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SPECIAL ISSUE - ORIGINAL ARTICLE

User interaction in smart ambient environment targeted for senior citizen

Petri Pulli · Jaakko Hyry · Matti Pouke · Goshiro Yamamoto

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Abstract Many countries are facing a problem when the age-structure of the society is changing. The numbers of senior citizen are rising rapidly, and caretaking personnel numbers cannot match the problems and needs of these citizens. Using smart, ubiquitous technologies can offer ways in coping with the need of more nursing staff and the rising costs of taking care of senior citizens for the society. Helping senior citizens with a novel, easy to use interface that guides and helps, could improve their quality of living and make them participate more in daily activities. This paper presents a projection-based display system for elderly people with memory impairments and the proposed user interface for the system. The user's process recognition based on a sensor network is also described. Elderly people wearing the system can interact the projected user interface by tapping physical surfaces (such as walls, tables, or doors) using them as a natural, haptic feedback input surface.

Keywords Senior citizens · User interface, Projection-based mixed reality · Ambient environment · Memory problems · Alzheimer's

P. Pulli (✉) · J. Hyry · M. Pouke
Department of Information Processing Science,
University of Oulu, Oulu, Finland
e-mail: petri.pulli@oulu.fi

G. Yamamoto
Graduate School of Information Science,
Nara Institute of Science and Technology, Nara, Japan

1 Introduction

Society in Finland is aging at an alarming rate and is only slightly behind Japan in this regard [16, 17]. As the structure of the population is shifting toward the elderly, studies have shown that Finland is facing a crisis when the cost of supporting the elderly rises and the amount of caretaking personnel is not sufficient enough to support them [9]. The numbers of elderly who live alone grows and the older they get, the more assistance they require [11]. The amount of elderly people, suffering from varying degrees of memory impairment, also more than double during the next 30 years [3]. If we can improve the caretaking personnel's productivity by just 1 % and postpone the decline in cognitive and memory functionality of the elderly by just 5 years, for example, an 80-year-old person has the same functionality as that of a 75-year-old person, the need for more caretaking personnel plummets from near 25 % to about 15 % [11]. Thus, accumulating vast savings accumulated for the society until the year 2040 [9].

Technological innovations in communications, portable devices, and computers in general have created a vast net of wireless information exchange between individuals. Devices used in such cases create ubiquitous services and solutions, which could also be harnessed to improve the quality of living among senior citizens. It is necessary to think about the availability and uses of computers or mobile devices in different situations and to create novel, easy to use interfaces that meet the demands of users that are normally outside of the average user spectrum. Human computer interaction systems for senior citizens are required especially in many advanced countries where there are an increasing number of elderly people who feel alienated in the use of new technologies.

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Nordic countries made a collaborative case study to 29 persons suffering from dementia. The projects task was to find out what kind of aid-devices are used, their suitability for demented persons, and their caretakers as well as gathering feedback of proposed improvements [15]. This two-year study concluded that introducing aid-devices into the homes for people suffering from dementia improved management of daily activities, helped in maintaining skills, and activated people suffering from dementia to be more active in society, which lessened feelings of loneliness often associated with dementia. Based on the study, we can deduct four basic requirements for the design of technological aid-devices aimed at people suffering from dementia and their caretakers: combining device functionalities, lessening the amount of devices, creating adaptive and tailored user interfaces, and implementing telepresence assistance.

Participants of the study used over 40 different kinds of aid-devices from 3 weeks to 3 years. Median of use was a year and 4 months. Based on several different types of listed aid-devices, such as GPS device, paper and electronic calendar, portable security alarm device and a monitoring safety camera, a conclusion can be made. Functions of these devices can be combined and lessen the amount of devices used.

Usage feedback was gathered as interviews from the users, close relatives, such as a spouse, or from professional caretakers. Based on the collected data, the need to learn usage of new devices was constant. This was due to the degrading nature of the disease, which presented new problems the aid-devices should handle. The devices had to be changed to match the problems. It would be beneficial to create aid-devices that can more easily adapt to the requirements of changing needs of people suffering from dementia and their caretakers. An aid-device that is introduced early on to the user was also shown to be beneficial when the symptoms of dementia were still in their early stages.

