Ambient Kitchen: designing situated services using a high fidelity prototyping environment

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ABSTRACT

The Ambient Kitchen is a high fidelity prototype for exploring the design of pervasive computing algorithms and applications for everyday environments. The environment integrates data projectors, cameras, RFID tags and readers, object mounted accelerometers, and under-floor pressure sensing using a combination of wired and wireless networks. The Ambient Kitchen is a lab-based replication of a real kitchen where careful design has hidden the additional technology, and allows both the evaluation of pervasive computing prototypes and the simultaneous capture of the multiple synchronized streams of sensor data. Previous work exploring the requirements for situated support for people with cognitive impairments motivated the design of the physical and technical infrastructure and we describe both our motivations and previous work on interaction design in kitchen environments. Finally, we describe how our lab-based prototype has been put to use as: a design tool for designers; a design tool for users; an observatory to collect sensor data for activity recognition algorithm development, and an evaluation test bed. The limitations and advantages of lab-based, as opposed to in situ home-based testing, are discussed.

Categories and Subject Descriptors

Categories and subject descriptors: H.4.m [**Information Systems Applications**]: Miscellaneous — Kitchen; J.7 [**Computers in Other Systems**]: Consumer products, Kitchen counter; H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems — Video; General Terms: Human Factors; Keywords: Ubiquitous computing.

General Terms
Experimentation; Design; Human Factors.

Keywords
Pervasive computing, ubiquitous computing, multi-modal prompting, sensor networks assistance in daily activities, people with dementia, prompting, kitchen tasks.

1. INTRODUCTION

The design of the Ambient Kitchen was motivated by the clinical problem of prompting people in the early stages of dementia through multi-step tasks (Wherton & Monk, 2008). Carefully conducted interviews with people with dementia and their carers, and in depth observational studies revealed both the nature of the support that people with dementia required in the kitchen, and just how important being able to prepare food and drink was to their sense of autonomy. The development of a system to support a person with dementia preparing even quite simple meals and drinks requires advances in pervasive computing technologies that are still well beyond the state-of-the-art. In particular, detecting actions and intentions, and the provision of situated prompts with the desired effect when things go awry are challenging. The Ambient Kitchen was developed as a test-bed for such research and incorporates a fully integrated set of sensors and displays (see section 4). The development of such a high fidelity environment can be utilized in a number of different ways:

1. **Design tool for designers**: as an environment in which full prototypes can be developed, and new technologies deployed in a setting that captures the structural and experiential qualities of the real world.
2. **Design tool for users**: as a setting for eliciting user feedback on the functionality and utility of pervasive computing designs in a setting in which the environment (the kitchen itself) and associated activities, and not the technical instrumentation of the environment, are the focus.
3. **Observatory to collect sensor data**: as a means of collecting structured synchronized streams of sensor data for an array of everyday activities using heterogeneous sensing technologies (video, accelerometer, RFID, pressure) for the development of activity recognition algorithms.
4. **Evaluation test bed**: as an environment in which the evaluation of fully integrated applications that utilize the sensing and display capabilities can be conducted.

In the following sections we contextualize our goals by first reviewing the scope of previous work to provide situated support for people with cognitive impairments (Section 2). We then describe the technical infrastructure and design choices made for the Ambient Kitchen (Section 3) and describe and discuss the different ways in which the Ambient Kitchen is being used to support the research and design of pervasive computing environments (Sections 4-5).

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2. SITUATED SUPPORT

Numerous technologies have been exploited to provide timed reminders and cognitive support at specified intervals, including the use of computer-controlled telephone calls (Friedman, 1998), pagers (Hersh & Treadgold, 1994) and personal digital assistants (Kim, 2000). Fixed scheduled prompting has proved valuable for applications such as the provision of medication reminders (Kirsch, 1992) but falls short of supporting deficits in episodic memory, that is memory of personally experienced events - the symptom most commonly associated with conditions such as mild-to-moderate dementia. In terms of the ability to perform activities of daily living, the parallel deficits observed in executive function are also very important (Nadler et al., 1993; Boyle et al., 2004). Deficits in executive function manifest as problems in planning, sequencing and attentional control. These significantly increase the need for external help in the conduct of everyday tasks such as preparing food, washing, or cleaning.

