Context and Location-Awareness for an Indoor Mobile Guide

Lara Leite, Marco Vala, and Ana Paiva
INESC-ID, Instituto Superior Técnico,
Lisboa, Portugal
lara.leite@ist.utl.pt

Rui Rocha
Instituto de Telecomunicações, Instituto
Superior Técnico, Lisboa, Portugal

ABSTRACT
The proliferation of mobile devices and wireless communications contributed to the development of context-aware applications. This work aims to develop a system that gathers users' contextual information, in indoor environments, and handles such information to help users in their daily tasks. The system comprises an interface hybrid agent that is aware of the user's context and infers relationships between users by observing their interactions. The users' location is estimated using an existing Wireless LAN, to facilitate the propagation and integration of the system in other environments. To validate our initial hypothesis, we performed two experiments. The first intended to measure the usefulness of the system to users. The latter evaluates the accuracy of the estimated location. The results indicate that users found the system useful and the estimated location is accurate.

Author Keywords
Context-aware, Location, Wireless LAN, Indoor environment, Intelligent Agent, User's relationships, Points of interest.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: Miscellaneous—*Optional sub-category*

INTRODUCTION
Nowadays technology is everywhere in our daily lives and devices are becoming increasingly mobile. The evolution of mobile devices combined with the development of wireless communications allows us to access, everywhere and any time, to a large amount of information [4]. With all this information, it becomes difficult to find the specific information that matters to us. Over the last few years, a large amount of location-based applications have emerged, such as *Google Latitude* [1], *Foursquare* [2] or *Facebook Places* [3]. These applications enable users to share their location and related information with their friends, getting back information about them. Most of these applications use GPS or GSM technology to locate users. Such technologies work well on outdoor environments, but do not work or cannot provide the required accuracy in indoor environments.

Dey and Abowd [5] defined **context-aware applications** as *"applications that use context to provide task-relevant information and/or services to a user"*. Context-aware applications differ from each other on the form of gathering the contextual information and on the way that such information is used. Chen and Kotz [4] reorganised context in four categories: *computing context* (e.g. network connectivity), *user context* (e.g. user's location), *physical context* (e.g. lighting) and *time context* (e.g. time of the day). This paper addresses the problem of gathering information about the user's surroundings (e.g. user's location, interesting places around, which friends are nearby) and how such information should be handled in order to help users in their daily tasks and to guide them in indoor environments. The application should take into account the current context in which the user is, preferably without any input from the user. Considering the motivation presented above, the research question that we propose to solve is the following:

How a context-aware system should be developed, in order to be useful to users in indoor environments, helping them to be in touch with other users and points of interest?

To answer this question, first we need to decide on how to obtain the user's context information, including the user's location, the points of interest information, and the information of other relevant people nearby. Regarding the location component of the system, previous systems were surveyed to understand the state-of-the-art in terms of properties, technologies and methodologies to localize users in an indoor environment. Since the contextual information appropriate to users depends on each circumstance, a real scenario was analysed. An interface agent for a mobile device was chosen to handle the contextual information and decide which information provide to users. The agent comprises a reactive and a proactive component, to give users the information they specifically request, and to pro-actively give them information that might be relevant. Given this, our hypothesis is:

A context-aware interface agent, implemented in a mobile device, aware of the user's location and other relevant users and points of interest around, will be useful to users

[1]Google Latitude, http://www.google.com/mobile/latitude
[2]Foursquare, http://foursquare.com/
[3]Facebook Places, http://www.facebook.com/places

IUI Workshop on Location Awareness for Mixed and Dual Reality
LAMDa'11, 13. February 2011, Palo Alto, California, USA.

in an indoor environment.

To validate our hypothesis, a system was modelled, a prototype in a university campus was implemented and an evaluation regarding two metrics (the usefulness and the usability of our context-aware system to users, and the accuracy of the estimated location) was performed.

RELATED WORK

Context-aware applications are applications that are constantly observing the user's environment, to provide useful and appropriate information in every situation, preferably without any user input. However, the context information used can be quite diverse. For example, there are context-aware applications in smart environments [9], applications that are developed with the purpose of adding information to what the user sees [8], applications with mobile agents that aim to interact with users in order to establish closer relationships with them [3] and applications mainly based on user's location information [1].

