ITE Trans. on MTA Vol. 5, No. 2, pp. 57-66 (2017)

Paper

Design of Assistive Tabletop Projector-Camera System for the Elderly with Cognitive and Motor Skill Impairments

Jaakko Hyry †,††, Max Krichenbauer †, Goshiro Yamamoto †,†††, Takafumi Taketomi †, Christian Sandor †, Hirokazu Kato †, Petri Pulli ††

Abstract Projector-camera (ProCam) systems have a potential to become popular and affordable as they can create interactive surfaces for example on tabletops, walls, household items or on a palm of a hand. The possibility that these systems will be used at homes in the future is increasing. The elderly living alone at home often need assistance in their daily tasks as the likelihood of cognitive and motor skill related impairments increases with age. ProCam systems could be used for guidance due to easy to manipulate large interaction surfaces, but research on its suitability for elderly users is scarce. Our research focus is on elderly users and examining their characteristics as potential users of ProCam systems and the implications for interaction design. We conducted a user study with a mixed impairments group of elderly aged 82-94 to investigate how a personalized and skill-suited user interface should be designed. In our qualitative approach, we discovered that the combinations of both cognitive and motor skill deficiencies of the elderly prohibit one-for-all designs so the user interface design should be adapted to each individual's interaction skills. Lastly, we make suggestions for designing ProCam interaction for elderly.

Key words: projector-camera systems, elderly, interaction, cognitive impairments, motor skill impairment

1. Introduction

The rapidly aging population is posing an increasing burden on many countries around the world to keep up with the rising cost of healthcare and lack of professional caregivers for the elderly[1]. While the advancements in information technology offer a number of solutions to ease the burden of personal caregivers, fewer applications are available to support the independent living of the elderly so that they can continue living at home as long as possible[2].

The elderly with severe Alzheimer's need constant support from caregivers and cannot be assisted with technology at home. However, the elderly with early or mild stages of cognitive impairments, such as Age-Associated Memory Impairment (AAMI) require less support and would be a better target for assistive technology. If the elderly are more capable at home themselves, it will reduce the need for more caregivers in the future[1]. From this perspective, technology designed for elderly use is a necessary and an important challenge.

There are several additional challenges when developing supporting technologies for the elderly. The acceptance and use of new technology are often difficult due to the convoluted guides and structures[3]. Designs should take into consideration the abilities elderly have and what kind of physical or mental changes aging causes for these individuals[4].

The problem is that the elderly are often less computer literate and that there is a gap in technology skills between the young and the old[5] as the elderly prefer previously learned methods and have trouble learning newer technologies[6]. Younger users also often adopt new technologies faster and use a multitude of devices, such as laptops, tablets and smartphones effortlessly. Motor skill impairments affect speed, precision and the ability to manipulate small devices, while cognitive impairments affect memory functions for learning.

Received June 13, 2016; Revised January 10, 2017; Accepted March 2, 2017

† Interactive Media Design Lab, Nara Institute of Science and Technology
(Nara, Japan)
†† University of Oulu
(Oulu, Finland)
††† Kyoto University Hospital
(Kyoto, Japan)

Considering these factors, projection-based user interfaces have a number of advantages over traditional indirect input methods, or touchscreens. Firstly, they allow projection on top of objects and surfaces in a real-world environment and secondly they provide large projections that are easier targets for interaction purposes. To the best of our knowledge, there are no previous studies on the best practices for user interface design for a projector-camera system (ProCam UI design) for elderly users. Thus, we examine how the elderly behave with our ProCam system, as it is not clear how the individual characteristics, cognitive and physical impairments may affect the use and design for a projection tabletop systems. Therefore, we are interested in the following research questions: 1) To what degree does area pointing selection methods suit impaired elderly? 2) In what way does motor skill impairments affect interaction? In this paper, we conducted a user study with elderly participants using our ProCam tabletop interface. Our results inform the design of projection-based tabletop interfaces for elderly users with varying degrees of cognitive and physical impairments.

2. Related Work

2.1 Prior Research on ProCam Systems

Recently, ProCam systems have become less costly than before and offer various solutions for task assistance, often work support or navigation assistance for younger users. As examples, cooking support with projection assistance[7], reliable interaction detection using a depth sensor[8] and multiple surface projections with several input methods demonstrated with the OmniTouch system[9]. These previous studies show the potential of using ProCam system in assistive tasks.

Studies using ProCam technology for elderly assistance are increasing, such as ambient environment that conduct everyday task scenarios[10] or have remote caregiver assistance using on-site projection[7)11]. There are some prior studies on wearable ProCam systems that display information on wall surfaces. Yamamoto et al.[12] present an assistive system for the elderly that projects icons on a wall with tapping interaction capability. ProCam systems show promise for assistance but more research on how elderly interact with these systems and how interaction should be designed from an empirical point of view is needed.

2.2 Interaction Methods

The suitability of ProCam systems for the elderly needs focus on user's interaction performance and acceptance. The common problems the elderly have with technology are generalized in references[3,13,14]:

(1) Lack of knowledge: Use metaphors of new UI's is less known, so learning new is difficult compared to younger

(2) Hard to learn: Indirect manipulation is cognitively challenging, as it requires more mental processing

(3) Motor skills limitations: Movements become less precise with old age so small targets are harder to manipulate

(4) Eyesight limitations: Worse eyesight makes small screens difficult to read and manipulate.

