Context-aware assistive devices for older adults with dementia

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A.Mihailidis, G. R. Fernie, Context-aware assistive devices for older adults with dementia, Gerontechnology 2002; 2(2): 173-188 There has been a significant increase in research into assistive devices for people with cognitive disabilities. The majority of this research has focused on the development of devices for younger adults who have learning impairments or brain injury. These devices have not been acceptable for use by older adults who have dementia. This paper will provide an overview of how the principles of context-aware design may be applied to the design of future assistive devices to make them suitable for older adults with dementia. Several examples of devices specifically designed for this population will be provided.

Keywords: Assistive devices, context-aware, design, dementia, older adults, elderly

Dementia is a common clinical syndrome in the older-adult population and is characterized by a sustained decline in cognitive function and memory. Eventually the dementia becomes so severe that it impairs a person's ability to work and perform common tasks in the home[1,2]. It is estimated that there are nearly 18 million people with dementia in the world, and by 2025, this number is expected to reach 34 million[3].

The effects of dementia on a person's ability to perform activities of daily living (ADL) tasks have been well-documented[4-7]. The current solution is to have a caregiver continually provide verbal reminders. However, this dependence is difficult to accept and often contributes to anger or helplessness. Family caregivers find assisting with toilet-related activities to be particularly upsetting and embarrassing as it necessitates invasion of privacy and role reversal.

Assistive devices are often used to offset the impact of physical impairments resulting from the aging process and related disorders[8,9]. Recently, recognition of the growth in numbers of people with dementia and the availability of affordable computing power have resulted in more research being conducted into developing assistive devices to address cognitive impairments. Several assistive devices that provide the verbal prompts that a person with dementia requires during ADL completion have been developed. Typically, these prompting systems have been inappropriate because they provided prompts whether they were needed or not, and the users were required to provide their own feedback on the completion of each required step. Such systems tend to add to the frustrations of the users and caregivers. It has been suggested that these limitations may be addressed through the application of more sophisticated computer science techniques, such as the use of context-aware design principles and artificial intelligence.

This paper will outline the application of context-aware design, and how it may be used to develop future assistive devices that will allow users with dementia to perform ADL more independently, without having to provide feedback to the system.

COGNITIVE ASSISTIVE DEVICES

Devices have been used to assist people with cognitive disabilities to complete various tasks for almost 20 years[10]. For example, there are several commercially available devices to help people take medication at the appropriate time. These devices are well known and range from plastic segmented pillboxes to electronic systems that have various levels of sophistication[11]. In addition, there are several electronic cognitive devices and recording devices. Examples of such devices are the IQ Voice Organizer™ by Voice Powered Technology International Inc, the ISAAC by Cogent Systems Inc, and the PEAT by Attention Control Systems Inc[12-14]. Software products that serve as cognitive devices also exist on the market, such as Easy Alarms® from Nisus Software Inc, Essential Steps from MASTERY Rehabilitation Systems, and various software tools from the Institute of Cognitive Prosthetics[15-17].

There have been numerous cognitive devices that have been developed solely for research and clinical testing purposes—i.e. they are not commercially available. Levine and Kirsch[18] developed a preliminary environment for developing cognitive devices. They used a specialized computer programming language called COGORTH (COGnitive ORTHotic) to develop devices that provided sequential messages to assist a person complete a complex activity. This technique was used by Kirsch et al.[19] to develop a computerized task guidance system to help a person control incontinence, and to perform a cooking task (i.e. follow the steps in a recipe). Following the same concepts, an interactive task guidance system has been developed to assist users complete janitorial tasks[20]. By others, several similar devices were developed[21-27]. For a general overview see[6,7].

APPROPRIATENESS OF TECHNOLOGY FOR OLDER ADULTS WITH DEMENTIA

The majority of these devices were developed for younger adults who had learning impairments or traumatic brain injury. They were not designed for older adults with dementia. Generally the devices required manual input and feedback from the user and were not able to sense the context in which they were being used or the user's preferences.

