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REMOTE CARE FOR ELDERLY PEOPLE SUFFERING FROM DEMENTIA: A NOVEL INFORMATION SYSTEM DESIGN

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ABSTRACT

This study presents a novel design for an information system featuring workflow technology. The system enables formal or informal caregivers to remotely monitor and assist elderly people suffering from dementia in a smart kitchen environment. The system uses an industry-standard workflow language to assist in modelling and executing cooking activities. It introduces a novel approach for incorporating context-awareness in the workflow process models. The models themselves can be graphically designed and are directly machine readable. A systematic literature review was conducted to investigate the detailed functional requirements of elderly people suffering from dementia, and their caregivers, and to discover what they expect from assistive technologies. With a combination of quality function deployment and scenario-based methods, the identified functional requirements were applied to the designed system. A pilot test was conducted to ensure that the designed system functioned as specified.

KEYWORDS

Workflow technology, smart kitchen, assistive technology, dementia, remote caregiver

1. INTRODUCTION

A declining birth rate and an increased life expectancy have accelerated the aging of populations worldwide [7]. As the prevalence of dementia is known to increase with age, accelerated aging of the population is leading to increasing medical, social and economic challenges [17]. Assistive technological solutions offer an opportunity to alleviate the growing demand for specialised treatment for people suffering from memory impairment. These solutions can improve the quality of life for individuals as well as being financially beneficial for the health care system [8]. Another important aspect to consider is well-being of caregivers. Caregivers undergo stress and difficulties in caring for people with dementia that emerge from factors such as isolation and time demands [9]. When new technological solutions are designed for elderly people suffering from dementia, the needs of caregivers are often not taken into account. In the case of informal family caregivers, the priority is to look for practical solutions that enable a better balance between care giving and personal tasks [2]. There can be several other types of caregivers such as doctors, nurses or even police and emergency service workers [11].

The SmartFlow system design presented in this paper can help lessen stress and difficulties experienced by caregivers by aiding the provision of care between family members and formal caregivers [8]. Our research focused on developing the smart kitchen concept, which offers remote cooking guidance for elderly people suffering from mild to moderate dementia [6]. It provides a novel design for an information system that enables a formal or an informal caregiver to remotely monitor and guide any type of activity in a kitchen environment. The workflow technology used in this research enables real life activities to be modelled graphically into directly machine-executable processes [13]. In addition, our research suggests a novel approach for making the workflow process models context-aware.

The research follows design science research (DSR) framework where the research artifact is the designed information system [4]. The system was designed according to categorical functional requirements collected regarding elderly people suffering from dementia, and their caregivers, using a systematic literature review. Quality function deployment (QFD) and scenario-based methods were used to find optimal technical solutions, while taking into account the opinions of elderly people suffering from dementia. The developed system was pilot tested to validate technical feasibility.

2. RELATED RESEARCH

It is important to understand how technology can be used to assist elderly people suffering from dementia. In addition, it is imperative to include people suffering from dementia and their informal or formal caregivers in the design process [11]. Elderly dementia sufferers and their caregivers list the following as requirements for assistive technologies: reliability, affordability, privacy, portability, having multimodal input/output, being provided with sufficient written and verbal instructions and being easy to learn [1,7,10].

Because it is difficult to form a profile for an average dementia sufferer, due to the diverse nature of the physical and cognitive symptoms [14], it is reasonable to assume that the designed system should give priority to individual customization. Indeed, customization and the ability to adapt to a changing condition were features regarded as important by elderly people suffering from dementia and their caregivers [8]. The concept of a 'workflow' originally comes from the idea of automation found in business processes. It is designed to improve the efficiency of daily work in a controlled and logical manner through the use of information technology [15]. This concept has gradually expanded to be applied to the process of problem solving [10].

XPDL (Extensive Markup Language Process Definition Language) is a powerful standard language that enables a workflow engine to directly execute graphical human-designed workflow models [13]. XPDL also enables the distributed execution of processes through the use of pools to define different participants in the process execution. These participants can be in different run-time environments, or different human participants, in the case of the abstract business process. A single workflow can have multiple conditional execution paths, divided across different environments and users, allowing a very high level of customization [16]. An example of a graphical representation of a workflow process model is shown in figure 1.