These various factors affect use and are more common the older a person gets for example mouse manipulation and target acquisition are harder to perform[15,16]. While these studies use traditional, indirect input devices, some have also studied the use of touchscreen interfaces for the elderly[17,18]. Interaction in general for elderly users have some suggestions[19]:

(1) Use direct manipulation to reduce mental load

(2) Direct manipulation results in faster and more accurate target acquisition

(3) Larger screens and icons reduce input errors and enhance readability

Common user interface selection methods, such as tapping, for touch interaction can be hard for motor skill impaired users, so some alternative methods have been studied such as area pointing or crossing over an area[20,21]. All of these approaches are more suitable for novel users, which the elderly often are, and thus an assistive system should take into account these factors.

3. Our Projection Tabletop System

The overall vision behind our system is to project information in an elderly user's home and help them conduct daily tasks. However, first we need to examine what type of interaction methods would be the most suitable considering the cognitive and motor skill limitations for a tabletop ProCam system. For motor skill impaired users, a device occupying a hand limits the interaction possibilities to a single hand and holding a device for long periods at a time is tiresome. To overcome this limitation our projection is displayed from a fixed device installation in the ceiling.

To reduce memory load for memory-impaired users, interacting with objects is enhanced by augments graphics directly on top of or next to the objects and not through a device screen such as smartphones, tablets

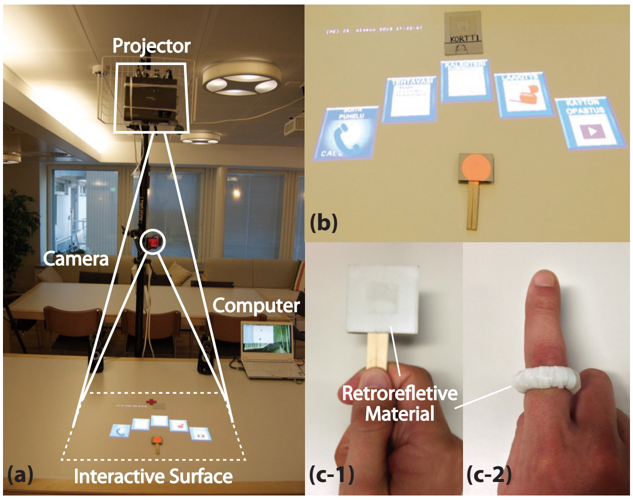

Fig. 1 System overview; (a) ProCam installation, (b) user interface, (c) interactive tools.

or smart glasses. The digital information can be associated directly on real-world objects to enhance a task. Projected graphical elements also do not block real world objects in comparison to a head-mounted display through which the user can only see graphical elements inside the device.

3.1 System Structure

Our system consists of PC (Fujitsu-Siemens 13.3 inch, i3-M380M 2.53 GHz Dual core laptop), camera (OptiTrack FLEX V100:R2, 640×480, 120 Hz), a projector (Optoma EW1691e DLP, 3000 lumens, 1280×800) and separate speakers for audio feedback as shown in Fig. 1 (a). The projector and camera are installed above a table pointing downwards from 140 cm and 80 cm, respectively. The projector displays the UI on the table surface with an area of 90 cm×56 cm, and the camera detects within an area of 60 cm×45 cm the location of the target objects placed on it; a menu-trigger card and input device options, a finger-worn ring and a handheld paddle (4 cm×4 cm), as shown in Fig. 1 (c-1) and (c-2). The paddle was thought to be easy for the elderly to associate the device with user interaction, although it might turn out difficult for people with hand motor skill impairments. The ring enables user interaction similar to touchscreens and lets the user to hold the hand on a table for support, which reduces negative impact of hand tremors or stiffness.

For ProCam calibration and marker detection with one camera, we chose an OptiTrack FLEX: V100:R2 camera because it has two alternative modes: a color mode (RGB) for initial scene calibration and an infrared mode (IR) for tracking the markers. Using an IR-camera in combination with retroreflective markers prevents ethical concerns of the elderly regarding video monitoring as the IR-camera can only see light reflected from the markers without seeing the user. The calibration is done instantly by projecting and capturing a checkerboard pattern with the camera in RGB mode. Any projected information at the location of the corresponding markers is based on geometrical calibration between the camera and the projection area. By limiting the interaction on the tabletop surface, we can calculate the homography between the camera coordinate system and the projection area.

For tracking and displaying the camera is switched to IR-mode. We use standard ARToolKit markers[22] for estimating the coordinates of the objects (e.g. menu card, a pillbox or a calendar) and the input paddle. Several markers can be tracked at the same time. To make the markers less visible to the users but easily visible in the IR-space we use retroreflective material. Using the homography, graphics for the menu-card can be projected onto the exact location and updated in real-time if the card is moved. The same can be done to any object with a marker on it. The system can handle pointing interaction with the paddle since location of the paddle can be estimated in each frame. For the ring, we use a different detection approach, as an AR marker on a tiny object is not practical. Instead, we track the ring from the IR-image by using the same retroreflective material on the ring's surface. To detect where a user points at with the ring, the IR-image is measured in eccentricity and ratio between width and height of a bounding rectangle along the axis of the orientation. The fingertip position is estimated as 5-6 centimeters from the ring's location and adjusted manually for each user if necessary.