Use of aid-devices in some cases was shown to be unique to the user's preferences. Different persons used the same aid-device differently. Also, people suffering from same severity level of dementia in the same kind of living environments did not always require the need of the same devices. Aid-devices that can display individual and tailored information would lessen the need to introduce new devices and would be familiar to the user throughout the process of dealing with dementia.

Implementation of a telepresence assistance service could provide help for the user suffering from dementia regardless of place and time. Studies showed that in addition to the demented persons need to feel safe and assisted, there was also needs for the caretaking spouse to be able to know what the demented person was doing while they were not at home to help them. Aid-device with telepresence capabilities could offer improved ways to help and inform caretakers.

This paper describes constructive research method applied to the projection-based display system for elderly people suffering from memory impairments. Construction is validated by user trials.

2 Methods

The conceptual assisting system, in the form a wearable computer, was developed using a web-camera, an accelerometer, and a small picoprojector. The conceptual overview is shown in Fig. 1. The system can be used naturally, because the acceleration sensor can be embedded in a watch and the projector can be worn around the neck as a necklace or embedded in clothes. Our proposed system offers touch feedback comparable to BOWL PROCAM system [7] and it features an easy to use graphical user interface.

Advantages of our design are that the user is able to use it without learning new control methods, as opposed to hand markers-based gesture navigation with adding color markers to fingers [8] or using IR-led fingertip attachment [4]. The design is more feasible for elderly as learning of new things becomes slower with age [5]. Also, the acceptance of new technology for elderly must be considered when designing new systems [2]. Using a projector as a display also offers a large screen from a small device [18].

The main interactions with the system are carried out with two separate user interfaces—one for the medical personnel or a trusted person, and one for senior citizen user. User interfaces division enables the use of separate design requirements, so that the senior citizens get a more refined solution, and the external users can have more complex set of tools at hand. As an example, the doctor can add appointments to senior citizens calendar via a computer or mobile interface or they can use them to monitor current health or check medical history of the senior citizen user. A trusted family member can check whether senior citizens calendar entries are acceptable and do not have any inconsistencies. They can also add entries to the calendar, offer personal guidance via communication tools, or otherwise guide the user based on his location and activities.

Graphical user interface for the senior citizen is built up of different modules. Communication module has tools for messaging between external contacts and the senior citizen such as video calls or regular phone calls. Guidance module is a subset of two areas—outdoors and home. It handles information to the senior user of routes to known or unknown locations via safe paths. This module also provides instructions for tasks the user wants to do. Home

