2. The generation and user perception of uncertainty in ubiquitous geoinformation

In this chapter, we report these valuable lessons from experiments based on a pervasive game called CatchBob!. This game was primarily developed as an artefact to explore social and cognitive implications of geolocalisation (see Nova (2007) for extended findings in that context). However, the availability of the CatchBob! platform also led us to investigate other issues, more related to the user experience of ubiquitous geoinformation and the inherent design issues of such platforms (for a discussion of the wide range of aspects, see Nova and Girardin, 2009). In the scope of this thesis, we particularly investigate the different roles played by the technological infrastructure (e.g. wireless access points, web servers, network modules on the mobile devices) as source of uncertainty in ubiquitous geoinformation perceived by the players. Indeed, 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 creates a social-technical gap that constantly challenges the coexistence of digital and physical spaces. In the context of CatchBob!, we were able to highlight that the quality of the ubiquitous geoinformation influences the user experience and the infrastructures must be consciously attended, as they are unevenly distributed, unevenly available.

This chapter includes papers that discuss the sources of spatial uncertainty, the perception of uncertainty and contextualize these findings within this research work in ubiquitous computing:

Girardin, F., Blackstock, M., Dillenbourg, P., Finke, M., Jeffrey, P., Nova, N. (2007). Issues from Deploying a Pervasive Game on Multiple Sites, *Common Models and Patterns for Pervasive Computing Workshop, 5th International Conference on Pervasive Computing*, May 13, Toronto, Ontario, Canada.

Girardin, F. and Nova, N. (2006). Getting real with ubiquitous computing: the impact of discrepancies on collaboration. *e-Minds International Journal on Human-Computer Interaction*, **1**(1):60–64.

However, as these papers have been published at the early stage of this thesis, they do not report on some valuable elements with regard to the user experience of ubiquitous geoinformation. We believe it is particularly worthy describing more in depth the research method as well as the contributions on the underwhelming effect of automatic location awareness and the ability to replay the players path.

2.1. Methods and participants

Players were recruited in teams of three, which led to a total of 30 teams and 90 players. The games were set up so that no teams played at the same time. The participants were all between 19 and 28 with a mean age of 23.1. More male than female players signed up, so teams were generally made up of two males and one female. Most were students from different disciplines (biology, mechanical engineering, computer sciences, architecture). Participants spoke either French or English but they used the same language within a group.

Each game lasted one hour and participants went through four steps. The first one consisted in receiving the game instruction by the experimenter at the lab. Participants were asked to find the virtual object and surround it with one constraint in mind: they should take the shortest path to it. We also let them try a demo of a TabletPC software; users could then try the annotation feature and ask questions about the software interface. The second phase was devoted to planning: groups were given five minutes to plan their strategy on a paper map, which was then left in the office. The third phase was the game itself. The experimenter led the group of three players to the common starting point at the centre of the campus. They had 30 minutes to complete the game, which – from the pretests we ran – was sufficient to achieve the goal without much time pressure. Finally, the last phase was a post-game interview that we recorded. After the game, players were debriefed with a replay of their activity.

2.2. Data collection and analysis

Data on the players' activity was collected via system logging and semi-structured interviews. Data logging captured all movements in space as well as players' communication through map annotations (content, moment of exchange). This logging allowed us to uncover the spatial strategies and review the discussion that led to their implementation. They were also compared to the discussion in the planning phase that we also recorded. The post-game semi-structured interviews were meant to elicit the players strategies, the implementation of the decided strategy (and how they reshaped it) and all the problems they had during the game.

The questions further probed the participants' experience with the application (communication and location-awareness feature); what elements of the environment they relied on to play the game; and how they experienced the game setting (activity, exploration of space, coordination tactics). A replay tool displayed in real time the position of each group member, as well as their annotations. Those traces of the activity were presented to help players in giving an account of what happened, an interview technique known as self-confrontation.