Various technologies have been brought to bear in the support of people with dementia undertaking activities of daily living. Baruch et al. (2004) presented temporal information on computer screens placed in prominent areas of the house. For example, at night, the screen will present a large digital clock along with a pictorial representation (e.g. the moon on a dark background) and a short message such as “It’s night time so you need to go to bed”. Kautz et al. (2002) developed a portable orientation aid, the ‘Activity Compass’, which guides patients both outdoors and indoors. If outdoors, this handheld device can detect when the user is lost through GPS and artificial intelligence algorithms. In such instances, the device provides the patient with a verbal prompt to return home, and directs them by presenting an arrow pointing in the appropriate direction on the display screen. Indoors, the Activity Compass uses sensors to track patients’ movements, and directs them when necessary. For example, if a mealtime is overdue, the device prompts the patient when they are in the kitchen to encourage them to make something to eat. The interface uses symbolic representations (e.g. the arrow and a picture of a house to indicate ‘going home’) and pre-recorded prompts to guide the person with dementia.

Perhaps the most fully developed system with the aim of prompting people with dementia was developed by Mihailidis, Barbenel and Fernie, (2004) and extended in (Hoey et al., 2007). The COACH (Cognitive Orthosis for Assisting Activities in the Home) system, is designed to guide hospitalized dementia sufferers through the process of washing their hands. The system uses image processing and probabilistic modeling techniques capable of monitoring a patient’s progress through the task and provides assistance when necessary. When an error is detected (e.g. an action out of sequence), or the patient fails to initiate an action after a set period, the system presents appropriate pre-recorded verbal prompts. Dishman (2004) presented a prototype system that could guide a patient through making a cup of tea. The system monitors the person’s progress using radio frequency identification (RFID) tags attached to the utensils. Audio prompts are then provided to the patient, with video clips of a person carrying-out the to-be-performed action, displayed on a TV screen.

Tran, Calcaterra and Mynatt (2005) devised the Cooks Collage to guide a patient through a cooking activity. The system includes a single screen located on the kitchen cupboard, which presents a series of close-up shots of previous actions performed during the activity as a visual summary of their progress. This is presented as a conceptual design, and although it was effective in supporting graduate students accomplish a dual task test (cooking whilst learning another language), it has not yet been tested on people with cognitive impairment.

The literature contains many proposals as to how one might use technology to support people with dementia when carrying out daily tasks, but only a few have been implemented as research prototypes, and none have as yet made it as mainstream products. There are significant technological problems to be solved before this can happen. An effective prompting system has to infer context: what activity is the user attempting, what have they done so far, and what is the current state of the environment. For example, COACH has to sense that someone is at the sink oriented in such a way that there is a high probability that they want to wash their hands. It has to track the steps in carrying out this activity and prompt only when necessary. It has to sense whether the tap is on or off and where the soap is. The usefulness of COACH is highly sensitive to errors in this process of sensing and inference. Prompting someone to do something they have already done is confusing. Prompting someone to do something they don't want to do or are about to do anyway can be confusing or at the very least irritating. However, if prompting can be done subtly and in a timely way, then many people could benefit. We all find ourselves cognitively overloaded on occasions. Systems that keep an eye on us and draw attention to errors of omission or commission could be of value in many contexts, especially where safety is a priority.

3. THE AMBIENT KITCHEN

Developments in pervasive computing (alternatively referred to as ubiquitous computing or ambient intelligence) have seen significant progress since Weiser's vision for the "computer of the 21st century" (Weiser, 1991), a world in which computers and sensors disappear as they are woven into the fabric of our surroundings. The technical basis and infrastructure to realize miniaturized computing and sensory devices, connected by wireless networks is already apparent. However, it is not enough simply to demonstrate that miniaturization and networking are possible. If this technology is to find its way into our homes it must be made to fit into existing home environments and then be able to support the things people wish to do there.

