PiTaSu: a wearable interface for assisting senior citizens with memory problems

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ABSTRACT

Little research has been carried out on specialized wearable user interfaced designs to assist memory impaired senior citizens. This paper proposes and implements PiTaSu (Picture based Tapping on wall Surfaces) to realize direct user interface system to offer visual feedback and tactile feedback. PiTaSu is based on a pictorial based Augmented and Alternative Communication (AAC) system. PiTaSu consists of a body-worn or shoulder-attached mobile projector, a camera and an accelerometer wrist band. The projector shows information that will help assist the memory impaired senior citizen in their daily task. The camera and the accelerometer detect a tapping position and tapping trigger. Experimental results have demonstrated that a senior citizen can use PiTaSu without learning special skills, and the projection based user interface has potential. Therefore, PiTaSu can assist memory-impaired senior citizens as a daily task reminder.

1. INTRODUCTION

Memory related illnesses are a common problem with senior citizens. A number of industrialized countries have a rapidly aging population, and consequently there is a corresponding rise in age related memory illness. This paper describes one part of a ubiquitous information support for senior citizens with memory problem that can be realized through an intuitive wearable interface. The realization of the support acts as a key for providing comfortable living for both supported and supporting people. The SESC (Smart Living Environment for Senior Citizens; Metso, 2009) project has been conducted based on such an idea.

Most senior citizens suffering from memory problems can tell their intentions though they are weak in their acknowledgement of time events. If they can access the information they need, they can have the potential to live independently. To realize this support using computer power, an easy-to-use interface is necessary and important for the senior citizens. Currently, health care professionals use Augmentative and Alternative Communication (AAC) to help people with memory problems in their daily activities (Tetzchner, 1992). There are numerous AAC methods. The representation system used in AAC include gestures, hand signal, photographs, pictures, line drawings, words and letters, but also different ways of managing computer aided communication tools. In this paper, a pictorial bases system is used with image-printed tags or pictures that can be placed on walls or places and these are shown to other people. AAC method that focus on picture communications using these tags or pictures are a common means to support memory-impaired patients perform daily tasks. The number of tags or pictures changes according to the complexly of the communication. It is difficult to make a deep conversation using physical real object as tags or pictures without mobility.

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This paper focuses on a user interface using a projection-based wearable system for assisting senior citizens with memory problems to support one type of pictorial based AAC system. Using mobile projectors would turn physical surfaces into information displays, thus providing ubiquitous information in a daily living environment. There are three main advantages for using projectors compared with flat panel monitors; Firstly, projectors can achieve a wide display originating from very small devices. Secondly they're able to project information on many physical, flat surfaces. Third, they provide a greater mobility that move with the person rather than been confined to fix contexts. These elements have potential for personal use applications added in mobile or wearable computing. There are some studies for developing a novel user interface on PROCAMS (projector camera system). The systems have one feature in common, which is to attach physical markers on a target surface for achieving stable projection of virtual images. The feature has a problem that a projected area which provides stable enough images are limited to surfaces that have attached markers.

In this paper, a wearable PROCAMS, PiTaSu (Picture based Tapping on wall Surfaces), with a novel user interface is proposed. The system accepts tapping action onto wall surfaces as an input, as shown in Figure 1. It is thought that tap action is suitable as an interactive input interface because it is operation that everyone is able to do easily. A contextual background system provides relevant information based on users action history from a database, but this part of the system is out of the scope of this paper. Since users tap real surfaces for physical input, they can get a sense of haptic feedback when tapping a wall. In this proposed system, projected images aren't corrected with markers. We think that users could recognize contents of a bit distorted images, or they can change the orientation of the projector to correct that.