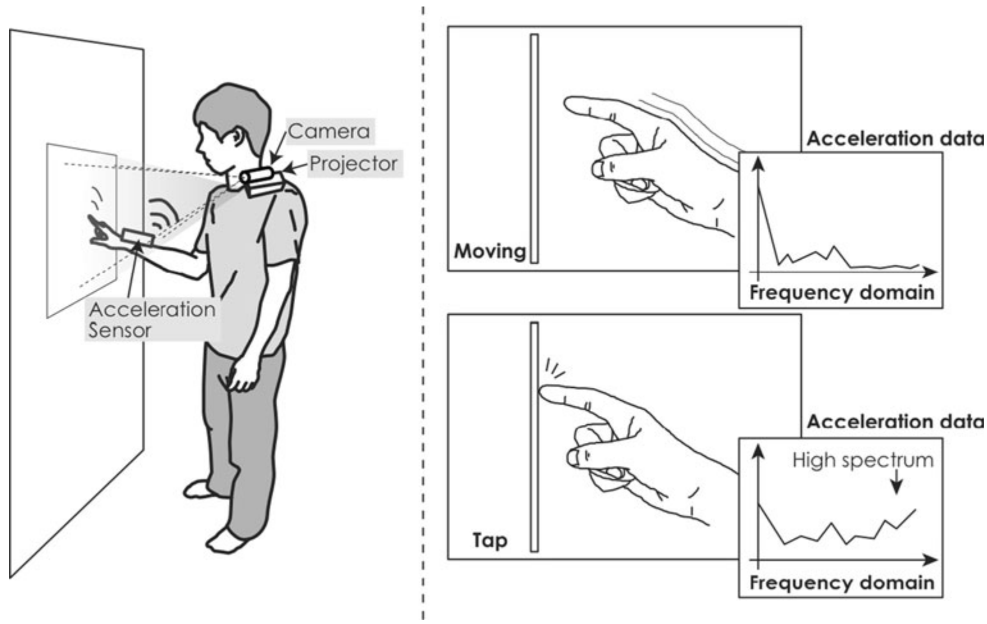

Fig. 1 A conceptual overview of the projection-based wearable system. A tap action is detected by analyzing frequency domain

guidance module is designed for home-specific tasks, such as cooking, cleaning, or other personified tasks that require the systems intervention or is triggered by the senior user. Home module also takes care of reminders for upcoming tasks made by the senior user or external members. Scheduling module is split between multiple users as data acquisition and entry is possible from different terminals. One of the most important features based on interviews with family members and caretaking personnel of senior citizens was the need for an emergency module. This module handles direct requests from the senior user or via automatic recognition and forwards these to the appropriate party.

Senior citizens user interface is designed using a design-for-all philosophy and it is divided into two main parts—user interaction and the information provider. The interaction interface uses familiar structure to written language, see Fig. 2. The desired action is created using simple word selection to create understandable inputs. Thus, UI actions are conveyed easier to the user, as the end result is a full sentence. Actions are chosen one-by-one, for example, *'I want, to call, Jim'*. Each step and the final sentence are shown as a feedback, so the user knows where they are, where they need to go in the structure, and can easily navigate back and forth. If the system detects a problem or the user triggers the Help-process, the UI is displayed.

The information provider part offers reminders, guides, and warnings to the user when necessary. The user or third-party members can create appointment, alarms, and notes for the system. Guides can provide step-by-step information on how to do specific tasks such as making coffee, or it can advice more broadly on future events with the help of simple text, pictures, video, or audio guides. The offered data must be divided into related blocks and paths as *GlueNotes*, because vast amounts of data from several processes are constantly available to the senior user. As an example, the senior user might repeat a following chain: senior user wakes up, showers, dresses and makes breakfast, shows that tasks are not always separate or one-time events and can be recognized and chained together. Space, time, or schedule provides a basis for linking relevant data together so that the cross-correlation inside the system can offer valid information to the user whenever needed.

The prototype system consists of a mobile projector (3 M Micro Professional Projector MPro110, SVGA), a web-camera (Logitech QuickCam Vision Pro, 960 × 720 pixels), an small accelerometer (ATR-Promotions WAA-006), and a notebook-size computer (Apple MacBook, Intel Core 2 Duo 2.4 GHz), which weight is about 300 g excluding the computer, as shown in Fig. 3.

This system can display information on physical plane surfaces according to markers. Using camera-based image capturing and the acceleration sensor, the system can detect taps of an index finger as inputs. Displaying the user interface, as shown in Fig. 4, has three basic steps. First is elimination, where the system applies near infrared domain to eliminate the influence of the projector light, because this projector light interferes with detecting the markers in the visible area. Second, image processing is performed to detect the 3D position and to analyze marker patterns. Finally, image correction is carried out using coordinates conversion to calculate projected image's position and the skew correction.

