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Abstract

Systems for assisted living that support people in their own home are becoming ever more important internationally as social and economic demands change. In our system, we view everyday activity around the home as travel between landmarks, with objects deposited and collected in locations that only need to be localised in relation to those landmarks rather than in terms of a fixed frame of reference. The placement of such landmarks – implemented as Radio Frequency Identification (RFID) tags – can be determined by the degree of resolution required, so that areas where there is more spatial complexity may have a higher density of tags than those areas that are less complex. In this paper we describe a prototype system built around RFID tags used as fixed landmarks and attached to moveable objects along with a portable interrogator, using commercially available hardware and software. Two methods were developed: history recall, using continuous object tracking and real-time object location sensing. Usability testing of the system is described and the results reported. Future development challenges, potential applications and critical technological development points are discussed.

Keywords

Radio Frequency Identification (RFID), Usability, Object Location, Object Tracking

Context

This paper reports on a usability testing project that is part of a much larger study of a low-infrastructure object location concept for the home. Several systems exist for tracking personal objects, but they are not suited to the home environment because they are not portable and they require a prohibitive amount of expensive high-end technology that requires professional installation (Symonds et al 2007). Much of our work to date is reported elsewhere. In this paper, we focus on investigating whether the theoretical locatable objects system proposed by us is practical. To do this, we undertook usability testing on our first prototype system.

Our Challenge

At our Software Engineering Research Lab at AUT University, we have developed a system using technology already available on the market that can track personal objects in the home that does not require extensive installation, is relatively portable and could cost less than NZ$4,000 to purchase. The system uses Radio Frequency Identification (RFID) technology to identify and track a system of objects and locations identified by the user. There are three main points of difference between traditional object location systems and the one that we have developed.

Firstly, many RFID systems have the tag on the user (e.g. car or live stock) and the reader positioned at a specific location (e.g. entry and exit to the system). In a system for finding personal objects in the home, this would require readers at least at the entry and exit to every room in the house as well as each entry and exit to the house. In the average sized family house, this would work out to be approximately fifteen readers for one system and would thus be prohibitively expensive. Our system places the reader on the user and uses tags to identify objects and locations of interest to the user. Therefore, the system requires just one reader and approximately 50 inexpensive RFID tags.

Secondly, many location systems produce an absolute location in terms of some frame of reference – for example latitude and longitude in the case of GPS. However, the level of precision of a system is directly related to its usefulness in a particular context. For example, the user might not immediately understand when the system tells them is 3500mm from the east wall and 4000mm from the bedroom door. What the user wants to know is whether the object was last close to them when they were near the microwave in the kitchen or beside the master bedroom tallboy drawers. This information is immediately meaningful to the user. By creating a topological model where the landmarks are relevant to the user, the concept of a single level of precision can be replaced with one where precision is appropriate to the task. Broad-brush location, in terms of a specific room for example, can be enhanced when necessary with more and more precise information, within an item of furniture, or indeed a specific drawer etc. By allowing the user to specify such domains, and increase the density of tagging where appropriate, the utility of the device is increased. Similarly, areas that are of relatively little interest may not be densely tagged.

Thirdly, the use of RFID tags on objects allows for more information than just their identity to be stored. So use-by dates or storage instructions may be included in the information presented, along with other information where appropriate – for example colour of clothing for people of limited vision. Indeed our approach allows the system to identify when the user is actually carrying the object they are looking for – as happens to those of us who tend to perch their glasses on top of their forehead!

However, the theoretical nature of our Aura Object Location model does not yet show that the system is practical. Therefore, we developed and tested a prototype system to help us understand more about research problems within the Aura Object Location model and the practical application of the system. This paper reports on the usability testing of the Aura Object Location model using two methods – movement history and real-time location sensing.

Research Question

In our project we theorised about how the object location system will work. However, we didn’t know if the approaches would actually work. Therefore, we asked the following research question.