Many devices were not designed to automatically provide the feedback required to indicate that a required task has been completed, or that an error has occurred and assistance is needed[28]. A majority of previous generation cognitive devices (both research and commercial) relied on input from the user for feedback (for example, pushing 'OK' after a step). This feedback, and for some devices the expiration of a time limit, was the only information used to determine whether a corrective action was required. Such responding may be achievable for a person with a less severe cognitive disability, but is less likely to be completed by a person with advanced dementia because he or she may lack the required planning and initiation skills. Such users may neither remember what step they had been asked to perform, nor the need to indicate that the step had been completed[28]. In addition, the user often required knowledge of computerized systems, or required extensive training to become familiar with the technology, in order to provide the necessary feedback, and properly interact with the device.

Many of the frustrations of today's software are often due to the program-taking actions that may be right given the software's assumptions, but wrong for the user's actual context[29]. For example, an automatic medication reminding device that plays a verbal prompt at a pre-specified time does not consider the context within which the device is being used and the place, mood, and needs of the user. What if the user is not in the same room as the reminding device, or has already taken the required medication 10 minutes before the reminder was to be issued? Since the device has not realized these changes in context, the reminders become inappropriate and ineffective, and in the case of the second scenario, could result in a dangerous situation if the person takes the medication a second time because of an inappropriate prompt. Another common example is a device that provides unnecessary reminders. Several past devices were programmed to give a reminder for every step in a task that a user needed to complete whether the reminder was needed or not. If a user had already successfully completed the step, the device still prompted the user to complete it. This may result in the user becoming annoyed and frustrated.

CONTEXT-AWARE DESIGN

There is no common way to acquire and handle context, and to apply these concepts in the design of computerized systems. In general, the use of context-aware design has been handled in an improvised manner, where application developers choose techniques that are the easiest to implement, and the most appropriate for the application[30]. The following is an overview of several concepts that have been applied in the design of context-aware assistive devices for older adults with dementia.

Overview of Concepts

The traditional approach in the development of computerized systems has been the concept of using a black box—i.e. functions, predicates, subroutines, I/O systems, and networks, which process input and provide output with the user not playing a significant role in these processes. Something goes in one side and something comes out the other side, and the output is completely determined by the input. This view of computer science is now being seen as too restrictive, and has started to change and be expanded to take into account context as an implicit input and output to the application. This new view allows the application to decide what to do, based not only on the explicitly presented input, but also on the context in which the system is being used, including time, place, weather, user preferences, or the history of interaction[29].

Moving away from the typical black-box model allows for two primary improvements to be made to computerized systems. First, the amount of explicit input required from a user can be reduced, if not removed alltogether. Explicit input from a user is expensive; it slows down the interaction, interrupts the user's train of thought, and raises the possibility of mistakes. The user may be uncertain as to the type of input that is required, and may not be able to provide it all at once. Second, explicit output from a computational process is not always desirable, especially when it may not be appropriate. For example, output from the system places immediate demands on a user's attention, which may interrupt the user's train of thought and raise the possibility of mistakes[29].

Many aspects of the physical and conceptual environment can be included in the notion of context. Time and place are some obvious elements. Personal information about the user is also an important part of context: 'Who is the user?', 'What does he or she like or dislike?', 'What does he or she know or not know?'. In addition, history is part of context. What has the user done in the past? How should that affect what happens in the future[29]? Context can be defined as any information that can be used to characterize the situation of entities (whether a person, place, object) that is considered relevant to the interaction between a user and an application, including the user and the application themselves. Context is typically the location, identity and state of people and groups, and computational and physical objects[30]. Context can be used to interpret explicit acts, making communication much more efficient and naturally fitting with a user's ongoing activities[31].

Context-aware systems sense or remember information about the person in order to reduce computer-user communication and effort[32]. This information is obtained via input that is measured from the environment such as the location of a user, type of environment in which the device is being used, and resources that are nearby, such as tools, objects, or other people.

The general challenge in context-aware design is to identify the set of relevant features that best define the situation or environment, and then to make use of these features effectively. Several researchers have developed models and 'tools' that have been used to assist in determining these features and incorporating them into new systems. The primary objective is to provide some structure for the consideration and use of context in the development of new computerized systems[33].

Two parallel trends in hardware and software have allowed for the emergence of context-aware computing. On the software-side, the movement toward 'software-agents' (software that perceives and acts) and the use of artificial intelligence techniques has allowed for the reduction in complexity of direct-manipulation screen-keyboard-and-mouse interfaces by shifting some of the burden of dealing with context from the human user to the software[29]. Smaller computation and communication hardware, and less expensive sensors and perceptual technologies make embedded computing in everyday devices more practical and easier. This gives new devices the ability to sense the environment in which they are being used, and to make decisions using that information.