3.2 User Interface Designs

While elderly users can be effective with technology, younger users adapt new devices and accumulate UI interaction methods in a faster pace creating a larger knowledge base. The elderly rely on existing mental models from past experiences that also apply to technology use. But the lack of experience with new technology like touchscreen devices or hand gestures creates obstacles for user interaction, so we studied how various selection methods would work in case of projector-camera systems. Home environment surfaces can act as projection displays, which is why in our test cases a table was used as an interactive surface. It also enables haptic properties, as it is a physical object that can be touched. The large interaction area also makes manip-

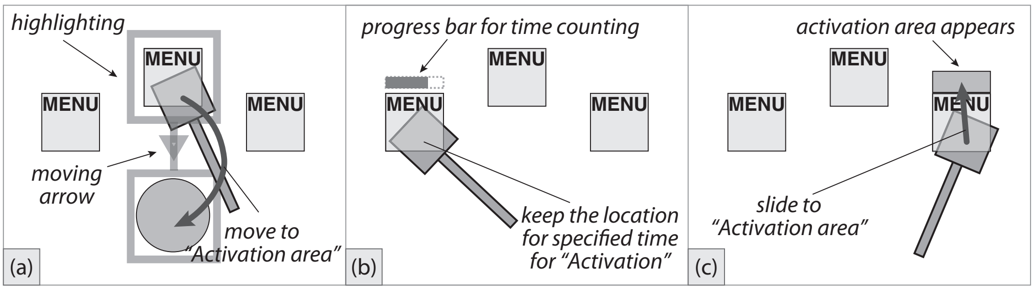

Fig. 2 Selection methods; (a) two-step, (b) hover, (c) slide.

ulation easier as there is no need for fine movements whereas small touchscreen need precision. The designs for the user interface are aimed at elderly based on the following considerations on existing guidelines[23)24)]. 1) We limited the number of icons to a maximum of eight so that the user does not have too many choices to interact with. 2) We considered how the layout for hand interaction should be performed with easy access to icons for the users. Based on average human arm ergonomics, a 50 cm length for a tabletop surface interaction was calculated to be sufficient and transferred as our detection capture area size limitation. Multiple rows of icons were unnecessary due to the reduced amount of icons and there is less chance of the user blocking information accidentally by having the interaction space as an arc. An arc shape also follows the arms natural movements in tabletop interaction.

The elderly often have a diminished field of view[10)], so we placed the icons in the center of the table. 3) We created larger, dynamic sized icons 1.25 times the size of the paddle (the physical size of it was approximately 5 cm×5 cm), with big fonts spread out evenly with an icon-icon distance of 1 cm. This also limits the amount of icons you can use on the current projection surface as seen in Fig. 1 (b) while keeping the user's focus in the same area. Research by Bakaev also support using larger icons for elderly users as it increases their interaction speed[25)]. 4) To help the user understand where the system tracks their finger's location a red circle is projected right in front of the input finger's tip as a cursor.

We wanted the users to clearly verify their choice of an icon because completion of critical tasks such as medication intake by a memory impaired individual should be forwarded to a doctor or to family members. To enable menu selection, we chose two interaction methods that have an additional verification step as shown in Figure 2 (a) and (c). But to reduce the number of interaction steps, we also chose a common time-based hover method as shown in Fig. 4 (b) for comparison. Tapping is a viable method for ProCam system but because motor skill impaired users have problems with tapping and accuracy[26)] in this study we implemented methods that require the user to only move over a target area for selection.

The **two-step method** (Fig. 2 (a)) uses a central verifying icon. The selection works by 1) first choosing a desired icon e.g. 'make a call' 2) then moving the finger to the confirmation icon 'SELECT' appearing in the center of the UI. This activation step was created in order to avoid unconscious or accidental selection. It also provides a single activation icon at a fixed location under the assumption that the same location is easy to see and learn. We added a highlight box around the icons when hovered over and an arrow to point to the activation area for clarification for the user. Dwell time on input was immediate. Distance to activation icon was 12 cm.

The **hover selection** (Fig. 2 (b)) is a common technique where selection is done, by holding a finger above an icon for a short period of time. We expected this method to have less errors compared to the other two, as the user does not move their finger from the selection spot. Additionally, touching a single icon might be a more intuitive for interaction. The speed of selection can also be customized for each user, as we do not know which speeds are suitable for the elderly participants. Dwell time on input was one second and four seconds.

In the **slide method** (Fig. 2 (c)) the user places their finger on top of an icon and the activation area 'SELECT' appears immediately above it. We assumed the elderly focusing on an icon would more aware of the activation icon as it appears in their point of focus. This method was expected to alleviate the problem of a narrowing field of view often presented by old age and reduce large movements of the hand. Dwell time on input was immediate.