What aspects of the Aura Object Location model are important to the user for locating personal belongings within the home?

> How useful is the ‘Where is my…?’ search? (Movement History)
>
> How useful is the ‘What is near me now?’ search? (Real-time Location Sensing)

We used a Design Science research approach (Hevner et al. 2004) to conduct our investigations and undertook a rapid prototype design software development approach (Nunamaker, Chen & Purdin 1991). To explore this research question we developed a software application prototype and undertook some preliminary usability testing.

System Development

Assistive technology is very intimate. It affects the user in their own home, in their daily activities, and communication with the technology is a constant throughout the day. While models such as task-technology fit and TAM deal with the use of new technology in defined environments, assistive technology devices have a greater impact on the lifestyle of the user. Building confidence that the system will work when required, that it will not be obtrusive to the user or their co-habitees, and that it will reduce rather than increase the difficulties of everyday living are key elements here which are less important in the traditional approach to technology adoption and testing. In some ways the device has to act as a companion rather than a tool, being available when needed but being acceptable to live with when not. As with a human or animal companion, the relationship between the device and the user changes with time and familiarity, but in this case the user must always be the master. We have not developed such a companion device yet, but in trying to work toward these, we are able to identify necessary changes in the development approach for this to occur. In this section we outline the prototype development including the environment, hardware and software.

The Prototype

The application software prototype was developed to record the presence of objects that were within a person's "Aura" at specific "Landmarks". The Aura is a user's personal space, either on the body or very close to the body. The Aura concept is based on the work of Satoh (2005). A landmark is a location. (For a more detailed description see Symonds et al., 2007 and Basrur & Parry, 2006).

The target user population are outpatients who suffer from memory loss and may benefit from an electronic prompt for where they last left a particular item. The intended users are novices and have only a basic working knowledge of how to use a Personal Digital Assistant (PDA). Given the type of users, the system will need to be:

(i) Easy to use.

(ii) Low cost.

(iii) Low in infrastructure and

(iv) Compact size

Environment

The system was developed on a Pocket PC running Windows CE, wirelessly via Bluetooth to a RFID reader. Windows CE was chosen as it is the more architecturally stable platform at the time of writing and there is wider support for speech recognition and natural handwriting recognition on Windows CE devices.

Hardware specification

We developed our application on a HP iPAQ hx2495 Pocket PC and a Feig LR2000 RFID interrogator (13.5Mhz) with serial Bluetooth to provide wireless connectivity and loop antenna. The interrogator alone weighs 1.6kg. Including a closed cell battery providing 9 volts and other equipment, it weighs approximately 2.5kg. We used commercially available gen-1 RFID tags (passive & read only) either in adhesive label or key tag configuration. At the time of development, this was the best commercially available equipment to give the required read range without going to UHF equipment and active tags.

Software specification

The application software was developed using the Windows CE platform and the .net programming environment, as it provides all the necessary tools to program for Windows Mobile. The application was programmed in C# .net making use of the Pocket PC emulator (that can emulate the loading time and the interface of the Pocket PC), and the database engine Microsoft SQL Server CE that works on the Pocket PC platform (installs with .net framework). Speech recognition and speech synthesis are currently supported on the Windows CE platform and can be migrated to the Pocket PC.

Although the system developed is fully mobile with battery power, it is large and bulky. The fixed loop antenna is difficult to work with and therefore it was decided to simulate the aura concept in these early usability tests. This means that the tester held and used the Pocket PC in the environment, but that one of the team simulated the sensing of tags within the environment by placing tags inside the antenna in a fixed position as the user moved about the environment.