2.3. Replay tool

The "Replay tool" allowed us to confront the players to a replay of their path after the game, as well as the actions they performed (Figure 1). With all the players' explicit (e.g. annotations, refresh of others' positions,) and implicit interactions (e.g. positions, connection loss) logged on each game mobile devices and server, the tool provided a richer appreciation of the recorded data with a fast overview of the recorded events. Other similar systems have been developed to support both log and media analysis through the synchronised presentation of media and information visualisation style data exploration tools. A number of visualisation tools are provided for the visual exploration of log data, allowing an analyst to summarise all statistical data from a trial, or focus on a particular factor of interest (see Morisson et al., 2006). This type of tool shows potential to help social scientists analyzing data from field studies involving user interactions with ubiquitous technologies. However, the use of a "Replay tool" also relies on technical knowledge such as the formats of system events and technological issues of the ubiquitous infrastructures. It typically requires one of the tool developers to be present during replay and analysis. This experience was at the source of the development of the algorithm that detects air travels from the mobile devices interactions with spotty wireless infrastructures, as presented in our third case study (Chapter 4).

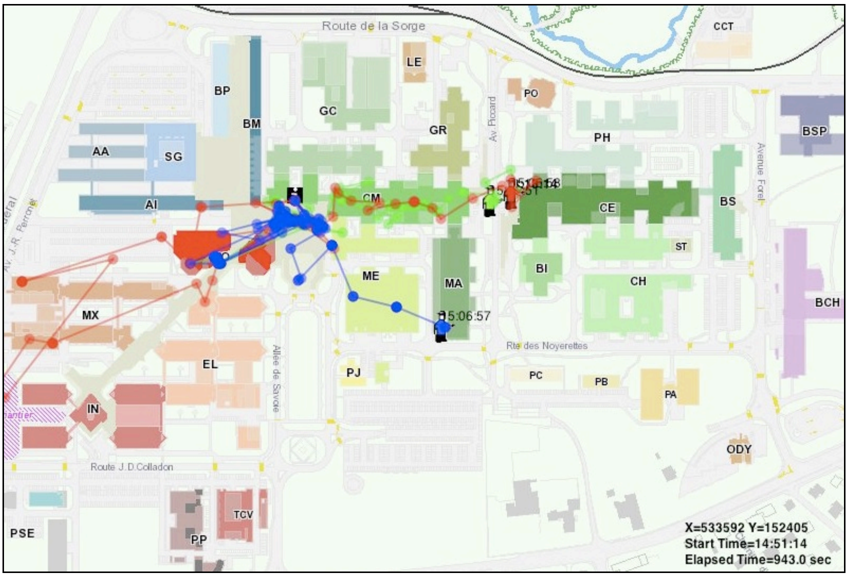

Figure 2. Screenshot of the Replay tool that displays the path of the three players from their positions.

2.4. Underwhelming effect of automatic location-awareness

The papers presented in this paper describe how the combination of both logging and interview data helped to give us a rich picture of how the spatial environment of the game was not uniform and homogeneous. However, as reported in Nova et al. (2006) another elements of the effect of automatic disclosure of location information (i.e. location-awareness) is worth reporting.

We tested CatchBob! using two interface configurations: in one case, we provided players with a mutual location-awareness interface (MLA), in the other case, without mutual location-awareness (NoMLA). MLA participants could see their own location as well as their partners' whereabouts updated in real-time on the interface. NoMLA participants could only see the update of their own location. These two experimental setting conditions allowed us to test the influence of location-awareness on collaboration. This field experiments illustrate that the following:

- An underwhelming effect of mutual location-awareness on players' mutual representations: participants in the NoMLA groups better recalled their partner's movement in space than participants in the MLA groups. The main reason is that participants in the NoMLA groups compensate for the lack of information about others' location in space by sending map annotations. Since self-reported location information was only sent when it made sense to the participants, it seemed that the players more effectively internalized them (see Nova, 2007 for a complete description).

- An underwhelming effect of mutual location-awareness on players' communication: the location-awareness feature not only lowered the exchange of messages about location (which is logical), it also diminished communication about strategy and direction issues.