4. User Study

After initial pilot tests, we conducted a user study with a task of performing a video call. We wanted to observe the UI interaction capabilities of the elderly while using touch-based selection methods on a ProCam system. We studied how inexperience with new technology, how cognitive and motor skill impairments and individual's characteristics affect the use. In addition we also wanted to compare younger (Y) and elderly (E) users' performance differences, and if a purposefully slow dwell-time-on-input differed between the elderly and younger users. We used a 4-second delay on our hover method, which normally had a 1-second dwell-time-on-input. Our hypotheses were that 1) the elderly would perform slower and make more errors due to aging impairments, 2) there is some tradeoff between using a method with and without verification steps on a ProCam system, and 3) system responsiveness affects younger users more than the elderly. We wanted to examine the exact nature of the tradeoff. It is important to note that normally testing user interface for example when using Fitt's Law[23], the assumption is that each user is cognitively and physically on the same level. In the case of the elderly, however, individual impairments of memory or motor skills affect this premise, so qualitative analysis is required. Due to the scarce availability of similarly skilled and impaired elderly users for the tests, especially in the case of memory impaired individuals, our study is limited in scale and scope. Agreements for tests, data collection and use in publications from the elderly users was gathered before the test. In the case of more severe mental impairment, the agreements was given by a family member as a legal guardian, but these cases were not used in our data analysis. In the experiments, we collected quantitative data to discover trends, which can then be explained using qualitative data from interviews and observations. Before testing, we also consulted an ethical committee who declared an approval was not required in our case.

4.1 Selection Methods Comparison

Participants: A total of 23 users participated in the test. Five elderly participants had to be excluded before and during the test due to severely diminished cognitive and physical capabilities. Therefore, a total of 18 participant's results were analyzed. Nine were randomly chosen students from University of Oulu, Finland (mean age 26.6) and nine were elderly users (mean age 89.1) available from two care-homes in Finland living there either permanently or in an interval care stay period. From the available pool, the elderly were chosen based on their need for assistance on Instrumental Activities of Daily Living (IADL) and their Mini-Mental State Exam (MMSE) scores between 30-12. In summary, a score between 30-27 is normal aging, 26-24 is either normal or mild cognitive impairment (MCI), 23-18 is mild dementia, 17-12 is moderate dementia and 11-0 severe dementia. Eight elderly users had memory impairments, four with AAMI and four with mild to moderate Alzheimer's. Motor skill limitations ranged from severe arthritis to slight hand tremors and joint stiffness on nearly all of the elderly. None of the elderly participants had used smartphones with a touchscreen or any type of tablet device. Only two elderly users had some experience with computers, one for work and one for writing at home.

The participants had short pre-interview on their technology experience (PC, tablet, smartphone, older mobile phone), impairment status (medical records)and a longer post-test interviews for test feedback. The participants filled out a questionnaire during and after the test. Table 1 details the elderly participant and general impairments based on the medical records and questionnaires.

Task: Making a video call task was chosen because elderly often need to communicate with family members or caregivers. Task itself is self-explanatory to everyone and thus should require less learning but with new interaction methods. The steps for the task were:

(1) Place the menu launcher card on the table to open the main menu
(2) Select 'Make a call' icon from the available five options
(3) Select the right person from six possible alternatives (shown as photos and name labels)
(4) Close the call by selecting the 'End call' icon
(5) Return to main menu by selecting 'Return' icon

Procedure: The ProCam system was installed on-location at the university for the students and in the two care-homes for the elderly. Before the tests, the systems main purpose as an assistive tool for the elderly was explained, and the large projection area on the table was identified as the usable interaction area. Finger pointing and the paddle were explained as the input interaction tools. No guidance was given to the users during the test. Test administrator (TA) assisted if there was a system error or if the user felt they could

Table 1 Characteristics of the elderly participants based on medical records.

No.	Age	Sex	Cognitive	Physical
1	87	F	None	Stiffness in hand/wrist, reduced hearing
2	88	F	AAMI	Slight hand tremors, hearing ok
3	94	F	AAMI	Stiffness in hand/wrist, reduced hearing
4	90	F	AAMI	No motor skill impairments
5	87	F	AAMI	Arthritis: limited hand/wrist movement
6	91	M	Mod. Alz.	Hand tremors, reduced hearing, left eye surgery
7	91	M	Mod. Alz.	Hand tremors, reduced hearing and corrected eyesight
8	92	M	Mild/Mod. Alz.	Stiffness in hand/wrist, slowness in movements
9	82	F	Mild Alz.	No index finger in dominant hand, little motor skill problems

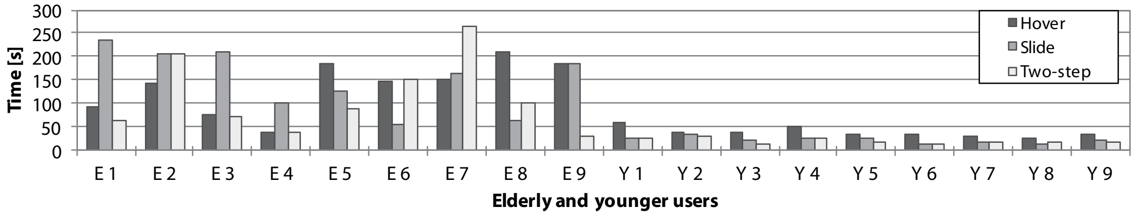

Fig. 3 Comparison of completion time in each method: (a) hover, (b) slide, and (c) two-step methods. (E=Elderly, Y=Younger.)