Usability Testing

Usability testing encompasses a number of methods that allow potential users of a technology, or representatives of those users, to interact with the technology at various stages of its development. The choice of method depends on a number of factors including the stage of development of the technology, and the nature of its use (Nielsen 1994). In this case a laboratory-based approach was used, involving the cooperation of healthy volunteers, who were asked to perform a number of tasks using a prototype of the system. Because the system is at an early stage of development, system failures and unexpected behaviours are relatively common and the protocol used was designed to be robust enough to provide useful information even in these circumstances. The usability testing protocol was less dependent on a purely quantitative model, i.e. times to perform certain tasks, as a qualitative interpretation of the users' reactions and experience with the device and the collaborative improvement of the device via user comments and suggestions.

A software application was developed for the Pocket PC platform. The application maintains a database of RFID tag identifiers, corresponding to both easily-losable objects (e.g. 'cordless telephone', 'wallet', 'keys' and 'glasses') and fixed locations (landmarks) (e.g. 'nightstand', 'refrigerator'). The database is updated whenever known object tags come into range and what landmark tags were also in range at the time. From this information, the user can request the last recorded location of any object known to the system. The user can add, modify and remove landmark and object tags from the system. Unrecognised tags (those that have never been set up and those that have previously been removed) are ignored as these may represent any RFID tag (such as item tags on store merchandise). Interaction with the system is via a combination of speech recognition/synthesis and on-screen display. Full on-screen interaction is supported for people with hearing impairment (and for situations where a voice interface would be unsuitable).

Method

The usability testing process we used is based on the Simulated Prototyping method (Hohmann 2003). At the beginning of the testing period each tester was informed of the usability testing process and reminded that the tests are a reflection of the software application and not of themselves. They were then provided with a brief walkthrough/demonstration of the features the RFID for Assisted living provides. Each tester was reminded that they could use the system in any way they felt comfortable with to complete their tasks, and could ask for assistance at any time.

During the tests one of our team members was with the tester to provide information and feedback about the testing process. Another team member moved tags in and out of range of the RFID reader during the testing phases, to simulate the tester's 'Aura'. The third team member was responsible for recording and managing the results of each test.

Before the testing began, two scenarios were developed for the testers to attempt. The two scenarios related to object location within the system and they were:

(i) Movement History

(ii) Real-time Location Sensing

Two different data collection techniques were used to ensure that user testing was done as effectively as possible. Firstly, we observed the users while they interacted with the application while they completed a range of predefined tasks. It must be noted that we made the observation in full view of the tester and although they knew and consented to this, it was an intrusive technique (as opposed to viewing the testers from behind a one way mirror for example) and this may have affected the results as a user may act differently when they know that they are being watched. Secondly, we used a simple questionnaire at the end of the process to collect overall feedback from the tester about their impressions of the application.

Test Scenario 1: The "Where is my…?" Search (Movement History)

This scenario tested searching for a lost item using the "Where is my…?" interface. There is an inherent trade-off in the design of this scenario between the user knowing where they have left the item by having physically done so (because our testers were following set instructions and they are not impaired) and having truly 'lost' the item by not knowing where it is (as in a real world situation where the user is impaired).

In this scenario, we attempted to simulate the loss of an item while still leading the tester through the test environment to build their 'mental map' of the area and landmarks. This was done by having the tester deposit several identical items, differentiated by their (invisible) RFID tags alone. We then asked the user to find one of these items. Though they may remember where each was placed, they will have no way of knowing where the particular item requested was left – it could be at any of the locations where they left an item.

Task 1

The tester was given a stack of ten small tagged items, all identical (blank notebooks). They were instructed that when they entered the test environment, they were to place one of the items on each of the 10 locations they could see marked with a large X in fluorescent masking tape.

Each location was somewhere between waist and chest height, such as a desk, shelf or chair. The tester did not have to 'hunt' for these locations – they were marked so as to be immediately obvious on approach. Any item may be left at any of these locations and they had a reasonable amount of time to complete this objective (3 minutes).

Each location marked with a large X was a landmark recognised by the system. Around each X a radius was marked in nondescript tape on the floor. When the user came within the tape circle, the landmark was determined to be in their aura.