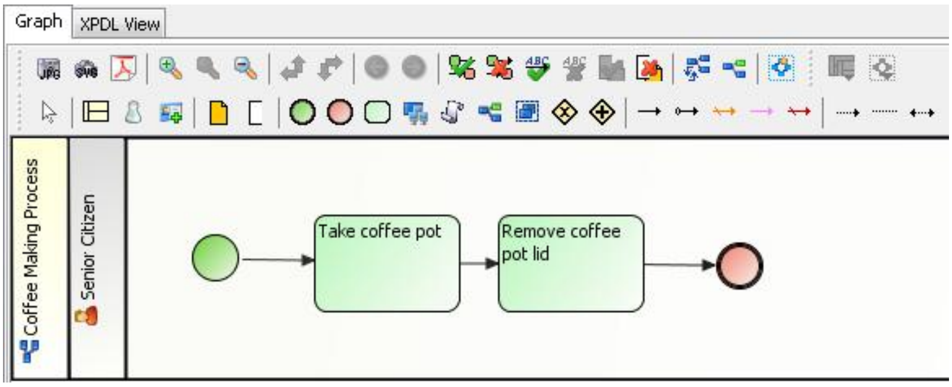

Figure 1. An example of a workflow process model

Workflow technology has been successfully applied in the smart kitchen context [3]. In contrast to this research, previous approaches have focused on an automated system where machine-triggered events, received from a kitchen environment, were used to control a workflow. Use of sensors in this manner reduces the amount of user interaction required. The disadvantage of this system is that manually specifying trigger conditions can be cumbersome and almost impossible in environments that are not known at the time when the workflow is being designed [3]. A typical smart kitchen is equipped with graphical displays and speakers used for providing assistance and prompts, and with cameras and microphones to capture situations around a supported user. Wearable cameras and projectors can cause discomfort for elderly people, implying that prompting devices should be in fixed positions as a part of the smart kitchen environment [6].

3. SYSTEM DESIGN

Scenario-based method was used to devise potential use cases and the QFD method was used to find the most suitable technical solutions, leading to the architectural design for the system, as illustrated in Figure 2. A caregiver client connects to the workflow server and loads the application for controlling a desired workflow. Once the application is loaded, the application initiates itself without the need for interaction from a caregiver, and connects to the video/audio stream component in the smart kitchen server. There can be different user groups with different access permissions for the smart kitchen environment. This is controlled by caregiver authorization when connecting to the workflow server. This leads to better control of privacy and security for an elderly person suffering from dementia.