Kitchens offer a unique challenge for the development of the situated services envisaged by Weiser, not only because there is an identifiable user group in people with dementia, whose lives would be transformed by effective situated support, but because kitchens are not typical sites for the deployment of digital technologies. Whilst the kitchen contains much existing technology in the form of appliances for cooking, washing and food preparation (TVs are also common) the level of integration of such devices is minimal and the very notion of the "appliance" emphasizes the stand alone character and well defined function of each device. Unlike many aspects of modern life, the kitchen is still a space where physical interaction with real objects (food and kitchen utensils) is valued and information access is furnished through traditional media such as cookbooks.

Only a small number of digital technology-led kitchen interventions have to date been developed by the human-computer interaction and pervasive computing communities. These include MIT's CounterIntelligence (Bonanni et al, 2005a, Bonanni et al, 2005b) that explored the use of displays that augment the kitchen contents and Chen et al.'s (2007) application of RFID embedded in a kitchen counter in which food ingredients on the kitchen counter are used to raise a user's awareness on healthy quality of food ingredients through the presentation of nutritional information on a display and speaker (an extension of Chang et al., 2006). A number of other design proposals relate to situated advice on food and cooking (Tran et al., 2005; Ju et al., 2001; Siio et al., 2004).

The Ambient Kitchen utilizes extensively deployed RFID readers (and tags associated with all moveable non-metallic objects), six cameras integrated into the walls of the kitchen, a mote-based wireless network of accelerometers attached to kitchen objects, cupboard doors and utensils, and the use of pressure sensitive flooring by which the location of users can be established. Projectors and speakers embedded in the environment facilitate the generation of spatially embedded cues. Spatially situated auditory cueing allows us to explore the various configurations by which auditory and visual cues can be realized. In this way we can explore the practical problems of creating technologies that are robust and acceptable in the home.

The Ambient Kitchen is a very loosely coupled set of off-the-shelf and custom developed technologies. Whilst it is not our explicit intention to extend current work on sensor networks or displays, some development was required to integrate the sensing and display infrastructure within a single sensor network. The current configuration uses blended projection from four small projectors placed under up-lighters in the main workbench. The projection is reflected by a mirror under the over-head cabinets onto the kitchen wall.

The position of people and objects on the floor of the kitchen can be detected using the custom developed 200 element array of capacitate sensors placed under the laminate floor. 8 multiplexed long range RFID readers are embedded in the main workbench and a subset of the kitchen cabinets. Finally, Micaz sensor motes have been integrated into a number of kitchen objects (food containers) and 5 IP video cameras embedded (hidden) in the walls. Sensor data is collected and synchronized using a set of loosely couple web services (to allow rapid application prototyping and remote monitoring) and a separate repository has been established in which we are collecting benchmark data for a range of kitchen activities and for use by our collaborators and the wider research community.

Figure 1. The Ambient Kitchen is a lab-based high fidelity pervasive computing prototyping environment. The kitchen is situated in the main research space in Culture Lab, Newcastle University and uses modified IKEA units and standard laminate flooring installed within a wooden structure (see top figures). Significant care was taken that the underlying technology is not apparent to the people using the kitchen – even the wall projection is achieved using "up-lighter" style projection onto mirrors below the overhead cabinets.

