Attention-Based Design of Augmented Reality Interfaces

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ABSTRACT
The objects and surfaces of a task-based environment can be layered with digital interfaces to make them easier and safer to use. Once information can be projected anywhere in the space, it becomes crucial to design the information to make optimal use of users' attention. We have prototyped and evaluated a real-world augmented reality kitchen where user-centered interfaces and displays can be projected anywhere in the space to improve its usability. The augmented environment is designed to support the activities of a variety of people in diverse kitchen environments.

This paper presents five intelligent kitchen systems that layer useful interfaces onto the refrigerator, range, cabinets, countertops and sink. The interface design is driven by human factors, especially attention theory and user evaluations. By projecting interfaces where they require the least cognitive load, we hope to improve the performance and confidence of users. The design employs cueing and search principles from attention theory. We present the results of pilot studies and future directions for our work.

Author Keywords
Perception, Attention, Augmented Reality, Interaction, Smart Rooms, Projection Techniques, User Evaluation.

ACM Classification Keywords
H.5.1 [**Information Interfaces**]: Multimedia Information Systems – *artificial, augmented, and virtual realities*. H.5.2 [**Information Interfaces**]: User Interfaces – *user-centered design*.

INTRODUCTION
Domestic kitchens are technologically integrated laboratories where multiple users carry out different, complex tasks with numerous tools, work surfaces and appliances. The tools of the kitchen are numerous and complex, often requiring instruction before they can be used. The appliances rarely provide feedback on their status or prompt users for interaction. The kitchen is a dangerous environment where lack of information about the status of tools and surfaces can result in burns or cuts. Kitchens are natural candidates for augmented reality interfaces because there is a high need for users to remain in contact with physical reality while using a number of sophisticated tools that benefit from digital information [3]. Our smart kitchen assists users in determining temperatures, finding things, following recipes and timing various steps of preparing a meal. Useful information can be overlaid on nearly every surface of the space without interfering with their functions (see Figure 1). In each case, the quality and quantity of information projection needs to be tailored to the amount and type of attention directed at each task.

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Figure 1. Augmented Reality Kitchen: information projection on the refrigerator (1), the range (2), the cabinet (3), the faucet(4) and drawers(5).

RELATED WORK
DigitalDesk and the *DigitalDesk Calculator* demonstrate the ability to project digital information and controls on normal work surfaces [9]. *CounterActive* teaches basic recipes by projecting an interactive recipe on a kitchen counter embedded with a capacitive touch-sensitive array [2]. In both *DigitalDesk* and *CounterActive*, the projected information is limited to a single user at a single surface and can not project information where users actually direct their attention during many cooking tasks. The *Everywhere Display* is capable of projecting interfaces on nearly all of

the surfaces and objects of a space [5]. One kitchen of the future uniformly tiles the backsplash with LCD displays, microphones, cameras and foot switches [8]. But indiscriminately plastering the environment with video-quality projection does not consider the scarce resource of attention. Various projection techniques are suited to different scenarios in a graphically annotated kitchen [1]. For example, water temperature can be usefully inferred from the simple projection of colored light – red for hot and blue for cold. Full-color images can be a simple way to describe the contents of a refrigerator. Projection onto real-world objects can be an effective means of adding significance to digital graphical user interfaces [6]. Peripheral Displays Toolkit [4] describes the importance of weighing attentional demands in designing peripheral displays. We have proposed a series of interfaces that project attention-based task interfaces onto the refrigerator, cabinets, countertop, even the water and food being prepared. We discuss the design and implementation of each interface as inspired by attention theory, as well as the results of pilot studies in the space.

DESIGN

To design the augmented reality interfaces, we begin with a consideration of the user's attention and the best ways to present information in general. The interfaces were designed according to several principles of attention theory: exogenous cues, endogenous cues, and serial and parallel visual searching. Existing kitchen interfaces like the faucet handle or the dials on the range require users to focus their attention away from the task of using the water or cooking food in order to read or adjust the interfaces. In many cases (such as two-handed work) the interfaces require a user to interrupt their task. Since attention is a limited resource, moving the user's focus away from the center of attention even slightly can hinder task performance.