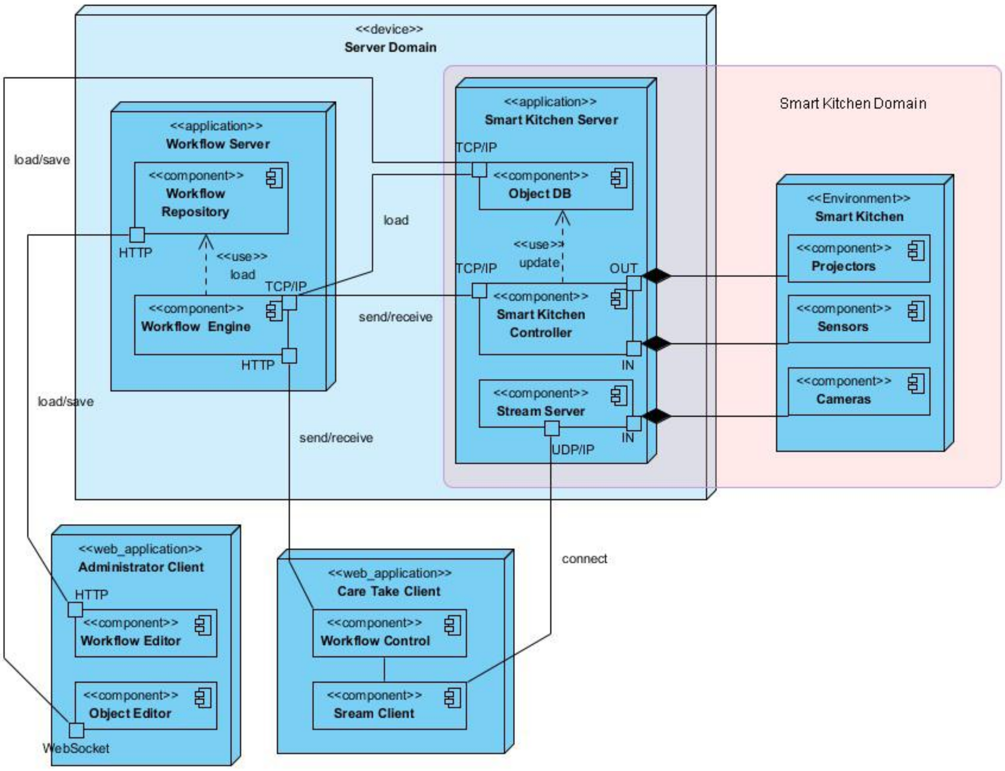

Figure 2. The architectural design for the SmartFlow system

The caregiver client application can be run in a web browser, which is supported by both handheld computer devices and desktop PCs. The client application can be used to either observe or control the execution of the workflow process. A connection between the workflow server and the smart kitchen server is established when a workflow model is being loaded. The workflow server draws context information from the smart kitchen server using a novel XML-schema design. When the workflow model is being executed, the workflow server sends new application content to the caregiver client while simultaneously sending guidance information to the smart kitchen server. When the smart kitchen server receives new guidance information, it uses the smart kitchen controller component to display the guidance information using projectors and speakers installed in the physical smart kitchen environment. This improves efficiency of the caregiver guidance and makes the system easier to use, while enabling a caregiver to observe what is happening.

The administrator client enables the editing of workflow models stored in the workflow repository. It can also be used to alter the object database in the smart kitchen server to edit, remove or add new objects. Similarly to the caregiver client, the administrator client application can be browser-based. The smart kitchen domain can be regarded as an independent component. The system design and XPDL modelling language (i.e. *pools*) allows multiple domains to be connected to a single workflow server simultaneously, or separately. In principle, bathroom or similar environments could be added to the system.

4. IMPLEMENTATION

According to DSR framework the designed artifact should be evaluated [4]. In this research the designed system was constructed by the researchers. Some elements of the system were adapted from existing components, some created by the researchers and some simulated with arrangements having equivalent effect. Following chapters describe the system elements (see figure 2) in more detail

4.1 Caregiver Client

A caregiver connects to the workflow server using a web browser (e.g. Internet Explorer, Firefox, Chrome, etc.). The web browser loads application data from the workflow server and starts the application. New content is loaded from the server for each workflow activity. Each activity in a workflow model can be embedded with a *duration* value representing an estimated duration of an activity in seconds. This value can be used to automate the workflow, enabling the caregiver to just observe the process. The caregiver can pause the timer or choose not to start the timer, and manually control the flow of activities using control buttons. Figure 3 shows a screenshot taken from the caregiver client application.