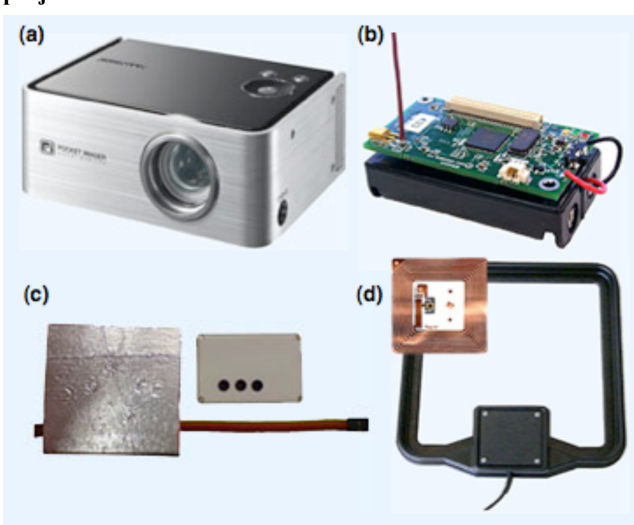

Figure 2. Sample off-the-shelf and custom technologies integrated in the Ambient Kitchen: (a) 4 × DLP projectors for situated displays; (b) 4 × Micaz zigbee motes and sensor boards for object motion sensing; (c) 200 x custom capacitive sensors for floor pressure measurement; (d) 8 × Feig long range RFID readers (and sample tag).

Figure 3. Using an RFID tagged control object the state of all the Ambient Kitchen sensors can be examined on the main display: floor pressure map (left); accelerometers (center-top); RFID (center-bottom); and video feeds (right).

4. CASE STUDIES

The Ambient Kitchen has been developed to support a range of research activities around the problem of providing situated support for people with dementia, and situated services associated with food planning, preparation and cooking. As a high fidelity prototyping environment it allows us to support these activities in a number of different ways, as an experimental space for designers, for explaining new technologies to users, for collecting sensor data in benchmark development for activity recognition algorithms, and for the evaluation of complete solutions in a naturalistic setting.

Figure 4. A current design scenario in which the pages of a cookbook have integrated RFID tags. The workbench can detect the current page and adapts the ambient display according the page's contents.

4.1 A design tool for designers

Developing design ideas for pervasive computing applications usually requires a significant effort on the part of designers to imagine what interacting in a fully instrumented environment might be like. In our kitchen scenario, there are no keyboards, mice or conventional input devices, and the ability to physically explore different configurations of sensor-dependent display behavior significantly helps in the exploration and crafting of design ideas. Figure 4 shows a prototype under development in which the ambient displays (on the wall above the main worktop) respond to the turning of the pages of a specially designed cookbook. The cookbook has an RFID tag embedded in each page allowing the kitchen to detect the page that the book is currently open at. Responding to this, the ambient displays present relevant food information and even personal media related to the recipe and past times in the cook's life when the corresponding meal was prepared.

4.2 A design tool for users

Another significant challenge in designing pervasive computing applications is the involvement with users in the design process. We have conducted a number participatory design exercises involving older users and found that a significant barrier to exploring design concepts is adequately explaining the scope of the technologies involved. By demonstrating simple mappings between sensors and display in demonstration applications in the Ambient Kitchen we have found that we can greatly improve lay users' understanding of the potential functionality. For example, figure 5 shows one such commonly used application in which sample recipes are projected in response to the ingredients placed on the bench. Traffic light indicators on the display also show which of the recipes ingredients are in the kitchen's cupboards. Though a simple demonstration of how sensor data can be mapped to information sources (and then to information displays) our experience is that such illustrations can help users think about both more mundane and adventurous (and useful) applications of such "invisible" technologies.

Figure 5. The Ambient Kitchen has been used to facilitate discussions and focus groups on the topic of pervasive computing as part of a wider participatory design process looking at ICT and nutrition for older people.

4.3 An observatory to collect sensor data

Realizing situated services that are responsive to both your actions and intentions requires significant development of activity recognition algorithms themselves. As such, multi-sensor benchmarks of everyday activities are not widely available, and as part of our own research, and to support the research of collaborators and the wider research community, we are developing a number of such benchmarks by capturing data for multiple subjects and activities, and hand annotating these datasets. Activities range from gaze data for head pose tracking algorithm development, primarily using video streams alone (see figure 6), to naturalistic data sets relating to multi-step food preparation for which RFID, accelerometer, pressure and video data is collected and hand annotated.