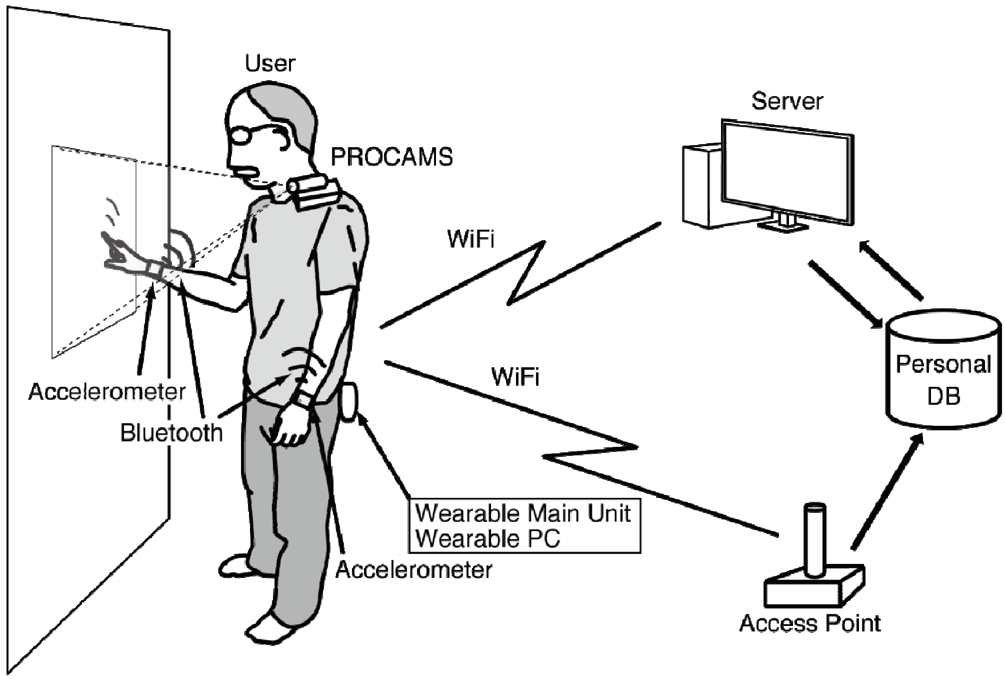

Figure 1. *Conceptual overview of proposed projection based wearable system. The wearable system that consists of PROCAMS and accelerometer and computer connects with server and access point via WiFi.*

2. A WEARABLE INTERFACE IN SMART LIVING ENVIRONMENT

Senior citizens have certain needs that designers normally don't have to take into account when designing new systems as the primary target groups often consist of a younger user base. Instead of making elderly people understand deep and often complex structures of varying mobile phone user interfaces, and the meaning of arbitrary icons and illogical functionalities created from bad design choices, the aim should be about simplifying things and taking advantage of the skills everyone learns when they grow up. Learning new things becomes slower with age (Kelley, 1995) and senior citizen also have a tendency to reject new technological devices (Bjørnerby, 1999), even though they could offer benefits to their lives. Advantages of PiTaSu design choices, which is the proposal system in this paper, is that the user is able to use it without learning new control methods, as opposed to hand marker based gesture navigation with colour markers added to fingers (Mistry, 2009) or using IR-led fingertip attachment (Karitsuka, 2003). Research on the wearable user interface needs focuses on Alzheimer's disease and its close, treatable variants. This is because a vast amount of different memory related illnesses require specific, customized designs. Other illnesses, such as semantic dementia, can present symptoms that are difficult or infeasible to assist with different technological devices. Choosing Alzheimer's is feasible because of the nature of the illnesses symptoms, such as episodic memory functioning problems (Dubois, 2007) and its frequency among the elderly. Based on discussions with medical doctors and a neuropsychologist, it can be also considered feasible for these technological aids to improve the lives of the patients. It is also possible that they assist in slowing down the rate of brain functions deterioration via memory supporting effects, environment, and with services originating both inside and outside of the living environment.

