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Exploring the Design Space

A brief overview of ubiquitous computing research at the Laboratory for Communication Engineering, Cambridge

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Abstract

We shouldn't expect technologies that impact peoples′ daily lives to be adopted before they are demonstrated as reliable, useful and simple to deploy. Measured against this criterion ubiquitous computing is still in its infancy. We present an overview of the spectrum of research in ubiquitous systems currently in progress at the LCE which aims to address some of these issues.

Ubiquitous computing is undergoing a long gestation period. The factors contributing to this are similar to those that delayed the acceptance of other technologies such as personal computing and computer networking. Like those technologies, ubiquitous computing demands substantial investments in infrastructure and changes in human behaviour. Our role as technologists is to ensure infrastructure is reliable and cost-effective and to understand the space of context-aware applications.

Research in ubiquitous computing at the LCE ranges from studies aimed at enhancing the accuracy, reliability and deployability of location-aware systems to investigations of augmented reality techniques as a means to add interactivity to a world in which computers and communication devices are pervasive. Between those extremes, we are also studying some possible approaches to achieving privacy in sentient environments and we have deployed several location-aware applications that seem to meet needs in our user community.

Accuracy, reliability, deployability

The Active Bat location sensing system [1] was originally developed and deployed in the AT&T Cambridge Laboratories and is now deployed in the LCE. As a research prototype, the Active Bat system was designed to provide the highest performance available with current technologies while paying due regard to user needs associated with its deployment, maintenance and use.

The system tracks small wearable tags with an accuracy of a few centimetres and a time resolution of a few milliseconds. The tags are small and lightweight and have a battery life of 1-2 years in normal use. In addition to their tracking functionality, they are equipped with two buttons for user input and two LEDs and a small speaker for user feedback. This frugal provision for interaction is dictated largely by a desire to achieve a long battery life.

Location tracking in the Bat system depends on the deployment of an array of ceiling-mounted receivers and the use of the signals that they receive to perform ranging calculations. The accuracy of these measurements is normally high, but environmental conditions have an impact on them through occlusion (producing weak signals) and reflection (producing ambiguous signals) and errors sometimes occur due to component failure. Investigations are in progress in the LCE into the detection and correction of all of these conditions. Another study has demonstrated that the mapping of a physical space in which the tracking system is deployed can be, at least to some extent, automated [2]. These studies are aimed at producing a more robust and more manageable location tracking technology.

Application deployment

The potential take-up of location-based technologies is a contentious topic. It is generally agreed that a critical mass of users is needed in order to enjoy many of the benefits, but loss of privacy and the small but non-negligible 'nuisance' cost associated with wearing a tag constitute disincentives for individual users.

A group of researchers at the LCE has recently carried out a study of the potential to increase the take-up of the Active Badge system by members of the laboratory [3]. They studied the activities of lab members and developed a set of simple applications that were designed to overcome the inherent resistance to wearing tags. They adopted a game-theoretic approach to the analysis of users' motivations, noting in particular that it is not sufficient to expect users to wear a tag for the benefit of others (i.e. to enable others to locate them) - users must be able to derive direct benefits from wearing a tag.

Their work has resulted in the deployment of 10-15 simple location-based applications in the LCE. Many of them are based on *spatial buttons* and *spatial posters,* picking up on a location-based interaction paradigm originally developed at the AT&T Cambridge Lab [4]. Space prevents us from describing more than a sample of these applications.

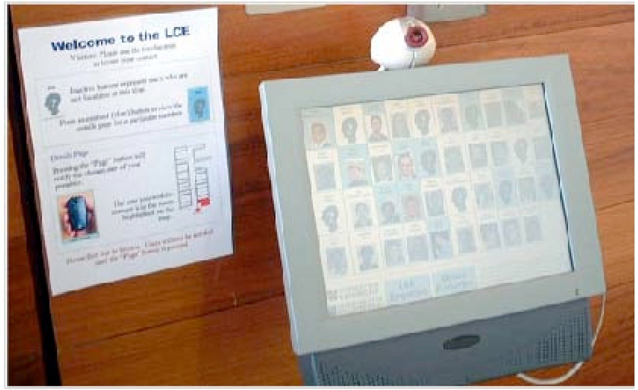

Fig 2. The LCE's 'Robot Receptionist' - *Andy Rice's work*

Spatial buttons associate a user action with a small region in space. These regions are linked with a simple paper menu called a spatial poster (generally A4-sized). Figure 1 shows a user using their bat to perform an action on a spatial poster. The action is performed by pressing a button on the bat while holding it in a region that is defined as a spatial button. Actions are confirmed by a tone on the bat's speaker. The application illustrated in the figure enables users to subscribe to and receive notifications whenever a fresh pot of coffee has been brewed. Notifications take the form of short tunes played on the user's bat.

