

Indoor Classroom Location: A Survey and Case Study

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With the advent of new low-energy wireless standards like BLE, affordable indoor location is becoming finally feasible. With the aim of using such location in our research to provide spatial and pedagogical “orchestration maps”, I have surveyed different technologies for indoor location, and I have tested one specific brand of BLE beacons. The main conclusion of our tests with Estimote beacons is that accuracy is around 1.5m. If we want higher accuracy, especially for a moving target, there are (costly) alternative technologies on the market. In the end, it all boils down to what kind of information we want to obtain.

Introduction

- Indoor location, Indoor positioning systems (IPS), also known by the name of “microlocation” are technological solutions to locate objects or people inside a building (where other methods like GPS cannot operate)
- Typical uses of these systems include augmented reality applications such as guided museum or city tours, store or warehouse or airport navigation, targeted advertising, sports, etc.
- A variety of technologies have been used to implement these systems, with varying degrees of success and accuracy: radio-frequency, infra-red (IR), acoustic signals, inertial measurements and even Earth’s magnetic field
- Our plan is to perform experiments with school teachers, where we provide them with a map of their movements in the classroom, so that they can reflect on the patterns that they observe
- Thus, we need an IPS solution that can track the teacher with enough accuracy to provide meaningful patterns/insights (e.g., <1m error)
- This document summarizes a) a survey of the IPS field (both research and commercial solutions) to find an accurate-enough solution we can use in a classroom, as well as b) the results of our first experiments with BLE beacons in our lab’s meeting room

Survey on Indoor Location Methods

Performance Metrics

- The most commonly used is *accuracy or location error* (mean distance error between the detected and the real position)

- Other metrics include *precision* (either robustness of the positioning, e.g., standard deviation of the location error, or its distribution, e.g., 90% within 2.3m), *complexity* (hardware, software, operational – often indicated by the location rate or lag), *robustness* (to the unavailability of certain signals/units), *scalability* (how large can the indoor location grow, and whether location is 2D or 3D), and of course, *cost* (including energy consumption too).
- Given our aim of measuring positions in a classroom, we will mainly use *accuracy* and *precision* as the main metrics, with an eye on cost, complexity and robustness

Systems and Solutions

- The resolution/accuracy of methods depends largely on the wireless technology being used (Fig. 1). We see that, for accuracies <1m, RF hybrid methods or UWB/microwave seem the best bet

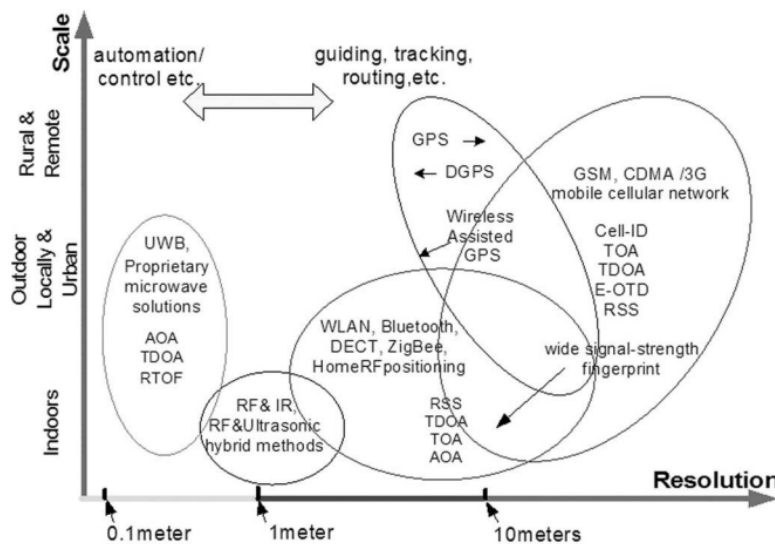


Figure 1: Wireless technologies used in indoor location and their typical accuracies

- Ultrasound systems seem to have very high accuracies up to a few centimeters... but as noted by ¹, these systems often require synchronized nodes, a dense grid of receptors (difficult to install in a school) and/or are prone to interference by ultrasound noise
- Looking into several reviews of the field ^{2 3 4}, we find several methods and systems with <1m accuracy: Ekahau (WLAN/Wifi), Ubisense (UWB), Sappire Dart (WLAN+ultrasound), SmartLOCUS (IR+UHF), EIRIS, Pinpoint 3D-ID (UHF), Active badge (IR), Active bat (ultrasound), Cricket (ultrasound), Dolphin (RF+ultrasound), UWB, or computer vision methods

¹ Ijaz, F., Yang, H. K., Ahmad, A. W., & Lee, C. (2013, January). Indoor positioning: A review of indoor ultrasonic positioning systems. In *Advanced Communication Technology (ICACT), 2013 15th International Conference on* (pp. 1146-1150). IEEE.