The primary job of the software agent is to understand the intent of the user, which can be achieved by either asking the user, or by inferring this information from context. In order to use context to infer this information, the software agent has to be able to use existing knowledge, which already may be previously embedded by the programmer, and generalize it by removing some of the details of the particular context so that the same or analogous experience will be applicable in different situations[29]. This can be achieved through various techniques; the most often used being via 'programming by example'. This technique couples a learning agent with a conventional direct-manipulation interface, such as a keyboard, touch screen, or the use of sensors that directly monitor the actions of a user. The agent records the actions performed by the user, which are one important aspect of the contextual information that will be used by the system to produce a generalized program. Generalization can be achieved through various knowledge-based methods and statistics, which help to detect patterns and regularities in data. The algorithm used is largely based on the specification and requirements of the overall system.

For example, a system that requires processing of data to occur as close to real-time as possible may use a neural network, or a parallel processing algorithm, which tends to be computationally faster than traditional programming techniques. In addition, these observations of the user can be recorded and analyzed heuristically to compute a profile of a user's preferences and interests, such as a preferred sequence of actions during a particular task. The user profile is then used as context in future applications. In addition to inferring information from these explicit inputs and data, context-aware computer systems also make use of implicit models of context that are used to explain the explicit inputs and to assist in the generalization of these data. In turn, explicit inputs help to modify this implicit knowledge as necessary, for example when a user's task preferences or abilities change, primarily through the use of simple IF-THEN rules used to specify how the context-aware system should change[34].

Recently a model was described[29,32] that can be used to interpret input from the environment. This model includes creating, maintaining, and using information about the task, the user, and the system. It helps the context-aware system to interpret the explicit inputs from the environment. The computerized system must remember things about a person, the way the system has worked in the past, and the way a person is trying to engage with the system in the present. This model is comprised of three interacting elements: task, user and system. Task models are the acts that a person performs to accomplish a goal with a system. For example, this may be something as simple as opening a door to travel from one room to another, to something as complex as all of the steps required to successfully use the toilet. A user's task model is based on the changing beliefs, preferences, and abilities of the user, which can change over time thus requiring updating as necessary[29]. User models have been applied extensively to identify a user based on stereotypical characteristics, such as age, sex, health, visual acuity, and mobility. These attributes can be used to adjust various parameters of a system accordingly, such as adjusting the parameters of a computerized database search tool according to the type of user[35]. For example, with respect to a prompting system, the gender of the voice used to provide the prompt can be changed according to whether the user is male or female. The user model consists of task-relevant background information about the user, which is typically affected by habit, personal preferences and tastes, and sometimes issues of motivation[32]. The system model refers to the capabilities of the computerized system, including its structure and ability to accomplish a task. This includes 'remembering' how the system has reacted to various scenarios and changes in the task and user models in the past, and using this information to adjust parameters accordingly[32]. The interaction of the elements in this model with the context-aware system is illustrated in Figure 1,which is an adaptation of the model originally presented by Lieberman and Selker[29].

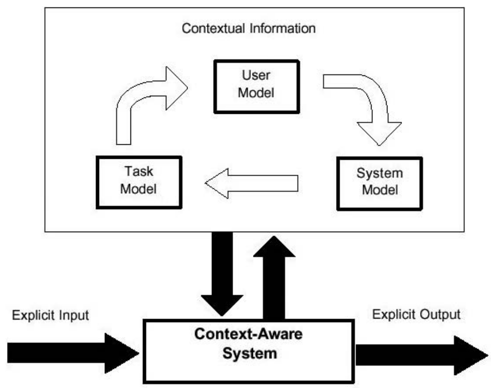

Figure 1. Explicit input from the environment is explained through the use of contextual information that is stored by the system according to the task, the user, and the system. The three elements are updated as necessary by the system in order to maintain up-to-date information as the environment and user change. In addition, the three elements must interact with each other in order to ensure that changes that may occur in one model do not negatively impact information stored in another, such as making other information out of date or redundant.