An important feature that context-aware systems can use to filter the useful information to users is their current location. The automatic location of users is a complex problem that has been addressed over the years. Each localization system may differ in many aspects, for example, it can be designed for a small or for a large area. The most important properties that characterise location systems are: physical position versus symbolic location, absolute versus relative coordinates, localized versus centralized computation, accuracy and precisions, scale and costs [7].

The problem of determining the location of a user depends on whether the user is indoors or outdoors. The type of environment (outdoor or indoor) determines the technologies that can be used and the ones that should be excluded. For example, in outdoor environments GPS is effective, but it does not work in indoor environments. In indoor environments, technologies such as infrared [11], ultrasound [12], RFID (Radio-Frequency IDentification) [6], vision [9], Wireless LAN [2] or bluetooth [13] can be used.

There are mainly three different types of methodologies: *proximity*, *lateration* or *angulation* and *scene analysis* [7]. In general, for any selected technology can be applied any of the methodologies, however there are some technologies that are more appropriate for certain methodologies.

CONTEXT GUIDE

The *Context Guide* is a context-aware application for mobile devices that users can use in their daily lives, in an indoor environment, to obtain useful information, such as friends or points of interest informations. The developed model was implemented in the building of a university campus, with three floors covered by a Wireless LAN 802.11. To implement the localization component a *Cartesian coordinate system* covering all the building was defined. The system's generic architecture is composed by three modules: *client*, *localization server* and *services server* (Figure 1). All the components are extensible and modular in order to facilitate the addition of new functionalities.

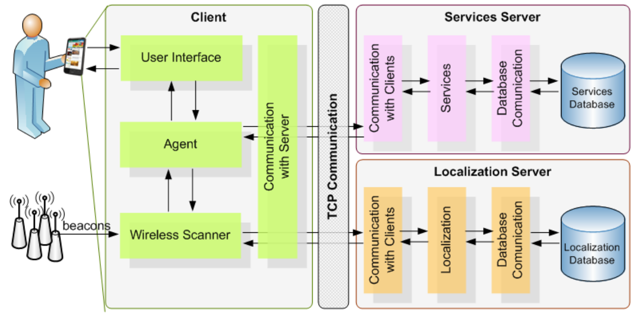

Figure 1. System's generic architecture.

Client

The client application runs in users' mobile devices and provides them contextual information. The application was developed to run on devices with Android OS. The interface in the mobile device is divided in 3 parts (Figure 2): two top parts where the agent can transmit textual and graphical information to the user and a bottom part where the user can interact with the system.

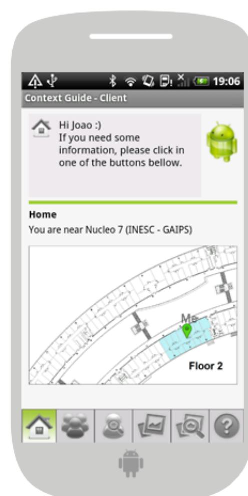

Figure 2. User interface in the mobile device.

The *wireless scanner* sends the information about the detectable access points by the mobile device (collected using the *WifiManager* package of *android.net.wifi*) to the *localization server* in order to receive the estimated location. An *agent* handles user's contextual information (e.g. friends or places nearby) and collects information about user's interactions, for inferring user's relationships. In order to not overload the mobile device the agent stores this information in services server. The *agent* is constantly receiving the location updates from *wireless scanner* and the inputs from the *user interface*. Besides responding to user requests (reactive component based on the *subsumption architecture* [14]), the *agent* also has a reasoning component to provide information to the user in a proactive way (based on *Pratical Reasoning Agent* algorithm [14]). To enrich the agent's knowledge about users and provide them useful information, the agent logs the user's interactions to infer different kinds of relations amongst them. The communication with the both servers is established through the wireless LAN. The communication between the client modules is based on events and was implemented using the ION Framework [10].

Localization Server

Due to the limitations of mobile devices (e.g. processing power or storage) the user's localization is done by a *localization server*, that receives from clients information about the detectable access points and returns the estimated location. The communication with the clients is anonymous, i.e., the server does no register any record about users or the estimated locations. The *localization* component is based on an existing wireless LAN infrastructure and combines the analysed methodologies (proximity, lateration and scene analysis), in order to improve location accuracy with the less deployment effort. The proximity and the lateration methodologies are applied to all the environment and the scene analysis methodology is applied in specific places of the building, where it is necessary to have a better location accuracy, in order to provide user precise information. The location result will depend on the results from each methodology. The measurable characteristic used in the methodologies is the Received Signal Strength Indicator (RSSI), which relates to the distance (it decreases as the mobile device moves away from the access point).