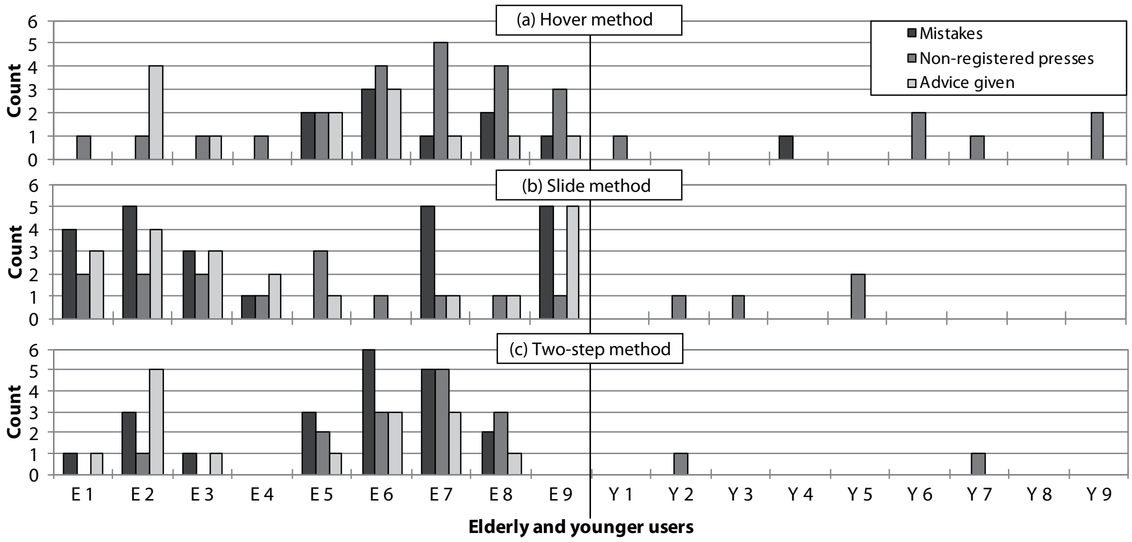

Fig. 4 Comparison of mistakes, non-registered pressed, and advice requested in each method: (a) hover, (b) slide, and (c) two-step methods. (E=Elderly, Y=Younger.)

not proceed. Each user completed a video-calling task twice to different targets while using all the three interaction methods (slide, hover, two-step). We cross-compared all methods with each participant. The participants were told to think-out-loud while using the system as the sessions were video recorded for closer analysis. A pre-and post-test video interview and questionnaire was also conducted to gather feedback in more detail. The interaction data was logged automatically. The methods were within subjects counterbalanced to avoid interaction-learning bias and a comparison between the younger users and elderly users was done.

Result: The task completion time variables were normally distributed as shown in Fig. 3. Levene's test for equality of variances showed that the variances in the two groups were not equal. As hypothesized the elderly (E) were slower in all methods compared to younger (Y). The independent t-test revealed statistically significant differences ($p<.05$) between groups for two-step $t(16)=3.4$, slide $t(16)=5.7$ and hover $t(16)=4.7$.

Figure 4 shows the elderly (E1-9) and the younger (Y1-9) users' mistakes, non-registered presses, and advice requests, using all three methods. We used the Two-sample Kolmogorov-Smirnov test to compare mistakes between the young and the old separately for each three methods. Statistically significant differences ($p<.05$) were found between the groups for slide method ($p=.037$) and two-step method ($p=.009$). We also performed non-parametric tests since the size of the sample

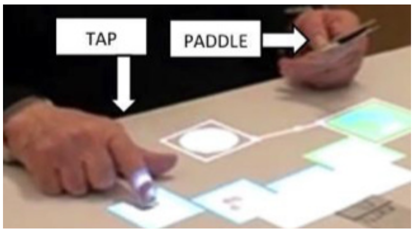

Fig. 5 User taps with the finger even when he was supposed to use a paddle to select.

Fig. 6 User obscuring an icon with the hand.

Fig. 7 Trying to select and icon by pressing with the ring instead of the fingertip.

data is small. Comparing all three methods between users with AAMI and Alzheimer's, statistical significant differences were not found. On the other hand, when comparing each method to one another using the Wilcoxon signed-rank test, we found a slight tendency to produce less mistakes between two-step and hover for users with AAMI (p=.059). Users with Alzheimer's users did not have (p=.317) the same tendency. While there was no significant difference regarding mistakes between all of the methods among the elderly users, there was a tendency (p=.053) for hover method using the Mann-Whitney test. For the elderly, the hover method (H) produced the least number of mistakes compared to slide (S) and two-step (T) methods, H: 9, S: 23 and T: 21 mistakes. The elderly also made more mistakes (E: 58, Y: 1) compared to the young. Due to the intentionally slowed down selection speed of the hover method (4-second delay) in one test, the younger users felt more frustrated compared to the elderly users, which was expected. In contrast, the elderly users felt the slowed down selection made them feel more in control and they had more time to comprehend the user interface. This also reduced the number of accidental selections in comparison to the other two methods.

Cognitive impairments resulted in three users calling to a wrong target person as a result of forgetting the task description. Both groups preferred the ring (16 users) and the reasoning by the elderly were e.g. "it's natural", "I cannot lose it", "this is easy" or "it felt comfortable".

When presented with a paddle for interaction and not the ring, we still observed many users tapping the icons with their finger instinctively even without guidance (Fig. 5).

Several repeating problems occurred where the users mistakenly tried to interact with the tooltips, guiding text boxes or users obscured icons accidentally (Fig. 6). While using the ring was natural for most, some tried to use the ring itself for selecting instead of using their fingertip (Fig. 7).

Using a guiding cursor resulted in users hovering over the interaction area instead of touching the icons straight. We also observed the elderly often reading the menu or the instructions out loud by pointing at the icon or text.