- Players in the "NoMLA" groups took better advantage of the annotation capabilities, using annotation to express their location, their path and their strategy. The players with the awareness tool were able to annotate as well but did not use this capability.

As a consequence, we found that automating the location-awareness of participants made them more passive. Indeed automating MLA is different than sending one's position in space. This fact raises an important issue regarding communication and spatial information: compared to automatic positioning in which location is just information, self-declared positioning is both a information and an act of communication. If A tells B where he or she is located, not only does B know A's location but he or she also knows that A considers that it is useful for B to know it. This is important for players in order to better coordinate themselves on the field.

2.5. Summary of the contributions

In summary, this case study contributes to these issues with:

- Guidelines from the lessons learned from the deployment of a collaborative pervasive game on two different sites. We emphasize on the practical aspects of getting a pervasive system deployed without any extra special infrastructure;

- Users of ubiquitous technologies often react to spatial uncertainty due to systems' limitations;

- Categories of reactions to spatial uncertainty;

- Design of a tool to replay players path from their logged interactions with the wireless infrastructure;

- Automating location-awareness can be detrimental to group collaboration.

Issues from Deploying and Maintaining a Pervasive Game on Multiple Sites

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Abstract. In this paper we present the lessons learned from the deployment of a collaborative pervasive game on two different sites. We emphasize on the practical aspects of getting a pervasive systems deployed without any extra special infrastructure. Based on our experience, we describe the issues providers and administrators must take into consideration to deploy and maintain pervasive environments. In this perspective, we highlight that ubiquitous technologies must be consciously attended, as they are unevenly distributed, unevenly available.

Keywords: ubiquitous computing, field study, seamful design.

1. Introduction

In the recent years, the research based on pervasive gaming have demonstrated principles and lessons that can be applied more generally in systems for mobile work in vast work settings [5]. Several studies reveal the diverse ways in which players experience the limitations of positioning and network technologies [3] and how to take advantage of the `seams' and heterogeneity inherent to pervasive systems [2]. Another investigation [4] discusses sketchy and slow mobile Internet access, variations in the quality of speech transmission, loss of connections or ambiguities in positioning as an everyday reality for mobile users.

These studies suggest that designers must understand how to meet the user needs taking in to consideration the limitations and availability of network connectivity and sensor data. However, the literature provides only sparse descriptions of the deployment and maintenance issues of providing pervasive games over multiple sites. In this paper, we describe CatchBob!, the pervasive game platform we designed and used on both the university campus of the Swiss Federal Institute of Technology Lausanne in Switzerland and the University of British Columbia in Vancouver, Canada. Then we present the main issues we experienced in deploying and maintaining the system. Finally, we conclude with open questions on the integration of the limitations of technologies as parts of large-scale ubiquitous environments.

2. The Platform: CatchBob!

CatchBob is a pervasive game running on Tablet PCs in which groups of 3 teammates have to collaboratively find an object on a university campus [7]. Completing the game requires the players to surround Bob with a triangle formed by each participant's position in the real space. When the players are close to the "Bob", the triangle they have to form appears on the display; they then have to adjust it in the proper way. The only mean of communication the players have is by annotating the map display on their mobile device with a stylus. The original game took place on the Swiss Federal Institute of Technology Lausanne campus, whose dimensions are a 850x510 meters field mixing both indoors and outdoors [Figure 1]. The second deployment of the game took place outdoors on a large part of the university campus, in an area approximately one kilometer square played outdoors.