Other applications based on spatial posters include a room reservation and timer application (to manage the use of a tutorial space), an 'office watcher' that notifies users when a particular colleague returns to their office and a reminder application that is associated with a given space. These applications are supplemented with posters to mute or activate notifications either in particular locations or globally. A viewable 'beep log' is maintained for each user and this includes a brief explanation for each notification that the user has received.

The limitations of the bat as a user interface device mean that applications requiring more sophisticated forms of interaction must rely on other devices for some of their user interface. For example, a fairly sophisticated system has been developed to act as a 'robot receptionist' for visitors to the lab (Figure 2).

This system was designed around the perception that visitor waiting time is a critical parameter for this application. Other requirements include the need for visitors to identify their host on arrival and for the host to authorize their entry to the Lab. The visitor also needs to be kept informed about the progress of their request for entry. All of these requirements were successfully addressed with the aid of the Bat system and a touch screen display and webcam mounted at the entrance to the Laboratory.

All the above-mentioned applications and the software framework that makes them possible are described in [3]. One outcome of this project has been a substantial increase in the proportion of bat wearers in the LCE, bringing the proportion to 70%-80% of lab members.

Augmented reality

Augmented reality presents users of 'active spaces' with information about services and activities. The presentation is usually in graphical form and may be presented to the user through handheld or wall-mounted displays or head-mounted mono or stereoscopic displays.

In the LCE, Kasim Rehman has developed a pilot system that aims to enable interactive applications to be developed that exploit augmented reality techniques to enable the user to visualize the interaction [5]. Figure 3 illustrates an instance of this in which the user sees 'teleport zones' surrounding each desktop computer. Rehman is exploring the software required to support interaction more generally while employing traditional interaction

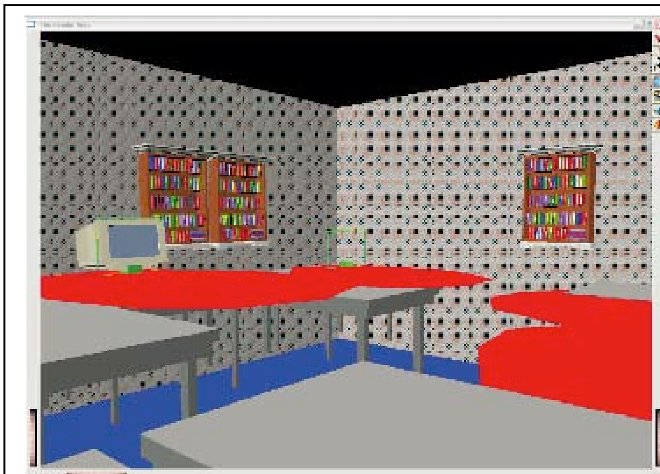
Figure 3. Augmented reality for visualising active objects.
Kasim Rehman's work.
(This is a simulation of the view - in the real system, only the red regions and the monitor framing are synthesized and superimposed on the wearer's normal view.)

design principles.

Privacy

Some ubiquitous applications, including several of the applications mentioned (e.g. coffee alerts) can be made to work without knowledge of the true user identity, and with some work they can be made to function with untraceable pseudonyms (identifiers an attacker cannot associate with any real-world entity).

Alastair Beresford and Frank Stajano have demonstrated a generic technique for achieving anonymity for users who are tracked in active spaces where there are enough users to allow them to 'hide in the crowd' from time-to-time [6]. It is possible that anonymizing information in this way can prevent an application from determining the true user identity hiding behind the pseudonym and therefore solve the location privacy problem without installing extensive access control policies.

Some applications will always require knowledge of user identity (e.g. the Office-Watcher). Our current solution is to build reciprocity into the system— providing feedback via a diary intranet page of requests for location information to the location data owner.

Conclusion

Location-aware applications require a location-sensing infrastructure that is reliable and that can be deployed and supported cost-effectively. These costs can be controlled by the use of techniques such as error detection and correction and automated mapping. A highly accurate infrastructure such as the Active Bat system enables a wide range of applications ideas to be explored for possible subsequent deployment using less accurate, lower-cost technologies.

Acknowledgements

Thanks are due to all whose work is mentioned – see figure captions and citations for names.

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