² Liu, H., Darabi, H., Banerjee, P., & Liu, J. (2007). Survey of wireless indoor positioning techniques and systems. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, 37(6), 1067-1080.

³ Koyuncu, H., & Yang, S. H. (2010). A survey of indoor positioning and object locating systems. *IJCSNS International Journal of Computer Science and Network Security*, 10(5), 121-128.

⁴ Bastos, A. S., Vieira, V., & Apolinário Jr, A. L. (2015). Indoor location systems in emergency scenarios-A Survey.

- One of the most prominent recent contenders are Bluetooth-based (especially, BLE and the iBeacon technology promoted by Apple), although experts say that it is more aimed at indoor *proximity* (activate something when very close to a beacon), not indoor *location* (determining distance to one or more beacons)
- However, this sector is moving fast, there are a number of startups working at this problem that might have interesting results soon ⁵

⁵ <https://angel.co/indoor-positioning>

The Bottom Line: Most Likely Options

- A quite complete and recent review/thesis ⁶ has found and categorized systems belonging to 13 different technologies, and concludes that <1m accuracy is really hard to find, with reasonable cost/infrastructure
- From that list, and Microsoft's latest "IPS competition" ⁷, some of the most promising options, that are available commercially or might be made available to us are:
 - ABATEC ⁸: Tracking for sports events, apparently centimeter precision. It consists on a set of transmitters in tripods around the area to track, plus a small transmitter that can be worn or put in the pocket. **Contacted by email, awaiting response**
 - UbiSense ⁹: claims to achieve 15cm accuracy, and has some kind of "location kit" for research use. It works by putting four box-sized modules on the room corners, plus a small device in the teacher's pocket. **Contacted them, their solution would have more likely an accuracy of 0.3m, the price tag is 12500 euro (!)**
 - Cricket ¹⁰: dates from 2005, but still claims high accuracy and it is an open architecture/product (now sold by stores like ¹¹). It works by putting 6-8 of these small modules on the ceiling, plus a transmitter on the teacher (we would have to tinker a bit to make the receptor wearable). **Contacted them, a package for indoor location would cost around 2500 euro, deliverable in about 3 weeks**

⁶ <http://e-collection.library.ethz.ch/eserv/eth:5659/eth-5659-01.pdf>

⁷ <http://research.microsoft.com/en-us/events/indoorloccompetition2015/>

⁸ <https://www.abatec-ag.com/en/inmotiotec/lpm-team/motiotrac-wireless-team/operating-principle-motiotrac-wireless-team-wireless-team>

⁹ <http://ubisense.net/en/information/resources>

¹⁰ <http://cricket.csail.mit.edu/>

¹¹ http://www.willow.co.uk/html/mcs410-_mcs_cricket_series.php

The Case of BLE Beacons (Estimate)

- As a first approximation to this idea of a teacher location map, we bought (cheap) Estimate ¹² BLE beacons, and did some experiments with its indoor location mechanisms

¹² <http://estimate.com/>

Initial Test Runs

- As an initial test of the technology, I did a "calibration walk" in our meeting room, in which the true location is known (for every

second), with the hope of adjusting the signals of each beacon and get more accurate results

- Then, results were tested on a second “test walk”, in which the true position is also known in advance
- As we can see in Fig. 1, results are not very accurate: using our most accurate smoothing method (see the red triangles in Fig. 1), the mean error was of 1.5460022 meters (and it looks like this is because the method keeps the positions always near the center of the room!).
- An alternative method which just considers the *static* triangulated positions (those that vary less than 1m in one second to the next) performs better (average error of 1.3815564 meters), by discarding about half of the position data

A Real Case: Journee des Classes 2015

- Using this kind of position estimation for the data data gathered during the JdC2015 experiment, we can start to have “classroom movement heatmaps”:
 - Gathering the data from all four sessions (Fig. 3, left), we see how the layout of the classroom (tabletops at the edges) influences the teacher overall position to be rather near the center, and towards his own desk (in the top of the figure)
 - We also can see the difference between sessions where the teacher had a helper handling the left half of the tables (Fig. 3, right), and the sessions that were managed without help (Fig. 3, center)