Schmidt, Beigl, and Gellerson[33] also defined and decomposed a working model for context-aware design. A hierarchically organized feature space for context was developed. At the top level, context was distinguished by factors related to human factors and those related to the physical environment. These factors are then further decomposed into relevant features. Human factors related context includes three categories: information on the user; the user's environment, including co-location of others, group dynamics, etc.; and the user's tasks, such as spontaneous tasks, engaged tasks, and general goals. Physical environment related context includes another three categories: location (absolute and relative positions), infrastructure, such as surrounding resources for communication, and physical conditions, such as noise, light, pressure, and temperature. Other models and guidelines that use similar principles have also been published[34,36].

Sensors allow a system to learn the state of the world and to continuously update its own model of the world without the need of a human operator[37]. The use of sensors to obtain context information is common in robotics and machine vision applications, and with the advances in sensor technology it has become affordable to use similar sensors and techniques in other applications[33]. For example, biosensors have been used in wearable computers to determine a user's level of attention and emotional state; simple audio sensors have been used to obtain information on whether a user was interrupted during the completion of a sequence of steps; and location sensors have been used to determine the states and locations of other objects in a user's environment[33].

Determining context requires more information than is supplied directly by single sensors. Contextual information at a level of abstraction that relates more to situations can be achieved through the fusion of information gathered from multiple simple sensors[33]. Multisensor fusion refers to the combination of sensory data from multiple sensors to provide more reliable and accurate information about the environment[38]. Fusion is a major factor in enabling some measure of intelligence to be incorporated into the overall operation of a system or device, so that it can interact with and operate in an unstructured environment[37]. The use of redundant information can reduce overall uncertainty and allows features in the environment to be perceived that would be impossible to determine if information from individual sensors were only used. Information about the user's actions can be obtained with less time delays by multiple sensors due to either the actual speed of operation of each sensor, or the processing parallelism that may be possible to achieve as part of the integration process[38]. Techniques and more detailed information can be found in[39-42].

PREVIOUS USES OF CONTEXT-AWARE DESIGN

The use of context-aware design has been emerging in several different fields, including robotics, mobile computing devices, online help systems, web browsing technologies, and supportive environments and smart homes. We have also started to see an increased effort in ubiquitous computing, emergent computing, and ambient computing, as principles from these areas of computer science have started to play a larger role in context-aware systems by helping designers develop more advanced computerized sensing systems. The following are some examples of how these techniques have been applied.

Several new devices not only look at where the user is, but also take into consideration the user's wants, preferences, and past performances. For example, computers online help systems have been developed using these criteria. These systems have been labelled as context-dependent help systems, because they provide help that is relevant to the commands and knowledge currently active. An example is a system called the Cognitive Adaptive Computer Help system[29] that used task, user, and system models to improve the kind of help that it provided as a user learned how to program. This system was able to help users to improve their programming abilities because it was able to track user experience and levels of expertise, and use this information to decide what level of help to provide.

The concept of context-dependent help has also been used in the development of new supportive environments and devices. These environments adapt and interact with an occupant based on where the person is and his or her preferences. For example, several interfaces and devices have been developed at the MIT Media Lab's Context-Aware Computing Lab that use sensors to automatically detect context and augment the environment. One example is the intelligent couch, which invites the user to take a break to wait for something to happen. The couch orients the person, suggesting what he or she could do during the break. If the person is wearing a specially designed personal digital assistant (PDA), the couch points out specific user information that is relevant to that individual, such as when the person's next meeting is and where it is located. A similar device was developed using a bed with computing capabilities[29].

Several attempts have been made to develop rooms, and even complete houses, that are able to determine the context of the occupants and use this information to adapt. The prospect of computerized homes and home automation has been well publicized. However, these systems have never been very popular because the benefits are seldom seen to outweigh the costs, such as the time it takes to manually program the various devices. Mozer[43] developed a house that adapts to its inhabitants. This particular environment used context-aware design principles and various sensors to have the home program itself by observing the inhabitants. Using these observations, the house's systems learned to anticipate and accommodate their needs with respect to various environmental factors, such as heating, cooling, and lighting. Franklin (1998) developed an intelligent classroom. The system used video cameras and microphones to sense a user's actions and associated software to infer what actions to take to best satisfy the user's desires, for example controlling the setting of the lights, playing videos, displaying slides, or whatever else was appropriate. At all times the classroom considered the perceived intentions of the speaker when it decided which actions to take[44].

