Towards Design Strategies to Deal with Spatial Uncertainty in Location-Aware Systems

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ABSTRACT

Building ubiquitous applications that exploit location requires integrating underlying infrastructure for linking sensors with high-level representation of the measured space to produce a pleasant user experience. However, the real-world constraints limit the efficiency of location technologies. An inherent spatial uncertainty embedded in mobile and location systems constantly challenges the coexistence of digital and physical spaces. This paper reports on a qualitative study of spatial uncertainty in the context of a pervasive game named CatchBob! It is part of ongoing work that aims at capturing information on users' perceptions of uncertain spatial information in uncontrolled, real-world settings as well as a key element for defining better design strategies to manage spatial uncertainty in location-aware applications.

Keywords

Location-awareness, spatial uncertainty, field study, pervasive game, ubiquitous computing, collaboration

INTRODUCTION

Location-based services play a central role in the development and deployment of context-aware systems. However, physical, technological, organizational or economical constraints limit their use in the real world. Each location technology (e.g. satellite-based, radio-frequency-based) carries its own set of limitations and problems in terms of service coverage, stability, connectivity, mobility and accuracy. Therefore, the advantage of location information can be easily obscured by these difficulties, with an impact on the usability and adoption of a ubiquitous system. As investigated in [2] and the authors' related papers, the inherent uncertainties caused by the positioning techniques (GPS in this case) lead to misunderstandings of the representation of participants' position with respect to their real whereabouts.

The fusion of multiple sources of readings as well as probabilistic solutions only partially decreases the uncertainty in the data [4].

Few user-centered studies have been done to understand how to design applications that take into account the lack of maturity, the underlying imperfections and inherent uncertainties of location technologies. As highlighted by Benford *et al.*, users were able to work with the uncertainties of location technologies and wireless networking when they were provided with some information about location and connectivity estimation. In this perspective, [3] arguments for seamful rather than seamless design to reveal the physical nature of the ubiquitous systems. Moreover, [1] confirms that users rely more often on the system when the system confidence is displayed. However, the authors claimed that further studies must be performed on the tradeoff between the increased cognitive load, caused by displaying uncertainty information causes, and the added value that it provides.

Based on these aforementioned studies, we aim at further investigating the integration of discrepancies in an improved design of location-aware applications.

This paper first describes the field study we conducted. Then, it presents and sketches a preliminary qualitative analysis of the collected data and design strategies we plan to investigate in the future.

FIELD STUDY: SPATIAL UNCERTAINTY IN CATCHBOB!

We deployed a field study in the form of a pervasive game called *CatchBob!* to investigate the relationship between the measured space and the user's experience.

CatchBob!

In *CatchBob!*, groups of 3 have to find and collaboratively "catch" a virtual object called Bob on a university campus. Each player is equipped with a Tablet PC with a map interface displaying the position of the teammates and indicating with a proximity sensor whether the user is close to, or far from, the object. Player communication is enabled via synchronous annotation of the map with a stylus. Tablet PCs self-determine their position with a basic centroid algorithm using the coordinates and the signal strength of nearby IEEE 802.11 access points.

The university campus presents features similar to real-world settings with its patchy wireless coverage, uneven connectivity, infrastructure upgrades and outdoor and indoor conditions (e.g. walls, humans, rain) creating disturbances.

Sixty students participated in this experiment. We collected quantitative data on both location quality and timeliness. Positions, annotations, getting others' positions, connectivity status, latency information, and failed location synchronization have been logged on the clients and server.

We used a replay tool that allows to confront the players to a replay of their actions and to lead post-game interviews on their perception of uncertainty.

From a preliminary analysis, we have been able to identify the types of spatial information and main sources of spatial uncertainty. We classified them according to the reactions of players confronted to a discrepancy.

Sources of spatial uncertainty

We define three main sources[1] of spatial uncertainty.

- The *location quality* predicted through sensor measurements and observations. Uncertainty is generated by patchy location service, fluctuating signal strength, deviations in positioning, devices limited resources, but also from processing the measured data themselves.
- The *location timeliness* indicated by the time that has elapsed since the location was acquired. The temporal accuracy of a location is influenced by the network connectivity, communication latency and location update mechanism.
- *Location presentation*, i.e., the ways which deliver location information to the user. Geometric, symbolic and map representation can be misleading or ambiguous.

Types of location information

We propose to distinguish two types of spatial information. On the one hand, *people-centered* information employs the user location to support awareness and communication. In CatchBob!, players' positions and freehand map annotation are used as location-awareness and communication tools. On the other hand, *place-centered* information offers clues on physical space to people such as the relative position to "Bob" provided by a proximity sensor.

Users and uncertain spatial information

Taking into account the source of spatial uncertainty and the type of location information, we additionally categorize the reactions of users confronted to a discrepancy into: believing, overcoming and not understanding the system. Next, we illustrate this classification with typical examples.

Players mentioned cases of not understanding the system when both place-based and people-based location information were greatly delayed (location timeliness). One user indicated, "I stopped for a long time as I was not receiving any messages and the proximity sensor was not moving. I started wondering whether the system was working".

While disturbing, location timeliness was often overcome in moments of lost location awareness of one teammate. For example: "It is quite disturbing. I was telling myself that Verena was in the CS building, we could see her there, but I was thinking that she was not there anymore because she had been static for too long".

[1] We deliberately do not cover non-technical aspects such as location disclosure and privacy issues

Jitters in the absolute and relative positions were perceived as disturbances that only slightly modified the experience as expressed by "I did not move physically, but I moved on the map. The proximity to Bob changed even though I did not move". However, we found very severe reactions such as this player who "stopped with 8 bars in the proximity sensor, then stepped back a bit and received 4 bars. I was not sure anymore if the proximity sensor was according to Bob or the other players"

TOWARDS DESIGN STRATEGIES

As proposed by Benford et al., design strategies such as hiding, managing or revealing uncertainty can lead to the improvement of the user experience in location-aware systems. To move beyond these general design suggestions, we have proposed to categorize the sources of spatial uncertainty and the types of spatial information to better analyze users' reactions.

The preliminary results of our investigation on how when confronted to a discrepancy, differ depending on the location information they receive, the source of uncertainty, implicit information (e.g. familiar with the environment, knowing the partner), and the activity (e.g. hunting, coordinating, catching).

In order to further feed and enrich general design strategies, we plan to analyze further our collected quantitive data to find patterns and correlations that describe which aspects of our defined spatial uncertainty sources, and types of location information to take into consideration, at what moment, and in what way.

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