*GVU Technical Report GIT-GVU 99-29, see http://www.gvu.gatech.edu/*

# Designing For Ubiquitous Computing: A Case Study in Context Sensing

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## ABSTRACT
This paper reports ongoing experience with the design and everyday use of an electronic context-enabled in/out board. We designed this application as part of the development of a context toolkit and it proved a fruitful test-bed for investigating issues of context sensor fusion. We describe the first version of the application that used a single context sensor and explain some usability problems it raised. We analyze the limitations of available context sensors and conclude that the usability problems cannot be overcome using a single sensor. We suggest solutions relying on the use of multiple context sensors and sensor fusion.

### Keywords
Context sensing, Sensor fusion, Ubiquitous computing

## INTRODUCTION
Context sensing is recognized as an important feature for ubiquitous computing. By sensing context information such as the location and identity of people and objects, context-enabled applications can present context information to users, or modify their behavior according to changes in the environment. However, there is little work to help designers of context-enabled applications decide which sensors can be used to sense a particular piece of context information. For example, it is not clear yet which sensors are adequate for sensing the presence and identity of people in an office building, or even if a single type of sensor would be sufficient.

In this paper, we report on our experience building and using a context-enabled in/out board. We point out usability problems we discovered and analyze the limitations of devices and techniques used to sense the presence and identity of people. We suggest that the combination of multiple sensors is required.

## THE IN/OUT BOARD APPLICATION
In office environments, we often find ourselves trying to determine if people are in their office in order to interact with them. Conventional in/out boards located at the entrance of a building often serve to indicate which people are in and out. We have built an electronic in/out board with two objectives in mind:

- Provide this information anywhere people might need it. This is accomplished through a web interface to the in/out board.[1]
- Automate the determination of the in or out status of users. This is accomplished through context sensing of the presence and identity of users.

In the first version of the in/out board, each user is assigned an iButton that identifies her uniquely [1]. The in/out board display and an iButton reader are located at the entrance of our building. When a user gets in or out, she docks her iButton in the reader and her status is updated accordingly (see figure 1).

Figure 1. Screenshot of the in/out board display. The dot next to a user name is green if the user is in and red if she is out.

The in/out board is part of a larger effort intended at developing a generic toolkit for context sensing [3]. We use the in/out board application as a test-bed for developing new capabilities in the toolkit, such as the sensor fusion mechanisms described in this paper.

## USABILITY PROBLEMS
After a few months of daily use, we are able to point out a number of usability problems in our implementation.

First and foremost, the sensor we have chosen requires an explicit docking action from the user. People will sometimes forget to dock on their way in or out or find it inconvenient if they are in a hurry or carrying equipment. As a consequence, their in/out status is not updated and the whole display cannot be trusted.

A related problem is that we chose to have context sensing happen in a single point, namely the entrance of our

[1] The web version of the in/out board is at: http://fire.cc.gt.atl.ga.us/inout.fcgi

building. People forgetting to dock on their way in to their office have to get back to the entrance to update their status (if they ever realize they forgot to dock).

Both problems could be overcome with more adequate sensing techniques. We now review available techniques for sensing presence and identity.

## A SINGLE SENSOR DOES NOT FIT ALL

In our view, sensing should blend naturally with the habitual actions of users while providing reliable information. But we found out that available sensors are either intrusive, uncertain, or unreliable. By intrusive, we mean that the sensor, either because of its operation or its form factor doesn't fit the natural flow of the user's activities. Uncertain sensors provide "best guess" results and cannot be trusted if the confidence factor is too low. Unreliable sensors have known failure modes that can usually be identified as such.

Active Badges [4] are a popular choice for sensing presence, identity and even location of people within a building. However, we consider them intrusive: They must be worn at all times and their form factor makes them difficult to dissimulate. Since they use IR for communication, keeping them in one's pocket is not an option. Most of our users are not used and not willing to wear a badge permanently. Face recognition from a video camera suffers from another form of intrusiveness: this technique requires the user to stand still in front of the camera at a set position for a couple of seconds to allow face acquisition. Face recognition is also an uncertain technique.

Other sensors are uncertain or downright unreliable under certain limit conditions, which are however not uncommon in our setting. Passive RF cannot be read reliably when two or more tags are simultaneously in the field of the antenna. Another sensor we consider is a smart floor that we have built. It relies on pressure-sensitive floor tiles. Since each user's footstep pressure pattern is unique, it allows both presence and identity sensing [2]. However, its results are uncertain: candidate user identities are provided with a confidence factor. If the confidence factor is below a threshold, the result cannot be trusted. The smart floor also requires that only one person at a time is walking on a tile of the sensitive floor surface. With both the RF tags and the smart floor, two people coming in together might not be sensed reliably. However, we expect to be able to set up a RF reader and the smart floor at the same location so that both do not fail under the same conditions.

This review of available sensors, although not exhaustive, shows that no single sensor allows us to sense presence and identity reliably while satisfying our usability requirements. Other sensors not mentioned here suffer from similar shortcomings. Thus, we must consider combining multiple sensors.

## COMBINING SENSORS

Combining multiple sensors raises the problem of fusing the information in a meaningful way. Inspired by the sensor fusion literature, we envision two general sensor fusion mechanisms based on competitive or complementary sensors.

### Competitive Sensors

Competitive sensors each provide equivalent information about the environment. This redundancy is particularly useful when sensors are uncertain or unreliable. In our case, the smart floor and the RF tags sensing techniques are both unreliable under different sets of conditions. Moreover, the smart floor provides uncertain results. By using both sensors simultaneously at the same location (entry point to the building), we can combine their output to offset their respective unreliability and compensate the uncertainty of the smart floor. When two users come in together, we would expect possible failure from one technique but correct sensing from the other. If both techniques provide correct sensing, their results can be matched to improve the quality of the result.

### Complementary Sensors

Complementary sensors do not depend on each other directly but the information they provide can be merged to form a more complete picture of the environment. In our case, we partition the space we wish to survey, our office environment, and assign a sensor or a set of competitive sensors to each partition. For instance, each office and common areas can be fitted with presence and identity sensors such as iButton readers or combinations of smart floors and RF tag antennas. The presence of a user is then detected by computing a logical OR of the input of all sensors. This solution solves the single docking point problem and alleviates to some extent the problem we encountered with users forgetting to dock. However, reliability requirements require set of competitive sensors to be installed in each partition.

## CONCLUSION

We have described our experience with a context-enabled in/out board. We reviewed the usability limitations of available techniques to sense presence and identity, and pointed out that combining multiple sensors is necessary. Sensor combinations are being implemented and we expect to report on their success elsewhere. Insights from sensor fusion literature proved useful but heuristic design rules for choosing and combining sensors are needed to support the development of future context-enabled applications.

## ACKNOWLEDGMENTS

We wish to thank our users and members of the FCE group at Georgia Tech for helpful feedback and Brian Reed for lending us the TIRIS RF tags system. This work is supported in part by an NSF ESS grant EIA-9806822.

## REFERENCES

1. Dallas Semiconductor. iButton Home Page. Available at http://www.ibutton.com/.
2. Orr, R.J. Smart Floor. Available at http://www.cc.gatech.edu/fce/smartfloor/.
3. Salber, D., Dey, A.K. and Abowd, G.D. The Context Toolkit: Aiding the Development of Context-Enabled Applications, in *CHI '99* (Pittsburgh PA, May 1998), ACM Press.
4. Want, R., Hopper, A., Falcao, V. and Gibbons, J. The Active Badge Location System. *ACM Transactions on Information Systems 10*, 1, 91-102.