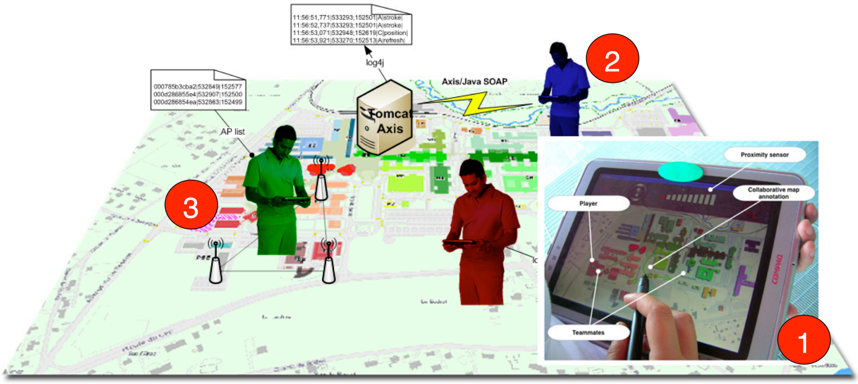

Figure 1: The CatchBob! architecture: (1) Players use TabletPCs to view their and the other players' position. They communicate by annotating the map with a stylus. (2) The data are synchronized over the campus 802.11 network using the SOAP protocol. (3) The positioning algorithm runs on each mobile device. It computes the player's location based on the position of the access points and the signal strength of a radio wave received by the Tablet PCs.

3. Issues from the Real World

Based on our experience of deploying and running CatchBob! in both locations (50 games played in Lausanne, 6 in Vancouver) over different periods, we have been able to identify a set of recurrent issues described in the following subsections.

3.1. Wireless Networks are neither Open nor Pervasive, nor Stable

During the development of the platform, the Lausanne campus network security policies drastically changed in forcing the unique use of the TCP (Transmission Control Protocol) port dedicated to HTTP (Hypertext Transfer Protocol) communications. In consequence, we developed our high-level remote access protocol upon SOAP (Simple Object Access Protocol). In fact, the versatility SOAP facilitated the iterative process of rapid prototyping and user-centered design required for the development of pervasive software in research since we did not need to concern ourselves with lower level protocol and data marshalling issues.

The WiFi network topologies in on both campuses were not planned for a pervasive mobile experience, but rather for a nomadic use of mobile device. Indeed, the coverage is limited to places where people work, study or gather. In contrary, alleys, big corridors and parks outdoors frequently proved to be cold spots.

Finally, the transfer of packets to and from access points can show significant asymmetry, and high packet loss can occur despite apparent network access. The latency inherent to wireless networks disturbed some players who questioned if all the messages were actually broadcasted to their teammates.

3.2. The Balance Between Positioning Accuracy and Network Connectivity

The mixed indoor and outdoor settings of the campus in Lausanne prevented us from employing GPS (Global Positioning System) to position the players. Indeed, the campus buildings, corridors and hallways do not offer a sufficient line of sight to the sky to acquire reasonable signals to compute a position. We therefore chose to use another positioning technique based on radio beacons. In this solution, an algorithm computes the position based on the position of the access points and the signal strength of a radio wave received by the Tablet PCs. The mobile clients self-determine their position using the Place Lab [6] native libraries and a simple centroid algorithm. This approach performs a positioning accuracy of 10-40 meters, which consistently decreases when the user is in areas of low network connectivity. It proved to be a viable strategy for the scale of our game as we could take advantage of the approximately 300 WiFi access points deployed on the campus. In Vancouver, while the number of access points is much higher (approximately 3000) due to the predominance of the outdoor settings of the campus, and the extensive changes to the UBC wireless network over the testing period we integrated GPS functionalities. While this improved the accuracy of the positioning, wireless network connectivity was mainly available indoors. This limited the outdoor playground to the areas near buildings with line of sight to satellites.

While many researches aim at improving accuracy and broadening availability of positioning system, our experience suggest that designers might first think of what location information granularity is expected by users of a location-aware system. We are conducting further investigations to understand the level of information accuracy a location-aware system must provide to support its users in certain activities.

3.3. Infrastructures are Inherently Messy

Early in the design process we were surprised that rain, humans, and leaves on trees strongly affect WiFi and GPS performance. The weather had a significant impact on game sessions. For instance we had to cancel several games to keep the rain and humidity from damaging our mobile devices. The outdoor setting used in Vancouver, forced us to improve the high contrast of colors on the screen for better use in sunny days and add audible queues for message and annotation delivery for the noisier outdoor environment.

Likewise, network infrastructures are living creatures regularly mutating into new standards and topologies. In consequence, the positioning system had to be maintained with the constant update of the position of the radio beacons. In that context, we concur with [1] in their general observation that infrastructures are inherently messy; uneven in their operation and their availability.