Some cognitive devices have been developed using context-aware principles. Several researchers have been looking at the problems associated with gathering the required information and developing an accurate context model using simple sensors and switches attached to various objects in the user's environment[45-47]. Other researchers have used simple sensors to gather information that can be used in a cognitive device[25,48,49]. Cognitive devices that use context-aware principles are also being developed for the mainstream population. Beigle[50] has developed the MemoClip that communicates with location beacons at places of interest in the environment, and DeVaul[51] has developed Memory Glasses, which detect objects, locations, or people by sensing transmitters or 'tags' in the environment. These tags are placed on landmarks or worn by people.

DESIGNING FOR OLDER ADULTS WITH DEMENTIA

The goal when designing a new cognitive device for older adults is to deliver the maximum amount of information transfer to the user under conditions of minimum cognitive effort. It is imperative to find an appropriate match between the needs and the abilities of the older adults and the design and capabilities of the technologies[8].

The first step in designing a new device for older adults, as is the case in designing for any user population, is to determine more about a users' needs, functional capabilities, attitudes, and perceptions as well as their physiological and psychological parameters. Although it is often noted that the older adult population is heterogeneous, it is useful to specify some of the sensory, motor, and cognitive limitations experienced by sizable percentages of this population[52]. Age-related hearing and visual deficits are common, and the ranges of such deficits differ between men and women. Reaction times become longer, mobility impairments become more common, and decreases in strength occur for many older adults[52]. Loss of working memory becomes more prevalent with age, often making it difficult to remember complex sequences of instructions. Older adults also may be more distractible and have difficulty both directing and inhibiting their attention in relation to irrelevant information. This is especially problematic in dual-task situations and when attention needs to be split between multiple sensory modalities - for example, following verbal prompts while using a visual display to provide explicit feedback to a device[52].

The past several years have seen a number of projects with the goal of developing new devices that meet the needs of older adults, who may or may not have a cognitive disability. However, this research has tended to focus on a user's personal competence, such as motor and cognitive skills. Far less consideration has been given to social, emotional, and environmental needs. Failure to consider these other aspects when designing for older adults may pose difficulties in the adoption and potential usefulness of new products and technologies[53]. In addition, the importance of cultural context needs to be addressed but little has been published on the topic.

The needs of elderly individuals are extraordinarily diverse, in part due to the specific effects of various impairments[54]. Furthermore, changes within an individual user may also occur affecting their capabilities and their needs from a device. It is quite common for a person with dementia to have very different needs and abilities from one day to another. There cannot be a one-size-fits-all approach to address the needs of every individual; instead, design must take in account the unique needs of each user, and fluctuations in those needs.

Applying Context-Aware Design

Context-aware design can be used to develop assistive devices that apply these needs, in addition to other important information such as the location of the user, his or her mental and physical state, and the task the user is completing, to name a few, when making decisions and providing assistance. The specific contextual information that needs to be applied is contingent on the type of persons that will be using the device (including type of dementia, level of severity, and other cognitive and physical impairments), the task for which the device will be used, and the environment within which the user and the system will be operating. These can be determined via various human factors (or ergonomic) techniques and tools, which are beyond the scope of this paper.

Basic principles, such as the use of task, user, and system models, can be applied to help reduce the amount of interaction that is required between the user and the system, and apply various types contextual information. A task model can be used by a device to learn about the way that a user wants to complete a certain task and adjust itself appropriately. Familiarity and habit are very important aspects in a person's ability to perform certain tasks. We all have certain ways of completing a task, and it is that familiarity and habitual nature that sometimes provides intrinsic cues when we forget what to do next. This notion of familiarity is very important when helping a person with dementia to complete a task, or remember an event. A user model can be developed for each individual user to take into account information about the person, such as gender and relevant health indicators. For example, relevant information for an older adult may include that he or she is hard of hearing. A cognitive device could use this parameter to adjust the volume of the verbal prompts that it provides. Like other parameters, these indicators are dynamic and would be adjusted by the device as the person's abilities and preferences change. Finally, a system model can be developed to maintain a record of how the person has responded to the device in the past and to adjust other system parameters accordingly, such as increasing or decreasing the device's response time to an user error.

These various models and the ability to adjust them automatically will allow older adults who may not be familiar or comfortable with technology to interact with the system without any extra required effort or cognitive functioning. In fact, if designed properly, the users would not even realize that they are interacting with the system, unless the system provides some type of feedback, such as a verbal prompt.