The user interface design used in this work is based on a path structured approach as shown in Figure 2 (Pitkanen, 2010). The language reads from left to right, with the left most pane featuring the key needs of the user, e.g. 'I want'. This first pane can be filled with alternatives which are partly based on the senior citizens contextual situation. Once a picture is selected, e.g. I want, a second list of options is opened in the 2nd pane, such as 'to go' or 'to call'. When one of these options is selected, the 3rd pane is opened with a further list of options, and so on. The selected options which make up the activity are shown at the top of the UI, in this case 'I want to call Anna'. The language also works in the reverse, with health care professionals creating a message for the senior citizen which can be linked to a context. When the senior citizen is in that context, the message can be shown to them pictorially.

The main interactions with the system are done with two separate user interfaces - one for the medical personnel or a trusted person, and one for senior citizen user. For example the doctor can add appointments to senior citizens calendar via a computer interface or they can monitor current health or check medical history of the user. A trusted family member can check if senior citizens calendar entries are acceptable and do not have any inconsistencies. Graphical user interface for the senior citizen is built up of different modules as shown in Figure 2 left. The communication module has tools for video, phone calls and messaging. The guidance module is a subset of two areas, home and outdoors, and handles information of routes, locations and instructions for tasks. The home module is designed for home specific tasks, such as cooking or reminders. Scheduling module is split for multiple users as data acquisition and entry is possible from different terminals. The emergency module handles direct requests from the user or via automatic recognition and forwards these to the appropriate party.

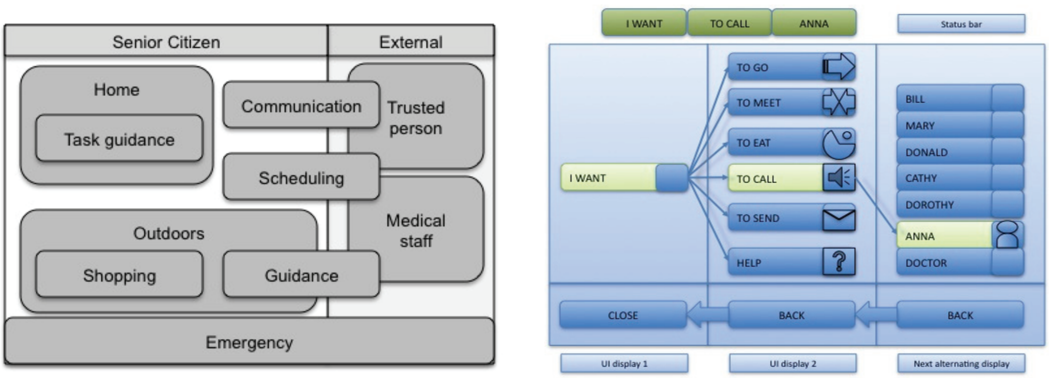

Figure 2. *Left: Modularity overview. Right: Senior citizens path-structured user interaction UI concept example.*

3. PiTaSu: SYSTEM OVERVIEW

This paper shows a proposal system that combines an accelerometer with a projector and camera, as shown in Figure 1. Using this wearable PROCAMS, which is called PiTaSu (Picture based Tapping on wall Surfaces), a novel user interface is suggested. A user takes on this projector-camera unit around on their own shoulder or chest, and wears an accelerometer on their own wrist. It offers and intuitive interface that accepts tapping images on wall surfaces as input action. To realise this proposed tapping input interface, PiTaSu should detect tapping trigger and a position of a finger-tip on the wall surface projected with light. In this section, the method of processing to detect this information is described.

3.1 A Process to detect tapping

The following describes how to detect direct tap input in PiTaSu system. The method is divided into four steps: detecting tapping trigger, calculating homography matrix, recognizing the hand area and estimating the finger-tip position, as shown in Figure 3. It explains each steps separately for 3.2 – 3.5 section.