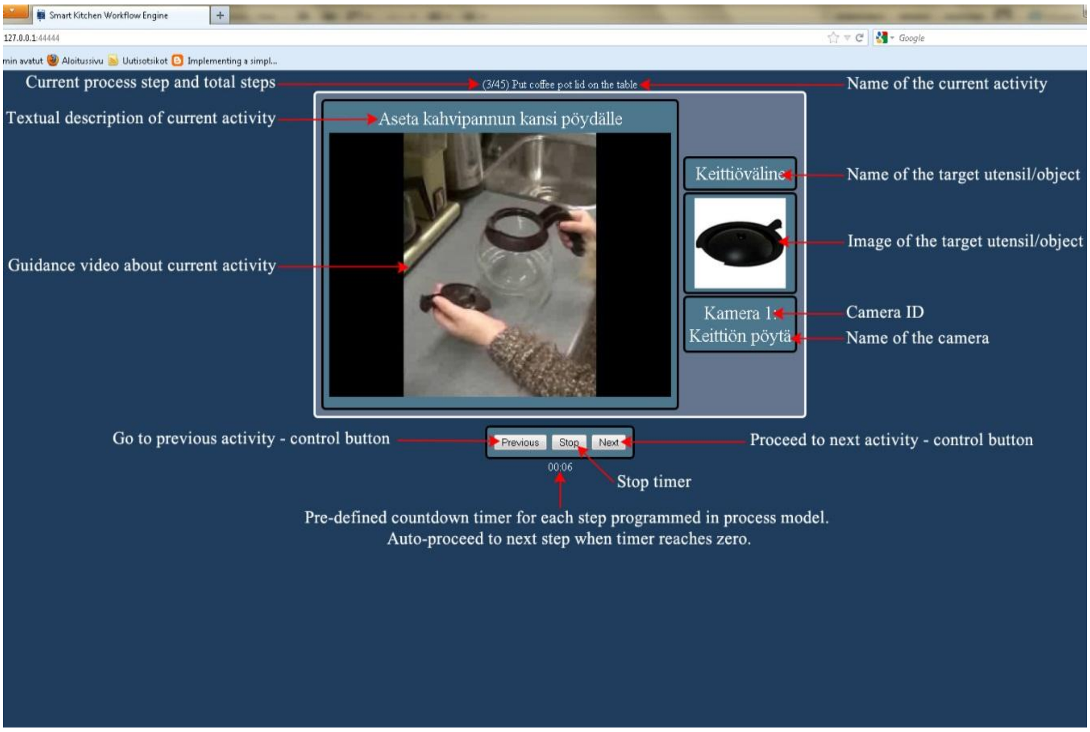

Figure 3. The caregiver client application

As caregivers may not be familiar with the executed cooking activities, the caregiver client also shows visual and written instructions for each activity, while offering a video stream from the camera giving the best view of the area where the activity is supposed to take place. If a caregiver observes that the elderly person is having difficulties performing a task, they have sufficient information as to how to help the subject in the completion of their task, regardless of whether the caregiver has any prior knowledge of the physical kitchen environment or the cooking activity.

4.2 Administrator Client

The administrator client application is used for creating and editing workflow process models. Externally developed software was adapted as an equivalent to administrator client. Together Workflow Editor 4.6.1 [Together Teamsolutions Co., Ltd., Chonburi, Thailand] was chosen as suitable open source software with sufficient compatibility with XPDL. Using externally developed software implementation ensures compatibility of the designed system with industry standards, and reduced development effort.

4.3 Workflow Server

In this research, the workflow server software was constructed by the researchers by using Java programming language. The implementation contains a HyperText Transfer Protocol (HTTP) server component, in a listening mode for connecting clients, and a workflow engine component. Both components are independent and communicate with each other using a separate message handler component. Such an arrangement ensures better maintainability and stability. Figure 4 shows a component diagram depicting the workflow server.