Detecting input action has three steps. Fourier analysis is used to detect tap based on the high spectrum of the tapping action. Then, rough fingertip position is

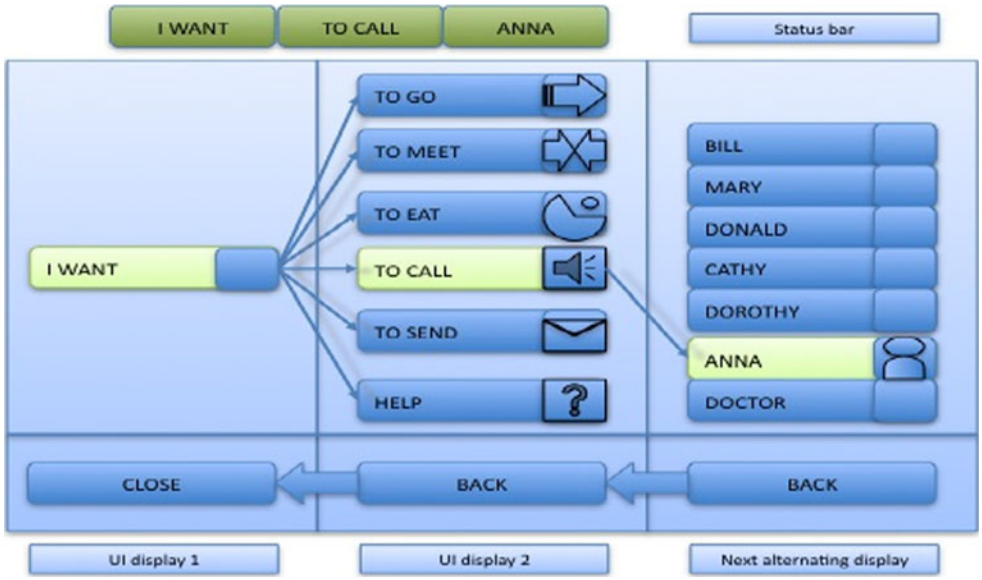

Fig. 2 Path-structured user input module concept

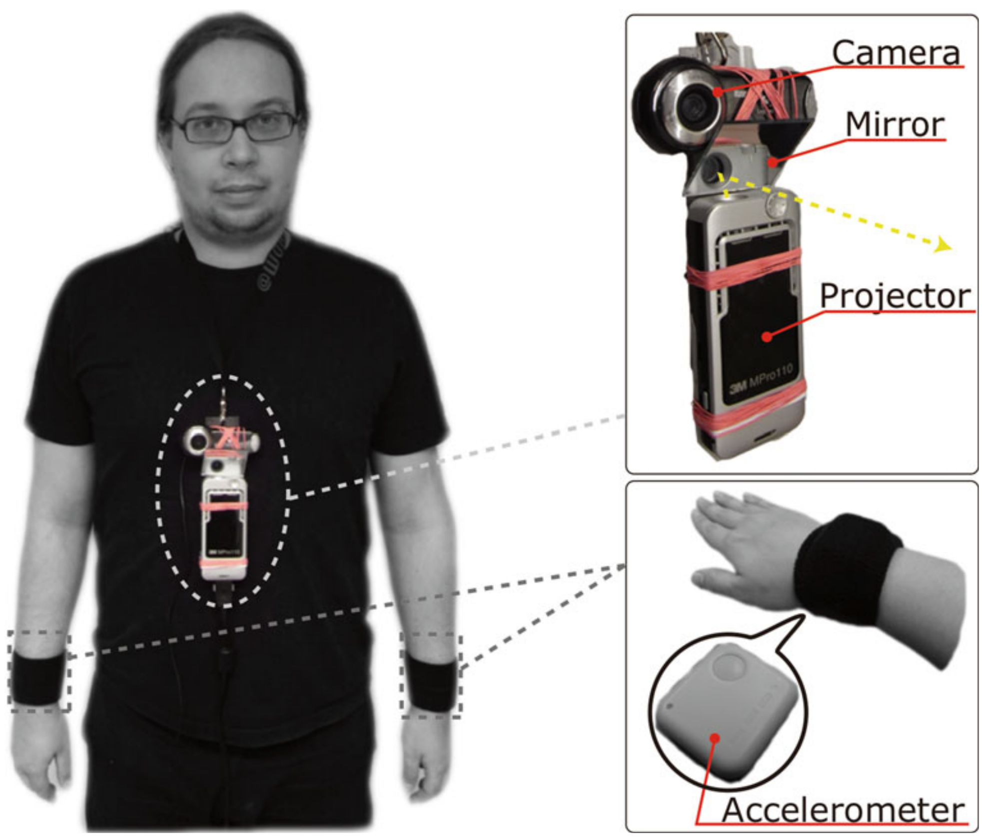

Fig. 3 Prototype system, which provides tapping interface on a wearable computer

estimated using the marker attached on the user wrist and the hand model. As a result, the 2D position of the tip of the finger is detected on top of the display surface. Finally, the system validates the input by analyzing both inputs. If the system detects tap trigger and the hand markers existence, the input from the fingertip position is accepted.

Figure 5 shows the interaction by tapping on the wall and the biggest one of projected images is changed according to tapping position. Displaying the user interface on any surface uses a method that is divided into four separate functions: detecting the tapping trigger, calculating a homography matrix, recognizing the hand area and estimating the finger-tip position, as shown in Fig. 6.