At the end of the scenario, they were asked to find two particular objects from the ten they had just put down. There was no way to do this by sight, as the items were identical. They only knew the names of the items they were looking for as a recipe book and an address book. Performing a "Where is my…?" search should have given the user the last known location of each of the two items they were looking for. They were asked to physically retrieve only the two items, using the Pocket PC to assist them. The scenario was considered explicitly 'failed' if they returned one or more incorrect items.

Test Scenario 2: The "What's near me now?" Search (Real-time Location Sensing)

This scenario tested searching for a lost item without exact history, using the "What's near me now?" interface (the 'walk around search'). In this scenario, a small RFID tagged item was 'hidden' in a room (such as a key placed under a folder). This item was pre-placed and its history loaded into the database – the history contained several of the landmarks the user learnt in Scenario 1, spaced 5-10 seconds apart, ending with 'you' (the item was in aura, but not near a landmark). These landmarks provided a 'trail' to a general area – for example:

Table 1: Location History

Last Seen Near…	At…
(the) Elevator	10:00:00 AM
(the) Hallway by Reception	10:00:10 AM
(the) Hallway by The Office	10:00:15 AM
(the) Office Door	10:00:25 AM
You	10:00:30AM

The information in Table 1 may be interpreted as the following scenario:

After reaching the 'Office Door' landmark, the item was placed somewhere away from any landmark. However, it should have been relatively obvious from the history that the item was likely to be in the office somewhere – the user appeared to have walked straight from the Elevator to the office door, and then placed the item somewhere without passing the office door again. The object was therefore inside the office, close to the door and not near any other landmark.

Task 2

The tester was told that the item was lost inside an office, and asked to find it with the help of the system. They were shown the office and told that the item was misplaced and not hidden – e.g. it was not be taped to the bottom of a desk or inside a ceiling tile. It was suggested that the "What's near me now?" option could be used to 'scan' for something while walking around. As the user moved around the room, landmark and item tags were placed in and removed from their simulated 'Aura' based on their position.

This history (see Table 1) was available only if the user chose to view it of their own accord. If the user chose to view the item history to help their search, the scenario provided a useful history (as there likely would be if the system were in actual use). By providing the history, we controlled for the problems in previous tasks that would make this task impossible to complete.

Results

Five testers were selected on the basis of convenience from University staff. We selected users who might be sympathetic to our needs and chose mostly allied staff rather than academic staff to get a better representation of everyday users of the system. None of the testers were elderly (over the age of 65), however, only one of our testers was familiar with the Pocket PC environment (see Table 2).

Table 2: Tester background

	Tester				
Background	#1	#2	#3	#4	#5
Age	33	34	60	61	49
Gender	F	F	M	F	F
Pocket PC Experience	N	Y	N	N	N
English is First Language	N	Y	Y	Y	Y

Test Scenario 1: The "Where is my…?" Search (Movement History)

All of the tasks for the first test scenario were completed successfully by all testers (see Table 3).

Table 3: Observations from Task One:

Task	**Yes**	**No**	**Not Sure**
Main Menu: Was the tester able to identify at first glance where to go to find their lost item?	5	0	0
Recipe book: Was the tester able to easily identify which item they were searching for from the list?	5	0	0
Recipe book: Was the tester able to understand where the recipe book was?	5	0	0
Address book: Was the tester able to easily identify which item they were searching for from the list?	5	0	0
Address book: Was the tester able to understand where the address book was?	4	0	1

N=5

One tester was unable to understand where the address book was. The tester went to the right location, but was unsure about the item (retrieved the paper placed in the recycling bin instead of the book on the television). We think that the tester retrieved the wrong item due to unclear directions on the part of the facilitator.

At least two testers made use of the speech output to locate items. One of these testers appeared to make use of the speech output exclusively (listened to the voice and did not look at the display). One tester did not actually walk into range of the 'Clock' tag, due to that tag being against the wall. This was noticed for various landmarks in subsequent tests. As a side-note, it appears that placement of tags against walls is not suitable in a large open room environment assuming an aura radius of ~75cm. Users do not walk close enough to the walls. On the positive side, this does reduce the likelihood of through-wall landmark conflicts.