Augmented reality projection can show information and project interfaces directly on the task being performed. This type of exogenous attention cueing requires the least mental processing. In the case of the faucet, we project the temperature as a simple color on the water itself, eliminating the need to look at the faucet handle. For more complex tasks, we employ endogenous cues to direct attention as efficiently as possible. For example, when a recipe calls for the user to retrieve something across the room, we project the recipe in front of the user, an endogenous cue (like an arrow) mid-way between the user and their task, and finally an illuminated drawer handle where the user needs to place their hand to retrieve the object. Endogenous cues require more processing than exogenous cues, but have been shown to reduce reaction time by helping guide attention with respect to no cueing. Projecting attention cues wherever they are needed in the space can simplify tasks and increase user confidence (see Figure 2).

The system employs the principle of pop-out in visual search to speed up the process of locating individual items throughout the kitchen. Cooks must often perform a serial search within cabinets and of one cabinet after another when looking for a specific tool or ingredient. Serial search duration is directly proportional to the number of items being searched, whereas parallel search takes a fixed time within a certain quantity of items searched. To simplify the process of finding items the system allows the user to perform a parallel search where the desired object pops out through colored illumination of cabinets themselves. Even practiced users of the space might experience a reduced reaction time and more confidence when the objects to concentrate on are illuminated (see Figure 2).

Figure 2. An example of endogenous cueing (left) and exogenous cueing (right) in the augmented reality kitchen.

Virtual Recipe

For user evaluation of the Augmented Reality Kitchen, the system guide users through a step-by-step recipe inspired by the instructional methods employed in *CounterActive.* Instead of being projected on the countertop alone, two multimedia projectors display recipes on the cabinets in front of users as well as on the work surfaces of the range and counter. Users navigate the steps of the recipe by passing their hand in front of projected "virtual buttons" interpreted through a vision recognition algorithm (C++ program in Microsoft Vision SDK). Users with wet or dirty hands don't have to touch any surface as webcams detect the change in appearance of the buttons when the hand passes over them. Infrared proximity sensors along the edge of the countertop determine the location of users and help to project the Virtual Recipe directly in front of them. When a certain step calls for an item stored in the cabinets, the Virtual Recipe cues the appropriate drawer handle to illuminate (see Figure 3).

RangeFinder

RangeFinder is a remote infrared thermometer that measures the surface temperature of food in pans on the range and projects the food temperature and cooking time directly onto the cabinet, counter, cookware and the food itself. RangeFinder can determine when food reaches a desired temperature (for example, when water boils or when meat is cooked) and time the duration of the state, eliminating the need for to set a separate timer or use a thermometer. In addition to cueing the recipe steps, the temperature information is displayed numerically on the cabinet in front of the user as well as onto the range itself (see Figure 3).

RangeFinder is a modified commercial infrared thermometer mounted inside the range hood that communicates to a PC running Virtual Recipe through a PIC-based microprocessor (see Figure 3).

Figure 3. Virtual Recipe projected onto the cabinets and Rangefinder temperature on the hood.

FridgeCam

Users of a kitchen often open the refrigerator too often and for too long because they are unsure of its contents or layout. FridgeCam is an augmented reality interface that projects spatial information about the contents of the refrigerator directly onto the door for the purpose of reducing the duration and frequency of door opening. By capturing different views each time the refrigerator door is opened and projecting an image on the outside of the door, FridgeCam helps users locate refrigerator contents in three dimensions.

Figure 4. FridgeCam: projection on the refrigerator door (left), location of digital cameras (right).

FridgeCam consists of two wide-angle CCD cameras mounted to the inside of the refrigerator that capture images when the refrigerator light turns on and projects them with a multimedia projector. The current FridgeCam is limited to the vertical resolution of the multimedia projector that is shared with Virtual Recipe. Pilot studies reveal that a low-resolution display hampers recognition of the refrigerator's contents because users often feel more confident when they can read text on labels too small to be projected. The advent of high-resolution displays and projectors in combination with multi-dimensional projection like FridgeCam will allow highly insulating enclosures such as the refrigerator door to perform better at helping users find items than transparent doors (see Figure 4).