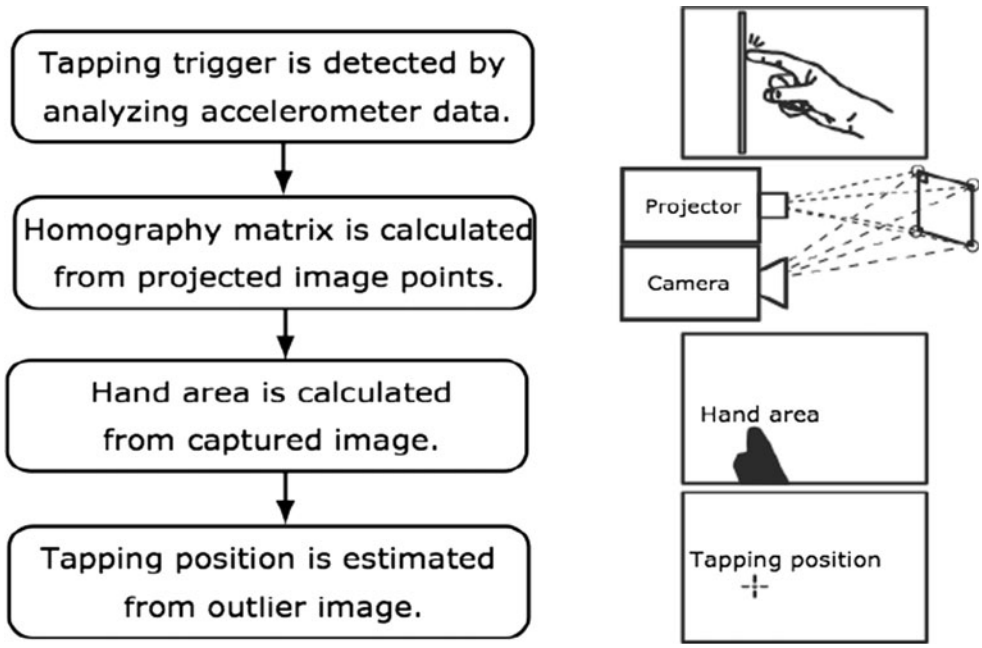

Fig. 4 Flow chart of processing to detect tapping and pointing position

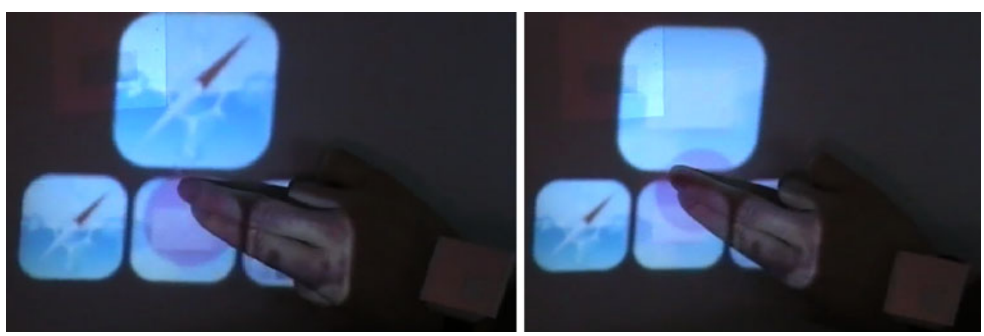

Fig. 5 Interaction by tapping on the wall. The biggest icon changes according to the tapping position

Tapping trigger is detected from the accelerometer on user's wrist through Fast Fourier transform analysis. When a spectrum value exceeds a certain threshold value in high frequency area, the action in that time is recognized as a tapping action.

To detect tapping position on a target surface, it is necessary to calculate a homography matrix. The homography is calculated from four projected points in each corner of the projected user interface. Some input hand motions may, however, cover one of these points when projected from the projector to the display surface. Therefore, the system must estimate a point in relation to the three projected points on the surface and calculate the homography based on these four points. A ray transfer model can be defined where the brightness ray from the projector is reflected on a target surface and captured. When it is assumed that the ambient light source and the ratio of the surface reflection are equal on all of the projection area, we can define transfer ray and ratio of a reflection as a simple equation in each case (RGB). Using a calculated transfer function of model, we can estimate brightness of the reflection on the surface. The system compares this estimated brightness and the captured brightness of the camera. If the captured brightness is an outlier, the ray is estimated to not be reflecting from the surface.

Upper-left of Fig. 7 is one of the outlier images. This image has noise from the shadow and from defocusing. The latter effect is caused when the projector is out of focus. The shadow noise is caused from user hand shadow and environmental shadows. To recognize the hand area, outlier image is processed with a labeling operation. Upper-right of Fig. 7 shows a result of this labeling operation. When it is assumed that an input action must enter the projection area, we can define that the hand area has a captured-image edge. Therefore, an area that does not have that edge can be considered as noise. In addition, the largest area that has the captured-image edge is recognized