Test Scenario 2: The "What's near me now?" Search (Real-time Location Sensing)

The 'what's near me now' search task was a little more difficult for our testers to understand, although only one of the testers could not complete the tasks (see table 4). However, given the type of users targeted, it is possible that this is an indication that the 'what's near me now test' needs some attention.

Table 4 Observations for Task Two

Task Description	**Yes**	**No**
Main Menu: Was the user able to identify at first glance where to go to search for items/landmarks are were currently in range?	4	1
Was the user able to interpret what was on screen?	4	1
Was the user able to successfully find the missing item without any help from the facilitator?	4	1

N=5

Two users were unclear that the "What's near me now?" form automatically refreshes, that they could walk around and it would always reflect what was near them without having to close/reopen it repeatedly as they moved. One was able to complete the scenario by opening and closing the form, the other required facilitator assistance to complete the scenario. One user did not initially realize how the "What's near me now?" option worked and waved the Pocket PC around, apparently without looking at it. They may have been expecting audio output, as in the first scenario. This was not confirmed with the respondent. The user with prior Pocket PC experience generally moved more quickly and confidently through the interface than the others.

Findings

In this particular part of our project we wanted to find out what aspects of the Aura Object Location model were useful to the user for locating personal belongings within the home? We tested two methods: 1. Where is my…? (Movement History) and 2. What is near me now? (Real-time Location Sensing).

In our testing we had good success with most testers being able to quickly understand and use the movement history method. Our testing also suggests that perhaps tag placement near walls in the home is problematic as the user does not walk close enough to walls and suggests that perhaps the 75cm radius aura is not large enough for this application. The testers seemed to appreciate the speech output aspect of the application.

However, our real-time location sensing method was not as easy for our testers to understand conceptually or to use. Perhaps some of this difficulty was due to the software interface which automatically updated location information without giving a sign to the user that it was doing so. As speech output was not implemented with this part of the application, it is difficult to say whether having speech output to announce the detection of new objects and landmarks would be useful or a hindrance.

The testers were asked about whether had any concerns about wearing an RFID reader in daily life. None of the testers had any health and safety issues and two of the testers likened the system to a cell phone. Research summarised by Moulder et al. (1999) could find no causal link between cancer and cell phones and more importantly, the testers perceived the health and safety risk of wearable RFID to be minimal.

Advantages of this Approach

An important part of the system is that it allows the user to register object tags and location tags. This allows for customisable usability. It is envisaged that a group of pre- registered tags could be provided and then an additional set of registrable tags provided with a simple registration process where the user is prompted and assisted by the system. This functionality would be much more difficult to achieve using a fixed interrogator scenario.

There are a number of well-established RFID security and privacy threats that include sniffing, spoofing, replay attacks, and denial of service[1] (Rieback et al. 2006), one aspect that makes this different from other applications e.g. library books, is that most of the tags are attached to objects that will always stay inside the home (the landmarks). Even objects that do get carried outside eg glasses can have encrypted ID's that are meaningless to anyone else (such as the Authentication Processing Framework (APF) – see Ayoade 2006). Until the system is used outside the home, then the denial of service attacks etc. are impossible, because the range is just too great for communication. In terms of privacy, the greatest threat would be if people from outside accessed the 'path taken' information, and if available on the Internet, the time sensitive location sensing information could facilitate cyber stalking. In terms of increasing privacy and security for the users, the system increases the time the user can spend at home without needing carers constantly present or moving to an institution with a resulting loss of privacy and autonomy.

Future Work

In our testing we simulated the aura concept because we weren't able to get technology that was both powerful and light enough to be worn by the user. Future projects are likely to explore UHF technology and antenna design. Research by Ukkonen et al. (2007) suggests that UHF RFID technology coupled with a balanced dipole antenna design may give the desired read range for the system.