Environmental sensors and vision systems can monitor the activities that a user is completing and predict what the person wants to accomplish. This information can automatically update the device's task model and determine the success/failure rate of the user in order to update the system model. In addition, physiological devices can be used to measure various health indicators, such as heart rate, to automatically update the user model with respect to health status and other vital parameters. Other automated techniques can also be used such as speech recognition to determine if the person is having trouble hearing or seeing objects. For example, if the device detects that after playing a verbal prompt the user has replied: "What's that, I can't hear you", it can use this information to update the user model parameters that are relevant to hearing impairment and increase the volume of future verbal prompts. Simple explicit techniques can also be used to initially develop the user model. For example, the device could ask a caregiver, therapist, or family member to answer a few simple questions about the user, such as the user's type and severity of dementia, level of hearing and vision impairment, mobility issues, and the other age-related limitations. The device would use the answers to these questions to develop a stereotypical profile of the user, which it would use to determine initial starting points in its operation.

The type of instrumentation that is used to collect data needs to be considered very carefully. As is the case when developing a task model that reflects the preferences of the user in order to maintain familiarity, the instrumentation selected should not alter the user's environment. For example, if a sensor is to be placed inside a water tap to determine if it has been turned on, the sensor must not alter how the water tap is normally operated. In addition, the instrumentation must be unobtrusive. Sensors and markers that need to be worn by a user need to look familiar and not impede the performance of the user.

Finally, context-aware design can be used to develop a cognitive device that acts more like a human caregiver. This includes taking into account various parameters that a caregiver would when monitoring and providing assistance to a patient. The device needs to learn about the various characteristics of the user, such as how long he or she should be left alone before intervening when an error occurs—i.e. given the opportunity, some people may be able to correct their own errors without any type of intervention. The device must provide the user with the same level of dignity that a caregiver would, and allow the user to remain in control of his or her environment and activities—i.e. the device must allow the user to do as much as possible independently before intervening.

EXAMPLES FOR OLDER ADULTS

In recent years, context-aware principles and new sensing technologies have been applied to increasing the opportunity for people to 'age in place'[55]. It is thought that through the careful placement of technological support, older adults can continue living in their own homes longer. This means that new devices, or environments, must recognize and accommodate the declining abilities of a person, while at the same time take advantage of those abilities that remain. The following are three examples of projects using these principles to develop cognitive devices for older adults.

The Aware Home at the Georgia Institute of Technology is a prototype that is currently being used as a 'living laboratory' for the development of context-aware computing in support of home life[56]. It is an intelligent environment, consisting of several cognitive devices that can: 1) automatically recognize crisis situations and act appropriately; 2) support everyday cognition; and 3) provide awareness of daily life and long-term trends[55,56]. The house has a wide range of sensing equipment, including video cameras, microphones, infra-red detectors, radio-frequency detectors, sonar, tactile sensors, and sensors to monitor utilities and appliances. The goals of this hardware are to automatically and unobtrusively measure activities of the residents and provide support for their daily needs and activities. Within this facility, a prototype device was developed that monitored and supported a user during an activity of daily living (ADL), while not impeding the flexible execution of the required tasks. The system used several video cameras to monitor the progress of a user during a cooking task, and provided visual reminders whenever he or she had forgotten which step was being completed, or if a step was left incomplete[55]. All of these images were presented on the graphical user interface with the hope that if the user forgot which step was just completed, or was interrupted during the activity, they would be useful in reminding him or her of what to do next[57]. Preliminary evaluations of the system were very encouraging and have prompted the researcher to continue developing this system.

The Bath Institute of Medical Engineering (BIME) has been developing various context-aware devices that are being incorporated in a residence for older adults with mild dementia, called the Gloucester Smart Home[58]. These devices include bath and basin monitors and a nighttime guidance system. The bath monitor checks on the water level in the bath and the water temperature. If the user turns on the taps it will monitor the water level. If the user goes out of the bathroom it will wait until the water level has reached a reasonable height and will then provide a reminder to the user. This may be in the form of a verbal reminder, possibly using a pre-recorded verbal prompt. If the user still does not respond it will turn off the taps after about another minute and let the user know[59]. The night-time guidance system uses a pressure sensor underneath one of the bed legs. The sensor is able to detect when the bed is occupied. If it is dark and the resident has been settled in the bed but decides to get up, the system will provide some guidance. It will initially fade up the bedroom light or bedside light. If the resident leaves the room the toilet lights will fade up and the bedroom lights fade down. If the resident goes into the toilet and then comes out again the bedroom lights will fade up and the toilet lights fade down. Once the resident is settled back in bed the bedroom lights will fade off again. It is planned to add verbal prompting to this system (at time of publication this feature has yet to be added).

