2] `http://nms.csail.mit.edu/cricket`

track the position of a moving LEGO train. Our system demonstration will showcase the Cricket v2 hardware.

Figure 1 shows the setup of our demonstration. We will instrument an area by attaching four to five Cricket beacons to a ceiling. The beacon will spread over an approximate area of 2m x 2m. We will lay LEGO train tracks on a large table (1.2m x 1.8m). A Cricket listener will be attached to the LEGO train to let our system track the position of the train while it is moving.

### 4.1 Assisted Coordinate Configuration

We developed an application called *BeaconConfig* to automate the beacon configuration process and allow rapid and ad hoc deployment of the Cricket system in any desired location.

BeaconConfig works by using the Cricket listener to collect distance measurements from all the beacons that needs to be configured.[3] The user picks three beacons as references and places the listener underneath each of them to collect distance samples. The references are used to define the origin and the orientation of the coordinate system. After collecting the measurements, the BeaconConfig program solves a set of simultaneous equations to compute the coordinates of each of the reference beacons. BeaconConfig can then use the three reference coordinates and the collected distance measurements to compute the coordinates for the rest of the beacons.

The configuration process is scalable: the user need to obtain measurements from only three locations regardless of the number of beacons that need configuration in the area.

### 4.2 Position Tracking

After configuring the beacon coordinates, BeaconConfig switches to a tracking mode to track the position of the mobile Cricket listener. Figure 2 is a screen shot of the BeaconConfig application tracking the current position and the trail of the LEGO train (red squares) relative to the position of the beacons attached to the ceiling (blue dots).

We are currently integrating the extended Kalman filter described in [3] into the BeaconConfig application. To showcase the performance improvement of the Kalman filter in tracking moving objects over traditional methods, we will modify BeaconConfig to simultaneously show both the positions computed by the traditional linearized least-squares method and by the extended Kalman filter.

## References

[1] PRIYANTHA, N., CHAKRABORTY, A., AND BALAKRISHNAN, H. The Cricket Location-Support System. In *Proc. 6th ACM MOBICOM Conf.* (Boston, MA, Aug. 2000).

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[3] SMITH, A. AND BALAKRISHNAN, H AND GORACZKO, M. AND PRIYANTHA, N. Tracking Moving Devices with the Cricket Location System. In *Proc. ACM MobiSys 2004* (Boston, MA, June 2004).

[4] `http://webs.cs.berkeley.edu/tos/`.

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[3] BeaconConfig implicitly assumes that all the beacons that need to be configured are within the listener's receiving range.