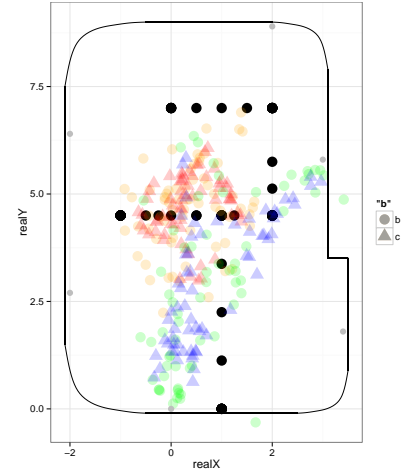
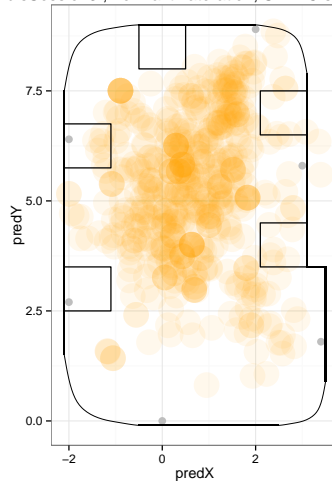
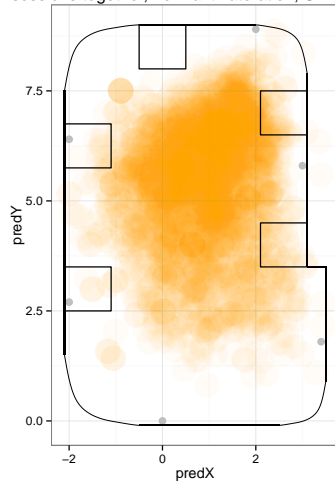


Figure 2: Real and estimated positions during the (short) test walk. In black, the true positions. The other colors represent different methods for estimating the position from the beacon signals.

4 sessions together, normal trilateration, STATIC samples luisSession3 , normal trilateration, STATIC samples



luisSession4 , normal trilateration, STATIC samples

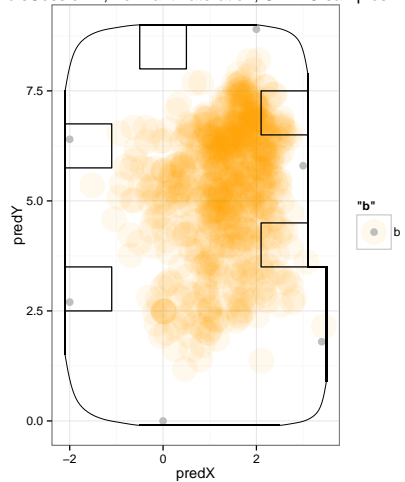


Figure 3: Estimated positions during Journee des Classes 2015, considering only the moments in which location was stable for more than 1 sec.

- We are still working on the more accurate estimation of position from the eyetracking video feed of these sessions, which will provide us with a more concrete idea of the accuracy to be expected from the BLE beacons in realistic conditions

Discussion: What Are Our Alternatives?

- With this survey and first results in mind, what is our best alternative for an indoor location technology for the classroom? It actually depends on what we want to get out of it:
 - a. If rough visualizations such as the ones provided above are enough (knowing that they might be off about 1.5m), then our current Estimote beacons provide a relatively inexpensive and unobtrusive technological option
 - b. If we are going to use the indoor location in conjunction with eye-trackers all the time, then a combination of chilitag-based (or even without chilitags, if we manage to do a feature-based computer vision detector) could be a good option, in which we have quite accurate location for the moments in which the teacher has the walls on the field of view, with fall-back to the beacons when the teacher is looking down (often, static moments)
 - c. If we need the increased accuracy to dm-level, and we are ready to shell out 2,000-12,000 euros, we can invest in one of the more advanced technology options mentioned at the end of the survey. These options also have the mild problem of being a bit more difficult to setup in the classroom, and the infrastructure might not be so “invisible”, compared to the eyetracker or the BLE beacons.
 - d. Depending on what we want to see, we could also change our current location-based strategy to a “proximity-based” one, in which we track when the teacher is very close to certain interesting point, in which we put a beacon (similar to Slotta & Moher’s “embedded phenomena” learning activities ¹³). This would lead to a more “symbolic map” of the classroom (e.g., how much time the teacher spent at her desk, how much at the whiteboard, what was the path of the teacher from one interesting point to another – i.e., from beacon to beacon).

¹³ Moher, T., Slotta, J., Acosta, A., Cober, R., Dasgupta, C., Fong, C., ... & Pessler, K. Knowledge Construction in the Instrumented Classroom: Supporting Student Investigations of Their Physical Learning Environment. *Proceedings of the CSCL 2015 Conference*.

Open Questions and Next Steps

- Should we buy any of the more advanced technologies, or develop further what we have (e.g., try the computer vision option)?

- Should we get back to Stephanie Fleck again with this report about the usage of the beacons? (What was her idea of collaborating with us again?)
- Are these visualizations of the teacher map OK? What else would be interesting?
- Depending on the previous responses, establish a calendar of contacts with schools to do the location tracking (and/or eyetracking)