In terms of the movement history search, we found that there was a fuzzy interpretation aspect to information provided to the user to help them locate the object. For example, our prototype reported that the glasses object was last seen near the side board table. We could find no studies on how users might interpret the concept of 'near'. To some users this might mean within 30 centimetres and to others, it might mean 3 metres. We suspect that this might relate to individual interpretations of personal space.

With the real-time location sensing search we found that without any audible prompt to signify that there has been some update in the user interface, many users were not aware that another object was detected unless they studied the device continuously. In a real world application, it will be important to find ways that a user might be informed that the interface has been updated, or might like to be informed of changes without creating distraction and annoyance with the system. These might be related to the volume and type of audible signal or they might be related to other types of ambient information.

Our test scenarios were designed with able-bodied testers in mind. We tried to design our tests to cater for this and so the testers could not easily do the tasks without the assistance of the system. Our next tests will try to focus on more realistic tasks such as a blind person looking for a blue T-shirt rather than a white one. Such a test might incorporate contextual knowledge such as the fact that blue clothes always go into the bottom drawer for example. Tests for objects that might be confused, reading glasses and long-distance glasses or keys for example, can be verified by picking up the objects in turn and stepping back out of range of the others. More testing might be carried out to test the advantages of having short range tags for objects and long range tags for landmarks. Also the notion of using topological maps may be explored further so that even if one of the landmarks shown in the movement history is missed by the system, the path is still obvious and confirmed with a degree of certainty.

[1] A sniffer is a software program used to monitor data traffic to a network used to gain information. Spoofing is an attempt to gain access to a network by posing as another user. A replay attack involves recording valid network messages and then playing these back at a later time to forge network messages that appear authentic. Denial of service is a hacker attack designed to overwhelm a system of network making it inoperable.

As we progress with the system we expect to use more qualitative approaches, as the system's aim is to support daily living which is a real jumble of tasks as opposed to a workplace where tasks can be ordered and quantified as the test scenarios have been in this experiment. Such an approach will perhaps allow us to see people use such a system in a way that the designers never expected (Dray et al. 2002). We will progress to testing our system with the targeted users. To do this effectively, we need to work more on the interface, perhaps with more voice output or even with speech recognition capability as small screens and controls are very delicate and can require concentration and dexterity to operate effectively. Our intended users will struggle with these problems and it may even prevent them from using the system at all.

Finally, in addition to ‘aiding’ the user to perform activities, it may well be that the RFID system has the potential to ‘train’ the user so that prompting is eventually not required. For example, one of the basic premises of rehabilitation after brain injury is ‘errorless learning’ (Baddeley & Wilson 1994). This means that for people with cognitive impairment, prevention of failure (such as preventing someone from leaving the house without their keys) is essential if they are to ever learn to remember without prompting. As such, the project offers potential for Assisted Living Environments to be reconsidered as being more than an ‘aid’ to compensate for impairment but as an active intervention to promote adaptation and enhance neural recovery (Smith et al. 2006). Future work will develop and test therapeutic intervention to allow the individual to develop internal mechanisms to recall important objects and the order they should be utilised without prompting from another person during practise. Given increasing evidence that the skills of regulating one’s own behaviour have an important role in enhancing mood and promoting motivation (van Exel et al. 2005), the gain in wellbeing from this novel approach is immense and likely to make a very real difference.

Conclusion

In this part of our project we set out to test the practicability of the Aura Object Location model by designing a prototype system and undertaking some laboratory-based usability testing. We have explored how the movement history search and real-time location sensing search methods might work and investigated potential future development. Along the way, we have struggled with the available technology and gained useful insight into the requirements of not only the Aura Object Location model, but also the unique requirements of a companion device. We can see promise in the Aura Object Location model as an assisted living concept and we can also see there is much more work in the assistive technology area in order to reach a point where such a device can be truly practical.

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