Mihailidis, Fernie and Barbenel[7] developed a cognitive device for people with dementia. It is a prototype of an intelligent computerized device that was developed to assist people with dementia complete activities of daily living (ADL) with less dependence on a caregiver. It uses artificial intelligence (AI) algorithms and a single video camera to monitor progress, determine context, and provide prerecorded verbal prompts when necessary. For example, if the person forgets to turn off the water the device prompts him/her to do so. The device has the capability of adjusting its parameters and cueing strategies to meet the changing needs and preferences of each user, including the amount of detail that is provided in the verbal cues. This is based on a system model that maintains the success rates of each individual user. In addition, a task model is used to determine the preferred sequence of steps for each user. An in-depth user model is not used in this prototype. Figure 2 is a schematic of the device operation.

The video camera (A) was used to find the two-dimensional (x and y) coordinates of a user's hand using a tracking bracelet worn on his/her dominant hand. Tracking was accomplished using a pattern matching algorithm (B) and an artificial neural network (C). These coordinates were used as input to the agent program, where they were analyzed and classified into corresponding categories or step identification numbers—i.e. each step in the ADL was defined by a set of coordinates, or location of the user's hand[7]. Once the program determined the step the user was completing, it found which plan he was trying to complete by conducting a search through a pre-existing plan library. A plan recognition and planning algorithm (D) achieved this. If the user changed the sequence of the steps required to be completed but could still reach the final goal, the pro-

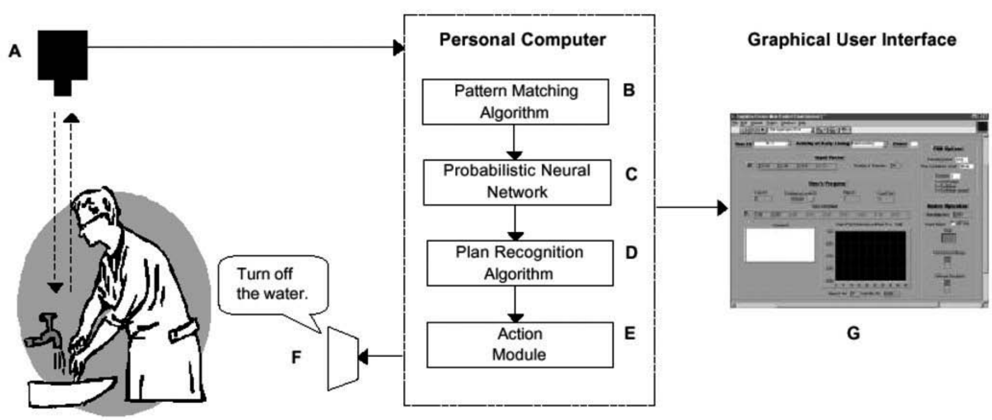

Figure 2. Device Operation. The operation of the device consisted of a video camera (A) and associated software (B) that tracked the position of a user's hand, and software that was used to determine the sequence of steps the user was completing and to deliver an appropriate verbal reminder over a set of stereo speakers (C, D, E, F). Information about the device operation and the user was displayed on a graphical interface (G).

gram adapted itself to guide the user through the new sequence. If a match could not be found, the program attempted to predict which plan the user was trying to complete using all of the user's correct inputs up to that point, and hence which step he should be performing. If the user made an error, such as completing a wrong step, or performed a step out of sequence, the action module (E) selected a pre-recorded verbal cue and played it over speakers inside the environment (F). If necessary the device repeated the cue after an interval. The level of description provided in the cue was adjusted as required; i.e. the next issued cue would have more description with respect to how to complete the step, such as location or colour of an object, or addressing the user by name if this was deemed appropriate using information from the user model. If the user did not respond to any of the cues issued, the device stopped and called for a caregiver to give assistance. Information about the user's progress, and actions taken by the device were displayed on a graphical user interface (G) located outside of the environment[7].