During the hover method, many elderly users did not hold their finger above the icon long enough to successfully register a selection if they did not understand the time-bar concept. Younger users noticed the selection progressing with the time-bar icon.

4.2 Grouping based on impairments

A person's age is not a significant factor in how well the elderly can use new technology. Instead various impairments vary from individual to individual although age might increase the likelihood of some form of impairment over time. We divided the elderly into different groups based on their cognitive or physical capabilities: People with A) normal or very mild cognitive impairment B) with cognitive impairment C) motor skill impairment D) visually impaired. We looked at the overall performance with the given tasks of the different groups and noticed the following. Group A without cognitive deficiencies needed less time with the interaction and could adjust to various selection methods effortlessly. Group B with cognitive problems needed more time and less complex input methods. The more options they had, the more likely they were to make mistakes. Group C with motor skill issues required direct input methods with the ring and could not properly hold objects steadily in their hands due to diminished grip strength, arthritis (Fig. 8) or hand tremors.

Their impairment also slowed down interaction speed and accuracy for pointing actions. Group D had people

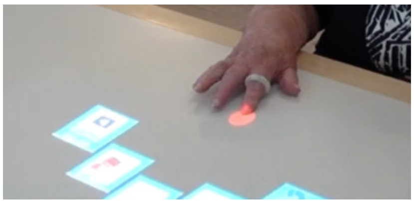

Fig. 8 A user suffering from arthritis wearing the ring was faster and more precise than with a paddle input tool.

with eyesight deficiencies in both or one eye. The group could interact with the UI well, as the icon sizes were large enough for all the users. However, age associated diminished field of view affected icons on the edge of the UI. Some users did not always see a change happening in the UI as it was located outside if their eyes peripheral vision. As an additional group E reluctance to use technology was created for some users. This group of users managed to use the UI interaction with varying degrees of success, but mostly the reasons for failure or slowness was a lack of confidence. They needed encouragement to proceed. Feelings of accomplishment through successful use of the UI were beneficial the further a test proceeded. Encouragement from other elderly on their successes was also a positive factor to get the reluctant users to do the experiments. It is important to note that many of the users are within several different groups, so interaction should be designed around a single user's personal capabilities. An adaptive UI is the most obvious solution to the various problems the elderly users might have.

5. Discussion

Our user study focused on finding out how ProCam systems should be designed for elderly users. The elderly participants we had in our user study had different preferences for selection methods due to the various physical and cognitive impairments so flexibility is needed. The commonly used and well researched tapping detection is a viable method for elderly technology use[18], but as discussed by[26], tapping can be problematic for motor skill impaired users. We avoided this problem by testing interaction methods that are based on area pointing. Yet, observations suggest that even area pointing has difficulties derived from age-related impairments. We cannot clearly say which method is the most suitable for each user even if we know their impairment levels. This is most likely due to the small sample sizes used in our test.

Interaction design for ProCam's has some similarities with touchscreens, but overlaying on top of objects is not possible with a touchscreen device. While the users felt that interacting with real-world objects benefitted from overlaying assistive graphics on top of objects, some users blocked UI elements with their body. Thus, interaction space needs to be clearly indicated so that the user knows its borders. When the projection is on top of objects, the association between the object and the graphical elements is easy to make as the object itself creates a perceivable border. More importantly objects themselves can be the interactive surface the user manipulates. With a touchscreen it is possible to point to the objects placed on its surface but as soon as you remove them from the screen, any interaction becomes indirect and presumable more difficult for elderly users to comprehend[19].

Regarding selection, we tested three methods for elderly use but did not find one single method that was the most suitable for all of them. As expected, our hypotheses confirmed the elderly's slow performance and high error count. While the hover method was the least error-prone for everyone, again preferences and impairments affect which method is the most suitable for each user.

For future research, it would be beneficial to look into how sequential tasks could be assisted with projection. In our study, the amount of guidance needed for each user was inconclusive. We would need to clarify if, for example, worse MMSE scores affect the amount of information that should be offered to the user at one time. Notably, the current system is not suitable for users with more severe forms of dementia, as these users need a more refined solution that is not possible with the current level of features. This study showed that currently, the design approach is more suitable for normal or slightly memory-impaired elderly users. In the long term, we aim to extend ProCam-based systems towards intelligent adaptive elderly care technology that would be able to track and analyze potential decline of performance in daily tasks. This would allow e.g. displaying more guidance when a person loses focus and stops a task suddenly. Or it would enable caregivers to target their support to the most necessary situations or even automatically analyze the impact of improved medication plans. Furthermore, as a limitation our system does not take into account the three-dimensional plane so all tracked objects were registered on a flat surface. Also the verification of a selection should be tested with tapping functionality in addition to area-selection methods.

In general, projection next or on top of objects does not confuse elderly users as using various projection types were clear for the elderly: 1) The elderly treated the table surface as interactive area naturally. 2) Assistive projections (menu card) were understood as being related to each other. Yet, we observed various unexpected challenges in the use of our system especially with memory impaired. We therefore suggest that ProCam systems should be adapted for each person's interaction capabilities. Based on the user study and on the user behaviors with the system (Fig. 9), we recommend taking into account the following points when designing similar systems for elderly users to increase the likelihood of better results:

(1) A cursor-like element may confuse some users, young and old, as the basic interaction is already understood as being finger or a separate control-object operated. Our added red pointer only added to the confusion and caused the interaction to turn from direct to indirect interaction.