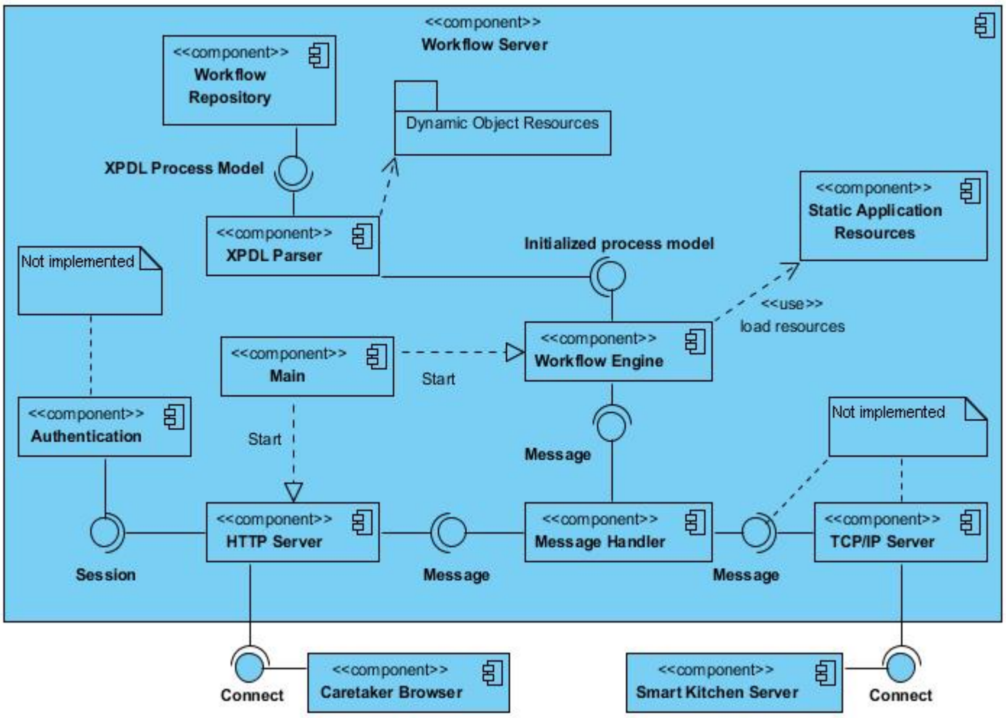

Figure 4. The component diagram for the workflow server

The workflow engine loads a XPDL file and parses it to a form that can be executed by the workflow engine, using a document object model (DOM) open source library. For each workflow process step the workflow server generates caregiver client content dynamically using JavaScript and HyperText Markup Language (HTML). The designed system also includes a connection between the workflow server and the smart kitchen server. This was not included in the final implementation, as the available resources did not allow development of the whole system.

4.4 SmartFlow Protocol

The information system designed in our research also included a detailed SmartFlow protocol design for storing and transferring objects between the smart kitchen server and the workflow server. In the designed system the workflow server retrieves objects related to the running workflow from the smart kitchen server using a XML type format. Objects can be divided into stationary and movable objects. Movable objects can be further divided into utensils and consumable objects. Stationary objects can be defined as objects that are not expected to move within the kitchen, such as a refrigerator, an oven, cupboards, etc. Utensils are considered as tool-like objects (a fork, a kettle, etc.) that can be moved. Consumables can be thought as edible or non-permanent substance, such as spices, coffee bags or flour.

An inventory of kitchen objects is recorded in the smart kitchen object database when the smart kitchen environment is initially built. Each related object is categorised and their location sent to the database. Exact spatial coordinates are only set for stationary objects. The location of all other objects can be defined in relation to stationary objects. For example, a cutlery drawer has fixed spatial coordinates set but if we want to find a fork in a kitchen, a database search will reveal that forks are located inside the cutlery drawer. In essence the fork inherits the spatial location of the cutlery drawer. This simplifies the creation of the workflow process models immensely, as they only need to contain the name or identifier of an object, and the smart kitchen server translates that into coordinates for the projectors, for example, to display the appropriate aid images. The same hierarchy and relations that exist with the objects can be directly transferred to the SmartFlow XML-schema as shown in following code sample:

```
<StationaryObject Id="001" Name="cutlery drawer">
        <Dimensions Width="35" Height="35" Depth="null"/>
        <Location X=223 Y=45 Z=50/>
        <ContainedObjects>
                <Utensil Id="002" Name="fork" Quantity="5">
                        <Image Path="/fork.jpg"/>
                </Utensil>
                <Utensil Id="003" Name="tea spoon" Quantity="5">
                        <Image Path="/tea_spoon.jpg"/>
                </Utensil>
        </ContainedObjects>
</StationaryObject>
```

As the kitchen does not track the objects physically, the workflow process models need to be used to complete as many activities as possible in the kitchen in order for the system to keep track of utensils and consumable objects. It is reasonable to assume that the locations of objects will become fragmented, meaning that the system will have the wrong location information stored. In such situations, the caregiver can adapt more easily than an automated machine can and would suggest likely alternatives for the location of the object in question. From time to time it would be necessary to undertake cleaning activities in the kitchen so that the object database is reset.

5. TESTING

In DSR the build artifact should be evaluated to determine whether it meet the identified need [4]. In this research a pilot test was conducted to evaluate the implementation built as specified by the designed system. Similarly to alpha tests used in the software industry, representatives of potential users or customers from within the developer organization were invited to use the system while developers observed and took notes [5]. Two participants, one student and one employee of the university, took part in the pilot test while two researchers observed. One participant acted as a caregiver guiding another participant, acting as a senior citizen, in a smart kitchen environment. A coffee-making process extracted from prior research was used as a test workflow model [6]. The workflow was tested and refined to suit the test kitchen conditions. The updated workflow model, including video clips, textual instructions, camera information and utensil images, was embedded into the XPDL workflow model.

In the design (see Figure 2), the video/audio stream would be incorporated into the caregiver client UI. Due to resource and time restrictions, this was simulated by using external camera software on another computer and placing the monitors next to each other. In the caregiver client software, each workflow step had the name and the number of the related camera shown in the UI (see Figure 3). The other monitor had view of cameras with corresponding names and numbers.