Fig. 6 Projector camera system detects markers on the wall and user's wrist and input signal by acceleration sensor

as the hand area. To detect the fingertip, the recognized hand area is processed with edge detection. The distance from image-screen edge is calculated along the hand area outline, as shown in Fig. 7 (lower-left). Furthest point on the outline is estimated as the fingertip direction, as shown in Fig. 7 (lower-right). Finally, that same point is defined as fingertip position.

3 Results

As the module should automatically trigger user guidance when detecting tasks, automatic activity recognition of the patients is separately studied. We have currently performed two activity capturing trials in two hospices including memory impaired and non-memory impaired elderly patients. We have then experimented various classification methods with the raw sensor data. The sensor network used for the data acquisition, as well as the first trial is described in more detail in [14]. The network consists of two 6 degree-of-freedom accelerometers (ATR-Promotions WAA-006), several proximity sensors (ATR-Promotions WAA-001), a PDA, and a laptop. The 6DOF sensors were placed in each wrist of the subject, while one proximity sensor pair was held in the pocket. The wrists are a suitable position for the accelerometers as they are also used to detect the tapping motions when interacting with the user interface. Other proximity sensors are placed within the environment (Fig. 8). The sensors send their data to the PDA with a Bluetooth connection. The PDA is connected by WLAN to a laptop running the server software. Similar sensor network has been previously used in nursing activity recognition [10]. The subjects are interviewed before the trial to figure out their common daily activities as well as possible health issues, which might affect the trial. Information about the daily activities reveals the key locations