The lateration methodology explores the geometric relations (e.g. distance), between the fixed and mobile nodes. To apply lateration in a two and three-dimensional plan it is necessary a minimum of three and four fixed points, respectively, and the *Cramer's Rule* is used to solve the equation system. However, since every distance measures have errors, the more fixed points are used, the more accurate the final result is (but more complex is in terms of mathematical resolution). In this case, it is necessary to solve an overdetermined system of equations [7].

The scene analysis methodology was implemented in a specific room. To perform the *off-line phase* we developed a simple application that collects the signal strength values from each detectable access point, and sends them to the *localization server*. Twenty measures in 4 directions [2] were collected in each point of the *Cartesian coordinate system* within the room and stored in the *localization database*. In the *on-line phase*, when the user is in a scene analysis zone, the algorithm tries to find a coordinate point that corresponds to more than 4 collected measures.

Using an existing infrastructure brings many advantages in terms of time, space, energy and capital costs. However, it is still necessary to analyse its components and its mode of operation, such as the building's infrastructure or how the access points are distributed throughout the building. The *localization database* stores required data for the users localization through the building, such as access points or locations information.

Services Server

The *services server* is responsible for handling the information about the users and theirs relationships and places in the environment, and to respond to client requests about such type of information. In the communication with clients, on contrary to what happens in the localization server, the server knows the client's identification, in order to provide personalized information to each user (e.g. their friends nearby). The *services database* stores information about users, the locations where the users could be within the system's scenario, the places and informations that may interest to users and the relationships between users. The *services* component is able to process different types of requests, such as update users' location or find users' friends.

EVALUATION

Two different experiments were performed to evaluate the implemented system. The first are intended to measure the usefulness and usability of our context-aware system with real users. The latter intended to measure the accuracy of the user's location results. Considering the research questions presented in the beginning of this document, our hypotheses are:

1. *Users will find our system useful and it will help them during their daily tasks inside the university campus;*
2. *The location accuracy provided will be enough to users.*

Usefulness and usability of the system

To evaluate the usefulness and the usability of the implemented system and confirm our first hypothesis we performed an experiment with two distinct groups of participants (each one with 8 students with ages between the 17 and 18 years old). One group of users was asked to complete a set of four tasks (find a friend, find a bar, find the ATM machine and find a research group) using the *Context Guide* application and the other group was asked to complete the same set of tasks without the *Context Guide* application. All participants started in the same place of the campus and received one task at a time. The time they took to complete each task was counted. When the participants completed their tasks, they were asked to complete a questionnaire. The participants that used the system were given a questionnaire with statements about the usefulness of the system, the quality of information, the quality of the interface and the difficulty of the tasks they had to complete. To the other ones it was given a questionnaire with statements about the tasks they had to complete.

Results. From this experiment we found significant differences on the amount of time users spent to complete a difficult task (*Mann-Whitney* test, $U = 3.5, z = -2.995, p < 0.001, r = -0.75$). Significant differences on the easiness to find the information to complete the tasks were also found (Independent t-Test, $t(14) = 1.989, p < 0.05, r = 0.47$). Participants that used the system felt that information is much easier to find than the other participants. Users also classified positively the overall system, and aspects regarding the usefulness of the system, the information quality provided, the quality of the interface and the location accuracy.

Location accuracy

In this experience we collected location results in four different kinds of environments (from open to closed environments). An amount of 20 results per location was collected. Besides the response time of *localization server* to a localization request, the location accuracy and precision were also measured. Accuracy measures the distance between the estimated and the real position and precision measures how often that accuracy is achieved [7]. *Euclidean distance* was used to measure the accuracy of location results.

Results. In the quantitative evaluation of the location accuracy of the system, we obtained results with errors always less than 9m, and in areas with a good coverage of access points we obtained estimated locations with errors in the order of the 5m, which we consider a good result (to a localization system based on wireless propagation model). In specific rooms, where we implemented the scene analysis methodology, we had a location accuracy of 3m with 90% precision. The accuracy achieved in an area with the scene analysis methodology is comparable to results obtained with systems that use the same methodology and in areas with good coverage of access points and using only the methodologies of proximity and lateration we got an acceptable average error(about 5 meters). Regarding the localization server response time, with one user, we obtained responses in an average time of 1.4 seconds.