The caregiver was given short verbal instructions concerning the user interface (UI) of the caregiver client and the camera software. The caregiver's task was to guide the participant acting as a senior citizen through the coffee making process once. After the test, both participants were given a questionnaire which followed formative usability testing guidelines [12].

The caregiver client was setup on different location from the smart kitchen environment. The caregiver was not able to see or hear anything directly from the kitchen environment. The caregiver had a microphone for guiding the senior citizen in the smart kitchen. One researcher observed the caregiver. The workflow model was embedded with duration values for each task, but the timer was disabled for the test. The caregiver client software was programmed to measure the actual time it took to complete a task for later analysis.

5.1 Smart Kitchen Test Setup

Five cameras were installed in the kitchen environment. The cameras were wirelessly linked to a router that was also connected to a pc running the caregiver client software, simulating remote connection. The cameras also had speakers that were connected to the caregiver's microphone. The cameras were placed so that they would have good coverage of stationary objects and so that their field of view would not be blocked by test participant during the tests. Cameras could be turned remotely to fine tune field of view. The projectors used in the smart kitchen environment in previous research were simulated using Post-it notes on drawers and cupboards [6]. The participant acting as a senior citizen had not used this particular kitchen before and was thus unaware of where the utensils needed in the coffee-making process were located. Figure 5 shows the test setup for the smart kitchen environment.

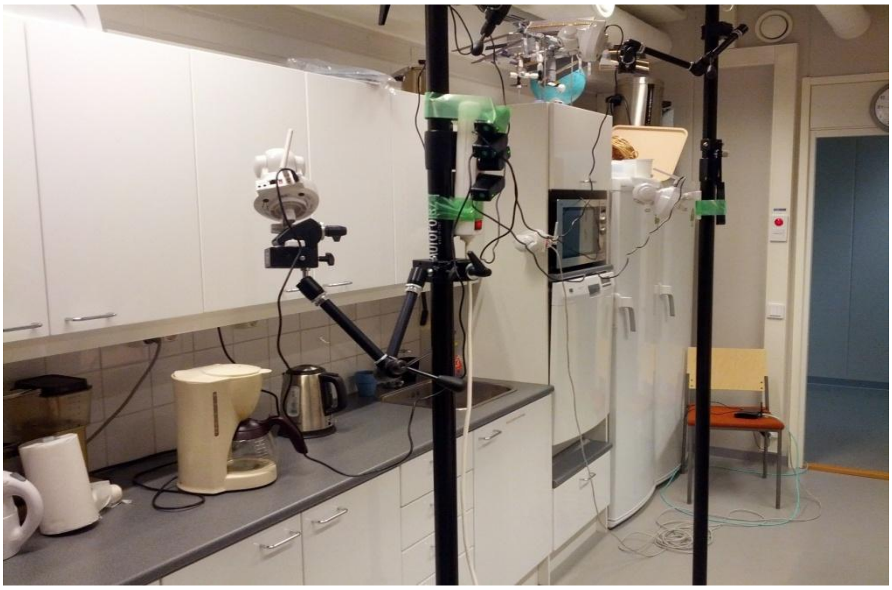

Figure 5. Smart kitchen test setup

During the test another researcher observed and filmed the test participant's actions in the kitchen environment. This video recording was used later to evaluate the performance of the system and analyze problem situations.

5.2 Test Results

The caregiver was able to guide the participant acting as a senior citizen. A total of eleven task-fails were observed by the researchers and five task-fails reported by the participants in questionnaires. Table 1 lists all task-fails, either observed by the researchers or reported by the participants.

Table 1. Summary of task-fails reported during the test

Reporter	Cause of task-fail	Minor	Moderate	Major
Observers	Technical error		3	3
Observers	Workflow model	3		
Observers	User error	2		
Senior citizen	Technical error		1	
Senior citizen	Workflow model	1		
Caregiver	Technical error		1	1
Caregiver	Workflow model	1		

Major level problems in this case can be understood as difficulties that could prevent usage of the system. Moderate level problems can cause errors during usage of the system. Minor problems can cause difficulties but do not affect the usage of the system. Technical errors were all deemed fixable by the researcher. Workflow model errors require further study with actual users to be corrected. As an example of a workflow model error, one participant reported that, “Finish language instructions informing about the location of cupboards sounded a bit unclear”. Without testing this with actual senior citizens (users) with memory impairments and/or health care professionals, all the workflow model related problems are to be treated as inconclusive.