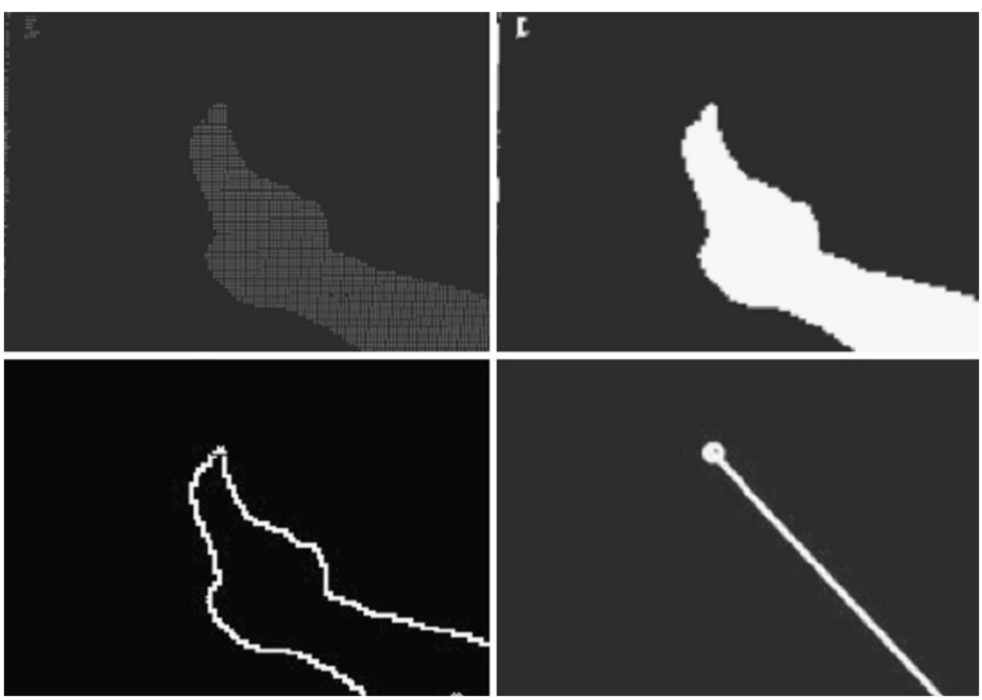

Fig. 7 Detect finger-pointing position from outlier image. *Upper-left* an outlier image, *upper-right* a result of labeling operation, *lower-left* outline of a hand area, *lower-right* estimation to fingertip direction

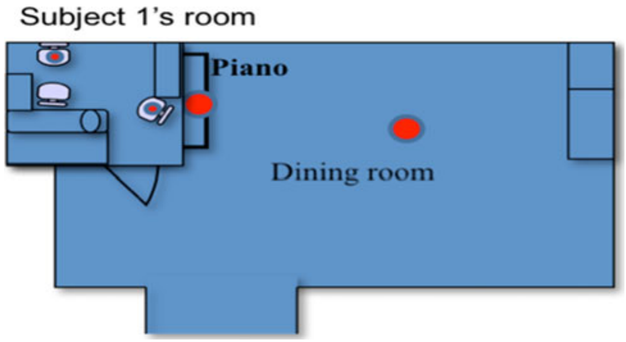

Fig. 8 Data acquisition via sensors. *Red dots mark* the placement of the four location sensors

into where proximity sensors are placed. During the trial, the patients are typically asked to perform same activities they mentioned during the interviews. In the later experiment, the patients were also asked to perform specific household tasks, such as cleaning or making coffee. The 6DOF sensors capture the patients' arm movements while the proximity sensors capture their rough location. Feature extraction and classification algorithms have been used to recognize activities from the captured sensor data. Similar method has been proven effective with time-based data in previous research [1, 10, 12]. Statistical features such as acceleration mean, standard deviation, or energy among small time windows are typically calculated from the raw data, and the resulting data set is ran through a classification algorithm. Our initial results published in [14] give classification rates ranging from about 60–80 % with mean and standard deviation calculated from 2- to 5-s time windows. Our current best results give a nearly 100 % recognition rate from the same experiment data when samples from raw acceleration data are acquired from a 200 ms time window and the resulting data set is ran through 1-Nearest Neighbor classifier with 10-fold cross-validation [13].