Augmented Cabinetry

One of the most time-consuming tasks in a kitchen is finding items in cabinets, when multiple people share a kitchen. While transparent cabinet doors can help identify the objects near the door, they add to the visual complexity of the space and can actually increase search time by increasing the number of items in the visual search. Augmented Cabinetry is a spatial user interface that reduces the time required to locate items in the kitchen cabinets without adding visual complexity to the space. LEDs embedded in translucent cabinet handles illuminate on cue from the virtual recipe system. If the required items are located far from the user, the system cues the final location with an arrow projected midway between the user and the item in question. Information on the user's location is gathered by the proximity sensor array along the countertop edge. The cues are timed to provide as much information as required depending on the experience and performance of a user. In the beginning, the handles illuminate continuously. Next, they start to modulate in brightness. If the drawer is not yet opened, an intermediary endogenous cue is projected midway between the user and the drawer. Finally, a projection appears in front of the user indicating the direction of the item with text and an arrow. In this way an expert user does not encounter needless information. If the cue is urgent, an auditory warning sounds as the last cue.

Figure 5. Augmented Cabinetry

Augmented Cabinetry works by a hard-wired network of illuminating drawer handles controlled by a PIC-based microcontroller through the Virtual Recipe system on a PC (see Figure 5).

HeatSink

How many times have you scalded yourself with hot tap water or wasted water while running it until it reaches a certain temperature? Users can only determine the actual temperature of tap water by touching the stream, which wastes time and cannot be done during a two-handed operation. HeatSink projects colored light inside the stream of tap water according to the temperature of the water. LEDs in the faucet aerator color the water stream blue when the water is cold and red when the water is hot. The intensity of the illumination varies with the distance from the threshold temperature. Dangerously hot water causes the red light to flash. The colored illumination projects the information directly where users need to see it, and allows them to make any necessary adjustments without wetting their hands or looking away.

HeatSink works through a solid-state sensor and a PIC-based microcontroller driving LEDs mounted around the faucet aerator. The reflective quality of a stainless steel sink enhances the ability of the colored water to illuminate the point where the water scatters, which is often the focus of the user's attention (see Figure 6).

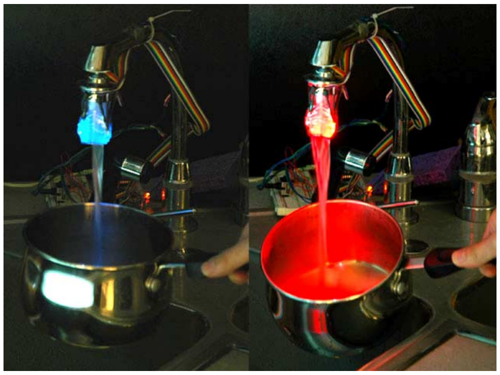

Figure 6. Heat Sink (right).

PILOT STUDY

We conducted a pilot study of the kitchen to shape the design of the augmented reality system. In the study, people were asked to familiarize themselves with the contents of the cabinets and refrigerator before executing a recipe with or without the augmented reality system. In one scenario the system helped people combine different steps into fewer. For example, when an user opened a cabinet to retrieve an item, a projection would appear next to the cabinet reminding them of all the ingredients they could get at one time. However, inexperienced users required more instruction than could be provided by simple recipes. This indicates that future versions must increase the information made available if the system detects that users are not completing a step. Since kitchens are used by people of diverse skill, the augmented reality system must provide multiple types of assistance based on the performance of a user. While ambient cues such as color-coding for temperature and illuminating drawers suffice for expert users, the system needs to add information for novices. If a drawer has not been opened, the system might switch to more and more central cues to direct users. Finally, an instructional video should be shown to inform new users of how to use specific machines or perform steps of a recipe. But showing these initially would over-burden the attention of expert users.

A questionnaire revealed that users preferred the illuminated drawers to remembering where items were located in the space. We hypothesize that providing visual cues decreases cognitive load even if a user knows were items are located because memory is a more complex process than pop-out in a visual search.

CONCLUSION

This paper presents an augmented reality kitchen with five user-centered spatial interfaces that project useful information by taking consideration of the user's attentional focus. Pilot studies and user evaluations reveal that spatial, attention-sensitive projections were most useful. Exogenous cues might increase user confidence in using tools, finding items and orienting themselves even in familiar environments. By taking account of a user's position and their performance we may be able to provide interfaces that do not interfere with tasks and account for the variety of skill levels and familiarity with a given space. This paper suggests that multimodal augmented interactions can enhance a variety of activities, including procedural ones.

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