4.4 An evaluation test bed

Evaluation means different things to different people. For an engineer the question is "does it work?" That is, are the functional requirements met, does it complete certain tests accurately and without failing. For the human factors engineer the question is "does it perform a useful function in the context that it is intended to be used". The latter question can only really be answered by installing the technology in a range of real contexts. In the case of kitchen technologies, this means real lived-in homes. Constraints such as household routines and the different uses different members of a family use different rooms for at different times can be critical in the success or failure of home technologies. These constraints are only really apparent in the context of real home use. Laboratory-based facilities such as the ambient kitchen thus are of limited use in this respect. However it is possible to use them to do more limited evaluations of functional requirements that still have face validity.

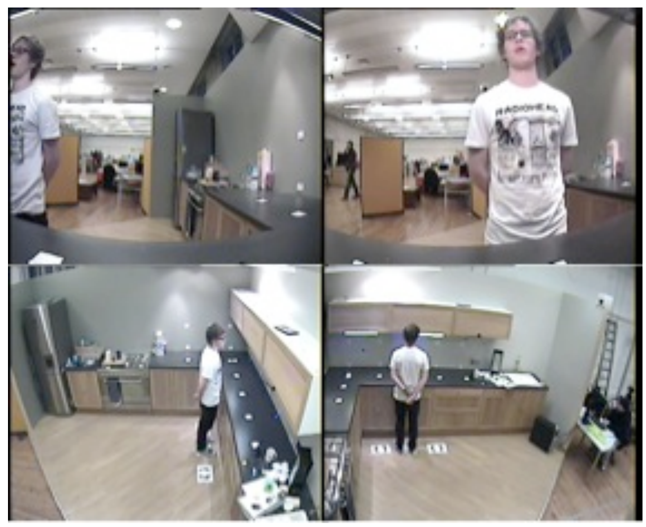

Figure 6. Simultaneously captured data from the embedded cameras allows us to develop a benchmark for attention detection algorithms based on tracking head pose and position from multiple viewpoints.

We yet have to complete any evaluations of this kind but we are planning to do so. For example, we will use actors trained using video recordings of people with dementia carrying out simple kitchen tasks such as making a hot drink. These recordings were made of people doing these tasks, which were of their own choosing, in their own kitchens. The intention is to make initial tests of algorithms to detect when these people need prompting because they have made an error or stopped in the middle of the task. It would be disorienting and therefore unrealistic to bring people with dementia into the lab but these existing videos can be used to configure the Ambient Kitchen to match the kitchen in the video and then to get an actor to perform the sequence of actions taken. Thus the teabags might be in a container on work surface, the milk in the fridge and the cup in the cupboard. The actor might then confuse the coffee jar for the teabag container, and so on. Another possibility we are considering is to simulate dementia in normal volunteers by giving them a secondary task that loads working memory (Morady & Humphreys, 2009). This has been found to produce errors that look very much like the executive function errors seen in people with mild to moderate dementia.

Figure 7. Initial evaluation of a food preparation support application incorporating a number of specially manufactured utensils with embedded accelerometers, and RFID tracked food.

5. DISCUSSION

The fact that every home is different and that different people have different ways of doing things, implies a need for practical ways of describing both home environments and tasks and then using these descriptions to automatically generate a pervasive computing system. A long-term goal of research based around the Ambient Kitchen is the development of a notation for this purpose and algorithms to generate a system from this description. The problem domain, prompting people with dementia through simple tasks in the kitchen, provides the essential practical constraints needed to make this demonstration convincing.

Indeed, although we describe a number of applications appropriate to new kitchen environments, prompting systems are of general value, and stand as an excellent example of how assistive technology research has the potential to push the boundaries of knowledge in a discipline and motivate new families of applications for all users. An analogy might be drawn with prostheses for sensory limitations. Contact lenses are almost invisible prostheses for vision that are unconsciously utilized by their users as they go about their daily lives. Pervasive computing offers the opportunity for cognitive prostheses that are equally invisible and equally useful. These prostheses will help us to carry out daily activities more safely and effectively, and the use of a high fidelity prototyping environment such as the Ambient Kitchen can only further this goal.

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