The system was installed inside a test washroom located on the long-term care unit of Sunnybrook & Women's College Health Sciences Centre (Toronto, Canada), and tested with 10 subjects with moderate-to-severe dementia. These subjects attempted to wash their hands with and without the assistance of the device in a study lasting 60 days. These trials showed that the device was able to decrease the dependence of the subjects on a caregiver during this ADL. The number of handwashing steps that the subjects were able to complete without assistance from the caregiver increased overall by approximately 25 percent when the device was present. Individual changes ranged from approximately 10 to 45 percent. These changes were proven to be statistically significant at a 99 percent confidence level[7]. The overall system operated with relatively low error with respect to performing the appropriate function in response to a user's action(s) (approximately 3.5 percent). The device was able to monitor the actions of the subjects, determine which step was being completed, and decide whether corrective action was required while taking into account the various contextually aware information previously described. The AI algorithms used to adjust the various parameters seemed to have worked efficiently and properly. It was observed that the level of cue detail was properly adjusted according to each subject's own performance, preferences, and past responses to the cues. The subjects ignored several cues from the device, and sometimes it was observed that they were not able to fully understand the directions they were being given. Overall, 45 percent of the verbal cues played by the device was ignored; however, it was observed that the proportion of ignored cues significantly decreased (from 55 percent to 20 percent) as the device learned about each individual user and updated the required context models[7].

Beyond these three examples, new research to develop context-aware cognitive devices for older adults includes work by Pollack[60] and Kautz et al.[61].

THE FUTURE

Context-aware design in future applications will be applied not only to new devices that help a person perform cognitive tasks (such as those described in this paper), but also to mobility, sensory, and perceptual tasks. For example, Slevin[62] is developing a walker that helps a user navigate safely using information gathered from various environmental and proximity sensors. We envision extending this technology to powered wheelchairs. Many older adults with cognitive disabilities are not allowed to use a powered wheelchair because of safety concerns—they may not be able to navigate the chair and avoid obstacles safely. Those who are allowed to use powered wheelchairs sometimes do not make use of them because they lack the motivation to explore their environments. The first issue of safe navigation can be solved using anti-collision devices that use models of the environment and prespecified constraints to not allow the user to drive the wheelchair into another object, person, or unsafe situation. The importance of context-awareness is emphasized by the need to recognize that the absence of an obstacle in the field of view of the sensor does not exclude the possibility of falling down stairs. The second issue of lack of motivation is where context-aware tools could have the greatest impact. These techniques can be used for the wheelchair to develop models of the user's preferences, environment, and context. Using this information the chair may then know where the person is situated, what, or who, is nearby, and even the person's daily schedule. Verbal prompts can then be provided to the user of the chair to provide motivation to explore the environment. For example, the user can be prompted to drive somewhere and visit with a friend, or the chair can realize that it is 10 minutes before lunch and prompt the user to start driving towards the dining hall. Similar techniques can be applied to everyday safety devices, such as handrails. If the environment senses that a person who is prone to falls and other balance difficulties is not using the handrail, verbal reminders can be provided to do so. Finally, context-aware design can be applied to home and health monitoring, especially in the area of emergency response systems. Current systems rely on a user to manually push a button on a device in order to seek medical attention from a live operator. However, if the person is unconscious or unwell enough to manually push the button then the system becomes useless. Context-aware design might be used to develop systems that can automatically detect a medical emergency using various types of sensors, and communicate with the required emergency agency automatically. If the system detects that the situation is not medically related, but that the person has perhaps become confused, it might be able to provide the assistance required before making a call to a live operator.

The authors are engaged in a collaborative effort between research centres in Canada and the United Kingdom to explore these possibilities and design context-aware assistive devices for older adults. For example, researchers at Simon Fraser University in Vancouver, Canada, have started in the development of a new context-aware medication reminding/dispensing device. We expect a first prototype to be completed by June 2003.

Context-aware design and advanced computer science techniques have now provided an opportunity to develop assistive devices that are more intelligent and sensitive to the needs and preferences of each individual user. Extensive training and setup times should no longer be required to customize a device for a particular user. These tools and techniques should allow us to make new devices that act more like a human caregiver when providing assistance, have the ability to continually learn about the user, and have the potential to 'grow' with the person through life stages. This should result in the acceptance and use of more devices, which in turn will help older adults to be able to function more independently, and remain in their own homes and communities.

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