3.4 The Uniqueness of Devices

While running the experiments, we became aware of the strong "uniqueness of devices" that we were only vaguely aware of ourselves. Similar types of TabletPC, with similar hardware and software, in a similar context had different network or stylus sensitivity. Players became aware—and angry about—the fact that his WiFi antenna had a significantly lower sensitivity than his team–mates', even though they were using the same device as was found in a similar work [2].

4. Conclusion and Open Questions

Many infrastructures assume an even quality of sensor data and reliable infrastructure. From our experiences of deploying and maintaining a large scale collaborative pervasive game we've found neither is true. Indeed, we suggest that the network and systems issues we present emerge from the current state of unevenly distributed and unevenly available ubiquitous technologies.

Furthermore, technological advances will hardly eliminate the constraints we dealt with in the near future. Therefore we question the paradigm of seamlessness in pervasive computing. In consequence, we would like to raise the following high-level questions:

- How can we make the limitations or "quality" of context like location more evident in infrastructures so that they can be used by designers, administrators and end users, either to allow them compensate for varying quality, or as part of the application?
- How can a general purpose platform for ubiquitous applications make use of the seams in infrastructure - is this something that needs to be done on a case by case basis?

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Getting real with ubiquitous computing: the impact of discrepancies on collaboration

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Abstract. Ubiquitous computing is still a maturing field of investigation. The vision of the seamless integration of computers to people's life has yet to happen, if it ever has to become a reality. Nowadays, most mobile, distributed systems and sensor technologies have their faults and limitations. Users of ubiquitous technologies often learn to avoid or rectify the systems failures. However, there is still a lack of quantitative information concerning how they impact the collaboration. Therefore, we propose to use a 'field of experiment' approach based on a pervasive game platform. Our aim is to rely on a mix of qualitative and quantitative evaluations to find out how uncertainties modified the collaborative processes.

1. Introduction

Nowadays, a considerable amount of development is taking place in ubiquitous computing and a growing number of research labs are investigating this field. They work in the various research topics that form ubiquitous computing, including distributed computing, mobile computing, sensor networks, human-computer interaction, and artificial intelligence. The father of ubiquitous computing, Mark Weiser [1], defined it as forcing the computer to live out here in the world with people. Currently, the field is still not as mature as Weiser envisioned.

Ubiquitous environments must deal with unreliable network, latency, bandwidth, security, unstable topology, and network homogeneity. The most ubiquitous device, the mobile phone, has its faults. Lack of coverage, broken conversations, bad roaming, empty batteries, the limitations are plentiful and must be dealt with on a daily basis. Many times we learn strategies to adapt to avoid of rectify the systems failures. We are still a far reach of the strict definition of ubiquitous "existing or being everywhere at the same time: omnipresent".

In our case, we are interested in studying the impacts of technological limitations and users manipulations by terms of collaborative interactions. The platform we use to meet this end is the emerging field of ubiquitous computing games, which offers an interesting platform to study the aforementioned phenomenon. This approach is also the one described by [2] and [3].

In this paper, we first introduce the current studies in that field. Then we explain the pervasive game we developed and the outcomes of the first experiment we conducted. We conclude by describing our method of mixing collaborative and quantitative data to study the role uncertainty plays in collaborative ubiquitous systems.

2. Dealing with myths of ubiquitous computing

Previous user-centered studies have been done to understand how to design applications based on the lack of maturity, the underlying imperfections and inherent uncertainties of ubiquitous technologies. The most common methodology to do so is the use of ethnography and hence the collection of qualitative data about people's behavior towards technology and collaboration.

Benford et al [4] reveal some of the complexities involved in designing collaborative location-based experiences. Based on qualitative data from the location-based educational game called Savannah, they describe the frustration when users are unable to establish a shared context and act together due to system limitations. Moreover mismatches between the designer's conceptual model and user's mental, inherent to ubiquitous technologies application design, lead to serious confusions among the players. They leave open design questions on how users avoid and rectify the difficulty of the system (e.g. when connectivity is temporarily lost, when the GPS unit loses line of sight or in case of poor latency between the mobile devices and the server).