(2) Decline in cognitive skills will most likely result in reduced understanding of the interaction. In these cases it might be suitable to slow down the interaction speed and reduce the amount of elements for the users.

(3) Several selection methods should be available for different impairments or preferences of the users. In the case of motor skill impairments, some approaches may obstruct or even prevent using just one method. Each of the selection methods we tested (slide, two-step and hover) was seen as the best method by some of the participants.

(4) Motor skill impairments may prohibit use of more complex ways of interaction. For example holding an object or rotating the wrist was shown to be difficult for many elderly. This stiffness of joints or weak grip limits the UI to simple pointing by finger or open hand interactions.

(5) Visually impaired users need graphical indicators for the UI if the elements are at the edge of their vision. The same feature would be also beneficial for regular users as diminished field or view is common among the elderly population[10]. This is a tradeoff between using a large projection and the users ability to see or realize the location of all of the graphical elements

(6) Encouragement to the use of an assistive systems should come from other elderly to create trust for the device. When a user interacts with the system successfully, it should also create feelings of accomplishment that will also increase the likelihood of repeated use.

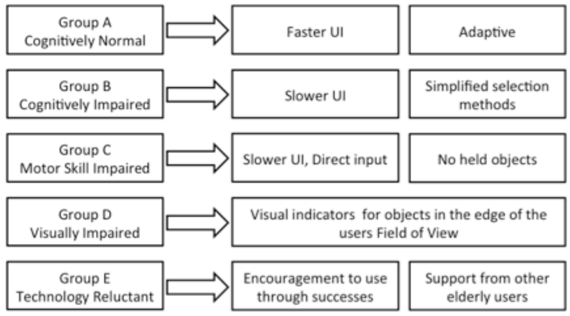

Fig. 9 User groups and the suggested solutions to their various impairments.

6. Conclusion

We argued that the increasing amount of new technology is difficult to use for the elderly due to inexperience and is most often not designed specifically for them. We studied if ProCam would be usable as assistive technology when the elderly have cognitive and physical impairments.

The findings from our user study suggest that ProCam is a viable technology for assistance if the interaction and the usability is properly adapted to each individual's skills. Each user's individual combinations of both cognitive and motor skill deficiencies prohibited one-for-all interaction design in our study. But in principle, the use of projection can be an effective way to present information as the elderly find the graphical elements projected onto a table and next to objects easy to comprehend. We suggested practical design approaches that might improve the creation, testing, effectiveness and the likelihood of acceptance of ProCam UIs for the elderly. We encourage research on the effects of cognitive problems in interaction, but also suggest that motor skill impairments will be a factor in almost all of the user study cases.

This study was limited by the small amount of available elderly participants, so in our future research we aim to confirm the proposed design suggestions in a quantitative study, test the guidance of sequential tasks and how adaptable UI's could benefit the elderly users. Especially impact of different levels of cognitive impairments would require further studies in order to make future ProCam-based assistive systems practical.