CONCLUSIONS

This work addressed the problem of context-aware applications that can be easily and without major costs deployed in indoor environments. The design of these applications can bring many advantages to the user, as they provide useful information requiring almost no effort from the user. To approach our problem, we developed an indoor location system (combining proximity, lateration and scene analysis methodologies) to gather users' location based on an existing Wireless LAN, and taking into account the costs and time of deployment. As a basis for our context-aware system, we opted to develop an interface agent to a mobile device that answers user's requests and pro-actively provides useful information to the user (using information about inferred relationships amongst users). To evaluate the developed system we performed two different experiments (one to measure the usefulness of our context-aware system and the other one to measure the accuracy of the location component). Overall, we had a good feedback from our system, and significant differences between the two groups were found on the time taken to complete a difficult task and on the easiness to find information to complete the tasks. The results of these experiment indicate that users consider our system useful and with a comfortable location accuracy. Given that, the outcome of this evaluation motivate us to continue the path of this work, in particular linking this type of applications with current social networks systems.

ACKNOWLEDGMENTS

The research leading to these results has received funding from European Community's Seventh Framework Program FP7/2007-2013) under grant agreement no 215554 and FCT (INESC-ID multiannual funding) through the PIDDAC Program funds. The content of this paper does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the paper lies entirely with the author(s).

REFERENCES

1. G. D. Abowd, C. G. Atkeson, J. Hong, S. Long, R. Kooper, and M. Pinkerton. Cyberguide: a mobile context-aware tour guide. *Wireless Networks*, 3(5):421–433, 1997.
2. P. Bahl and V. N. Padmanabhan. Radar: an in-building rf-based user location and tracking system. In *INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, volume 2, pages 775–784, 2000.
3. T. W. Bickmore, D. Mauer, and T. Brown. Context awareness in a handheld exercise agent. *Pervasive Mob. Comput.*, 5(3):226–235, 2009.
4. G. Chen and D. Kotz. A survey of context-aware mobile computing research. Technical report, Dartmouth College, Hanover, NH, USA, 2000.
5. A. K. Dey and G. D. Abowd. The context toolkit: Aiding the development of context-aware applications. In *Workshop on Software Engineering for Wearable and Pervasive Computing*, pages 434–441, Limerick, Ireland, 1999. ACM Press.
6. J. Hightower, R. Want, and G. Borriello. Spoton: An indoor 3d location sensing technology based on rf signal strength. UW CSE 00-02-02, University of Washington, Department of Computer Science and Engineering, Seattle, WA, February 2000.
7. H. Karl and A. Willig. *Protocols and Architectures for Wireless Sensor Networks*. John Wiley & Sons, 2005.
8. P. Mistry, P. Maes, and L. Chang. Wuw - wear ur world: a wearable gestural interface. In *CHI EA '09: Proceedings of the 27th international conference extended abstracts on Human factors in computing systems*, pages 4111–4116, New York, NY, USA, 2009. ACM.
9. S. Shafer, J. Krumm, B. Brumitt, B. Meyers, M. Czerwinski, and D. Robbins. The new easyliving project at microsoft research. In *Proceedings of the 1998 DARPA / NIST Smart Spaces Workshop*, pages 127–130, July 1998.
10. M. Vala, G. Raimundo, P. Sequeira, P. Cuba, R. Prada, C. Martinho, and A. Paiva. Ion framework — a simulation environment for worlds with virtual agents. In *IVA '09: Proceedings of the 9th International Conference on Intelligent Virtual Agents*, pages 418–424, Berlin, Heidelberg, 2009. Springer-Verlag.
11. R. Want, A. Hopper, V. Falcão, and J. Gibbons. The active badge location system. *ACM Trans. Inf. Syst.*, 10(1):91–102, January 1992.
12. A. Ward, A. Jones, and A. Hopper. A new location technique for the active office. *IEEE Personal Communications*, 4(5):42–47, October 1997.
13. Z. Weissman. Indoor location. White paper, Tadlys Ltd., 2004.
14. M. Wooldridge. *An Introduction to MultiAgent Systems*. Wiley Publishing, 2009.