4 Discussion

One of the problems that senior citizen might receive is called Age-Associated Memory Impairment (AAMI), which presents problems related to speed of processing information, storing, and remembering new information and decline in performing cognitive tasks, which require use of memory or organizing. This research focuses on Alzheimer's disease and its close variants because a vast amount of different memory-related illnesses require specific, customized designs. Other illnesses, such as semantic dementia, can also present symptoms that are difficult or infeasible. Choosing Alzheimer's is feasible because of the nature of the illnesses symptoms and its prevalence among the elderly. Based on discussions with a neuropsychologist and medical doctors, it is also feasible for these technological aids in improving the lives of the patients and the possibility of slowing down the rate of brain functions deterioration.

User tests were carried out on an elderly male without Alzheimer's symptoms at the ODL veteran's home in Oulu to test the device itself for improvements with normal aging disabilities. The usability of the user interface input methods was also tested. Tests showed that there were several needs for user interface and device improvement. The display size was too small for easy reading, because the user has to be close to the wall for tapping input. The selection of the preliminary graphical icons was cumbersome, because the icons did not provide clear association to the function it was supposed to represent. For example, a 'mobile phone' icon was confused to a 'door' icon. Wider lens would provide more input space on short distances. The tapping detection threshold was also set too low, so the user suffered from slight pain to fingers. 3 M MPro 110 micro-projector's brightness is only 10 lumen, so usable situations for this particular projector are very limited.

Output part of the projector has image flickering because the system allows geometry calculations of processed images on pixel level. One solution is to use sub-pixel level. The mobile projector also has low light output and lacks any image stabilization, but these problems can be solved in the future. The projector has the advantage of being able to use most physical surfaces as a display, which presents interesting uses for the device. The detection of the tap action is realized by a simple method of setting an input threshold on a high spectrum range, but using PCA would greatly raise the accuracy. The other issue to be solved is the estimation of the hand model and the fingertip position, which at the moment suffers inaccuracies if the user uses multiple fingers to tap.

Based on senior citizen and their caretaking personnel interviews, there is a need for a more thorough assessment of user needs validation. Studies suggest that activating senior citizens and enabling communications easily for the user might bring feeling of security both for the elderly and their family members. Discussions with medical staff has brought out some views on ethical sensitivity regarding the use of a systems that tracks the users every movement, so the information stored by the system has to be secure at all times and accessed only by people with sufficient privileges.

Regarding the activity recognition, future work includes testing the current activity recognition method within a larger data set acquired from the 2nd activity capturing trial. This allows us to see whether the activity rate remains the same with different patients and activities. We can also experiment with various teaching and training sets among different patients instead of using 10-fold cross-validation among a single small data set. Overall refinement of the classification algorithm includes more thorough testing of different features. Modern classifiers such as Support Vector Machines are to be experimented with as well as using the proximity sensors to delimit the recognition of certain activities into specific locations. Even though the wrist attached sensor is useful in tapping action detection, free sensor placement such as in [6] should also be looked into.

The developed user interface for senior citizen holds promise for applications more diverse than the application described in this paper. The system was tested on elderly for feedback on usability and the prototype functionality. Future work is to implement an improved user interface modules for more thorough elderly tests using this platform and to stabilize system output and input. We are studying applications in indoors meal preparation, outdoor navigation, and safety services, as well as grocery shopping. Research on markerless projection possibilities is also in progress. Multilingual user interface using semantic information based machine translation is also being researched. We are open to academic and industrial research cooperation with related technologies and services development and user interface–related controlled experiments.

5 Conclusion

Projection-based user interface, when combined with user activity recognition, reduces the cognitive load for senior users because guidance symbols can be projected to the user's immediate vicinity and user's selections can be made directly by hand. To gain full benefit of this approach, senior users' daily activities need to be modeled and activity-specific guidance need to be developed and provided to the senior users. Further controlled user experiments are necessary to obtain understanding on the applicability and scalability of this user interface approach within senior citizen smart living environments.

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