References

1) H. Niemelä and K. Salminen: "Kansallisten eläkestrategioiden muotoutuminen ja Euroopan unionin avoin koordinaatiomenetelmä" (2009)
2) Centers for Disease Control (CDC). The state of aging and health in America 2013. Atlanta, GA: Centers for Disease Control and Prevention, US Department of Health and Human Services (2013)
3) D. Hawthorn: "Interface Design and Engagement with Older People", Behavaviour & Information Technology 26(4): pp.333–341 (2007)
4) T. Broady, A. Chan, and P. Caputi: "Comparison of older and younger adults' attitudes towards and abilities with computers: Implications for training and learning", British Journal of Educational Technology 41(3): pp.473–485 (2010)
5) N. Charness and W. R. Boot: "Aging and Information Technology Use: Potential and Barriers", Current Directions in Psychological Science 18(5) pp.253–258 (2009)
6) K. Mikkola and R. Halonen: "Nonsense? - ICT perceived by the elderly", The European, Mediterranean & Middle Eastern Conference on Information Systems (2011)
7) S. Ikeda, Z. Asghar, J. Hyry, P. Pulli, A. Pitkänen, and H. Kato: "Remote assistance using visual prompts for demented elderly in cooking", In Proc. International Symposium on Applied Sciences in Biomedical and Communication Technologies, pp.46:1–46:5 (2011)
8) A. D. Wilson: "Using a depth camera as a touch sensor", In Proc. International Conference on Interactive Tabletops and Surfaces: pp.69–72 (2010)
9) C. Harrison, H. Benko, and A.D. Wilson: "OmniTouch: wearable multitouch interaction everywhere", In Proceedings of the 24th annual ACM symposium on User interface software and technology, pp.441–450 (2011)
10) B. Sekuler, P.J. Bennett, and M. Mamelak: "Effects of aging on the useful field of view", Experimental aging research, 26(2), pp.103–120 (2000)
11) G. Yamamoto, Z. Asghar, Y. Uranishi, T. Taketomi, C. Sandor, T. Kuroda, P. Pulli, and H. Kato: "Grid-pattern indicating interface for ambient assisted living", In Proc. International Conference on Disability, Virtual Reality and Associated Technologies, pp.405–408 (2014)
12) G. Yamamoto, T. Kuroda, D. Yoshitake, S. Hickey, J. Hyry, K. Chihara, and P. Pulli: "PiTaSu: wearable interface for assisting senior citizens with memory problems", IJDHD 2011, 10(4): pp.295–300 (2011)
13) Y. Asano, H. Saito, H. Sato, L. Wang, Q. Gao, and P.-L. P. Rau: "Tips for designing mobile phone web pages for the elderly", In Proc. HCII 2007, pp.675–680 (2007)
14) C. L. Kelley and N. Charness: "Issues in training older adults to use computers", Behavior & Information Technology, 14(2), pp.107–120 (1995)
15) C. J. Ketcham, R. D. Seidler, A. W. V. Gemmert, and G. E. Stelmach: "Age-related kinematic differences as influenced by task difficulty, target size, and movement amplitude", Journal of Gerontology: Psychological Sciences, 57B(1) pp.54–64 (2002)
16) M. W. Smith, J. Sharit, and S. J. Czaja: "Aging, motor control, and the performance of computer mouse tasks", Human Factors, 41(3) pp.389–396 (1999)
17) L. Findlater, J. E. Froehlich, K. Fatal, J. O. Wobbrock, and T. Dastyar: "Age-related differences in performance with touchscreens compared to traditional mouse input", In Proc. SIGCHI 2013: pp.343–346 (2013)
18) Z. X. Jin, T. Plocher, and L. Kiff: "Touch screen user interfaces for older adults: button size and spacing", In Proc. international conference on Universal access in human computer interaction: coping with diversity, pp.933–941 (2007)
19) W. K. English, D. C. Engelbart, and M. L. Berman: "Display-selection techniques for text manipulation", IEEE Transactions on Human Factors in Electronics, HFE-8(1), pp.5–15 (1967)
20) N. Vigouroux, P. Rumeau, F. Vella, and B. Vellas: "Studying point-select-drag interaction techniques for older people with cognitive impairment", In Universal Access in HCI, Part I, HCII 2009, LNCS 5614: pp.422–428 (2009)
21) L. Findlater, A. Jansen, K. Shinohara, M. Dixon, P. Kamb, J. Rakita, and J. O. Wobbrock: "Enhanced Area Cursors: Reducing Fine Pointing Demands for People with Motor Impairments", Proceedings of the 23Nd Annual ACM Symposium on User Interface Software and Technology, No. 10, pp. 153–162 (2010)
22) ARToolKit: http://www.hitl.washington.edu/artoolkit/ Retreived 21.11.2015
23) R. W. Soukoreff and I. S. MacKenzie: "Towards a standard for pointing device evaluation, perspectives on 27 years of Fitts' law research in HCI", International journal of human-computer studies, 61(6), pp.751–789 (2004)
24) R. Hyman: "Stimulus information as a determinant of reaction time", Journal of Experimental Psychology, Vol 45(3), pp. 188–196 (1953)
25) M. Bakaev: "Fitts' law for older adults: considering a factor of age", In Proceedings of the VIII Brazilian Symposium on Human Factors in Computing Systems, pp. 260–263 (2008)
26) J. O. Wobbrock and K.Z. Gajos: "A comparison of area pointing and goal crossing for people with and without motor impairments", In Proceedings of the 9th international ACM SIGACCESS conference on Computers and accessibility, pp.3–10) (2007)

Jaakko Hyry received his M.Sc. and Ph.D. in Information processing science from University of Oulu in 2008 and 2015 respectively. He was a doctoral student at Nara Institute of Science and Technology between 2012-2014. He is going to work as a post-doc researcher at Yokohama National University from April 2017.

Max Krichenbauer is a doctoral student at Nara Institute of Science and Technology, Graduate School of Information Science, Interactive Media Design Lab. He received his B.Sc. from the University of Applied Sciences Upper Austria in 2010 and his M.Sc. from Nara Institute of Science and Technology in 2014. His research focus is 3D user intefaces for media production.

Goshiro Yamamoto received his B.E., M.E., and Ph.D. in Engineering degrees from Osaka University, Japan in 2004, 2006, and 2009 respectively. Since 2016, he has been a senior lecturer in Kyoto University Hospital. Before joining Kyoto University Hospital, he had been an assistant professor in Nara Institute of Science and Technology for five years.

Takafumi Taketomi received his B.E. degree in National Institute for Academic Degrees and University Evaluation in 2006. He received his M.E. and Ph.D. degrees in Engineering degrees from Nara Institute of Science and Technology (NAIST) in 2008 and 2011, respectively. He has been an assistant professor at NAIST since 2011.

Christian Sandor is an Associate Professor at Nara Institute of Science and Technology, Japan. He previously worked at Canons Leading-Edge Technology Research Headquarters in Tokyo, Japan. Before joining Canon, he obtained a doctor-ate in computer science from the Technische Universität München, Germany.

Hirokazu Kato received his B.E., M.E. and Dr. Eng. degrees from Osaka University, Japan in 1986, 1988 and 1996, respectively. Since 2007, he has been a professor in the Graduate School of Information Science of Nara Institute of Science and Technology. He received the Virtual Reality Techni-cal Achievement Award from IEEE VGTC in 2009, and Lasting Impact Award at the 11th IEEE Inter-national Symposium on Mixed and Augmented Re-ality in 2012.

Petri Pulli received his M.E. with the highest highest honours at the University of Oulu in 1981 where he also received his Ph.D. in 1991. He has been working as a professor from 1998 and currently also as the dean of education at the University of Oulu.