Likewise, Antifakos et al. [5] argue that perfect and reliable context information is hard if not impossible to obtain. They evaluated a feedback mechanism that displays the uncertainty inherent in the context information. Their study shows that human performance in a memory task is increased by explicitly displaying uncertainty information. However they claim that further studies must be performed on "the tradeoff between the cognitive load, which displaying uncertainty information causes, and the added value that it provides.

Finally, Chalmers et al [6] go a step further through the argumentation of seamful rather than seamless design to reveal the physical nature of the ubiquitous systems in, for example, the uncertainty in sensing and ambiguity in representations. Conversely, they emphasize that seamful design as just one potential way to “design for appropriation” and to support the more widespread acceptance of ubiquitous computing technologies.

3. CatchBob!

Our approach targets the use of a game to study how people deal with uncertainty. In line with this goal, we developed a pervasive game called CatchBob! as an experimental platform for running psychological experiments. Catchbob! has been designed to elicit collaborative behavior of people working together on a mobile activity. In the game, groups of 3 teammates have to find a virtual object on our campus at EPFL in Lausanne. Completing the game requires the players to surround the object with a triangle formed by each participant's position in the real space. To reach this goal, they employ an application running on Tablet PCs as depicted on figure 1.

Figure 1. CatchBob! interface as used by a player

In addition, the tool also enables communication: players can synchronously annotate the map with the stylus. The annotations constantly fade out until they become completely invisible (after 4 minutes). Another meaningful piece of information given by the software is an individual proximity sensor that indicates whether the user is close or far from the object through the number of red bars displayed at the top of the interface.

All the players' interactions with the applications (positions, annotations, getting others' positions, connection loss) are logged. We also developed a replay tool that allows showing the paths of each player. This application allows us to confront the players to a replay of the path they took during the game, as well as the actions they performed. A lot of information can be gathered from this to make sense of what happen during the game.

4. Previous experiment

The results of our previous study on location awareness [7] show that it is better to let users control and express their location the way they want as opposed to have it automated. Giving them the possibility to embed location cues with other kind of information like map annotations appeared to be a good solution to support collaborative processes like communication or strategy discussions. By extension, it is now fair to question the importance of positioning accuracy as well as the quality of the coverage and connectivity of ubiquitous system.

During post-game interviews, we also discovered mental model mismatches on how the players perceived the system would work and their actual experience. In talking about their experience of the game in general, some players said "I did not move physically, but I moved on the map" other "The proximity to Bob changed even though I did not move". Some players came with a pre-conception on the quality of indoor positioning systems. One stopped playing, because of the latency in the synchronization of the annotations. We now want to find out if the players overcome and adapt to the technological limitations or whether it impacted their overall performance in the game.

5. Conclusion

The approach deployed here is called 'field experiment' approach [8] which means that we want to take the advantage of both ethnographical studies (ecological validity, use of qualitative data) and controlled experiments (controlled factors, use of quantitative data). As we did to study the use of location-awareness tool [7], we plan to rely on a mix of qualitative and quantitative evaluations to find out how uncertainties modified the collaborative processes. First and foremost, qualitative data are interesting with regards to describe the kind of situations where people face discrepancies as well as the solutions they use to overcome the systems' limits. Then quantitative indexes would allow us to get some concrete measure of how uncertainties impact the task performance or collaborative processes. Among the quantitative index we have, there is the uncertainty of location which is represented by the amount of time when no position were given to the player, the positioning accuracy described by the number of scanned access points. The uncertainty of connection, the number of seconds and frequency the user has been disconnected, is also of interest since it might be detrimental to both the task performance and communication among the group. This will allow us, for instance, to check the correlation between these variables and the frequency/quality of communication, the players' spatial behavior or the time they spent to complete the game. Eventually, we believe that the articulation of both kinds of data is relevant to make sense of users' behavior.

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