6. DISCUSSION

The Smart kitchen concept has been tested previously with a coffee-making process using senior citizen suffering from dementia as test participants [6]. The focus of this research was to develop a design for an information system that would enable dividing remote care giving between any combination of formal and informal caregivers [11]. Another aspect was improving mobility of remote caregiver by enabling connection to a smart kitchen environment from PCs and mobile devices without need for installation of software. Both mobility and divided care giving could reduce stress experienced by the caregivers [9]. A novel concept of context-awareness that can be embedded into workflow process models that allow, not just the system to be aware of kitchen objects, but also caregivers to gain situational awareness without need for prior knowledge about a smart kitchen.

Functional requirements, such as affordability and reliability, can be considered as overall priorities for the system and important for both caregivers and elderly people suffering from dementia. A caregiver might be a spouse or other family member of a demented person. The test participant acting as a caregiver was able to use the system to guide another test participant in the kitchen. From this result we can confirm that the system works as designed, and from a technical perspective such a system is feasible to construct.

Workflows offer a flexible and highly customizable way to model real life processes [13]. The limitation is that both flexibility and customization need to be designed into the workflow model by an administrator. Considering the wide variety of possible processes and the changing nature of dementia, this can result in a considerable amount of work. An administrator needs to have knowledge concerning modeling workflows, the requirements of the elderly demented person using the system and about dementia. Further research is needed to determine suitable organizational models to either support caregivers and/or senior citizens in modeling processes themselves or identify an external organization that will do this for them.

In the designed system, the workflow engine sends information to projectors within the smart kitchen environment which display aid images to highlight objects related to the activity being carried out. This research introduces a novel design for context-awareness that enables designing workflow models that are not tied to a single smart kitchen environment. This design supports a solution where workflows can be centrally designed and need only modification for individual needs.

The designed system involves only partial elements of automation. Overseeing execution of workflow process models still require presence of a caregiver. In essence the system does not directly reduce the amount of work needed, but provides means to do it more efficiently and providing more freedom for caregivers. It is worthwhile to note that increased automation could further reduce need for caregiver presence, and could be helpful solution in remote areas and in cases where person suffering from dementia does not have comprehensive support network of family members that can offer informal care giving. In order to enable automated execution of workflow process models there would need to be a way for the information system to detect completion of activities [3]. Also ability to handle interruptions to workflow activities and handling unexpected events are challenges that need to be overcome before automation can be implemented. Although even a small increase in automation could be beneficial for caregivers and elderly people suffering from dementia.

7. CONCLUSION

This research presents an information system design that enables an informal or formal caregiver to guide cooking activities in a smart kitchen environment from a remote location. The cooking activities are graphically designed into machine-readable workflow process models. SmartFlow protocol enables creation of context-aware workflow models that can be centrally designed but executed in multiple locations.

The system was designed following the determination of the functional requirements of elderly people suffering from dementia and their caregivers using a systematic literature review. DSR describes research to be an iterative process. The designed artifact should be built, assessed, refined and assessed again until the artifact is able to satisfy the set goals [4]. A pilot test was conducted to assess the current state of the system. This along with knowledge gained through development of the system can be used to refine and develop the system further, until it is ready to be tested in actual environments and with elderly people suffering from dementia and their caregivers.

7.1 Limitations of Study

The pilot test only demonstrated that the designed system works in ideal conditions, not in a real life setting with actual caregivers and elderly people suffering from dementia across greater distances. This research also shows that a coffee-making process can be modelled and run by the system, but further tests are needed to verify that all kitchen processes can be modelled. As the projectors were simulated for the pilot test, and the smart kitchen server was not build, the design for context-awareness was not tested on a practical level.

7.2 Future Research

Future research will consist of finding ways to improve automation by looking in to technical possibilities of using image recognition in combination with sensor input to trigger completion of workflow activities and to detect workflow interruptions. This could help adapt the system for different environments as well. Also as learned from this research the possibility of auto-generating workflow process models needs to be studied, as this would considerably reduce the need for maintainability and ability for system to cope with interruptions. Third research subject is to study the workflow process models themselves to find customization patterns based on level and type of dementia that would optimize support for elderly persons suffering from dementia.

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