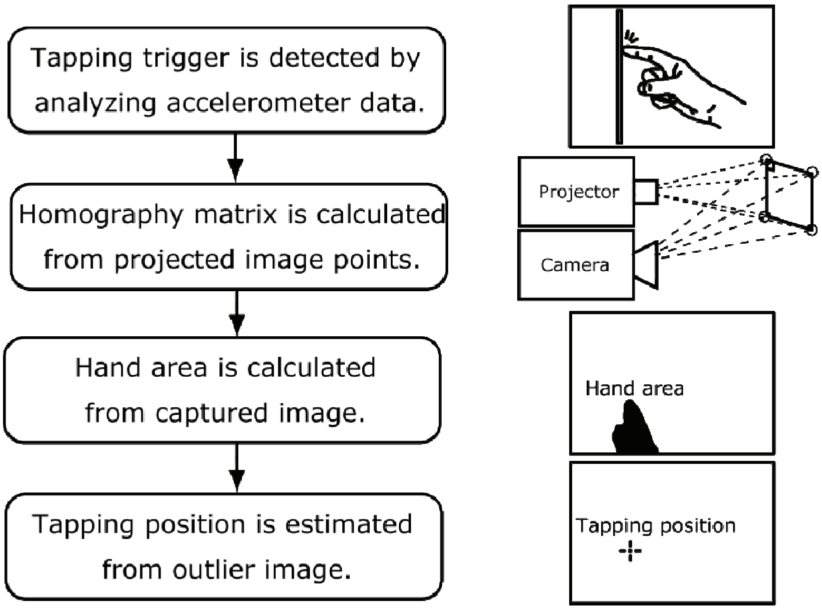

Figure 3. *Flow chart of processing to detect tapping and pointing finger-tip position. This process consists of four steps; detecting tap-trigger, calculation of homography, recognition of the hand area, and estimation of the finger-tip position.*

3.2 Detecting Tap-Trigger

The vibration of a user wrist when the user taps on surfaces can be acquired because the accelerometer is worn at the user wrist. Tapping trigger is detected from a sequence of acquired accelerometer data on user's wrist through a FFT. When a spectrum value exceeds a certain threshold value in a high frequency area, the action in that time is recognized as tapping. This system uses simple processing though it is necessary to use a method such as PCA to achieve recognition with high accuracy.

3.3 Calculation of Homography Matrix

It is necessary for detecting the tapping position on a target surface to calculate the homography matrix. The homography is calculated from four projected points on the surface. Some input hand motions, however, intercept one of these points. Therefore PiTaSu estimates a point from the relationship among three projected points on a wall surface. Then, a homography is calculated from using these four points.

3.4 Recognition of the Hand Area

A ray transfer model (Grossberg, 2004) could be defined for PROCAMS where the brightness ray from the projector is reflected on a target surface and captured. When it's assumed that the ambient light source and ratio of surface reflection are equal on the whole the projection area, we can define transfer ray and ratio of reflection as a simple equation in each case (RGB). The equation of transfer ray I_c is as follow,

$$I_c = R(I_p + I_0) \quad (1)$$

$$= RI_p + RI_0 \quad (2)$$

where I_0 is an environment light source, R is a ratio of a wall surface reflection, I_p is projection ray from the projector. In addition the environment light source and the ratio of the wall surface reflection are unknown variables. When it is assumed that the environment light source and the ratio of a wall surface reflection are equal on all of the projection area, then, we can define that RI_0 as a ray of 0 for projector brightness and substitute $I_{cBK} = RI_0$ for Equation 2.

$$R = \frac{I_c - I_{cBK}}{I_p} \quad (3)$$

The ray from projector has three values of RGB light source. Equation 2 and 3 are operated as follows,

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$$I_{c*} = RI_p + I_{cBK} \quad (4)$$

$$R_* = \frac{I_{c*} - I_{cBK}}{I_{p*}} \quad (5)$$

where * in Equation 4 and 5 means a value of RGB light sources.

If we assume that I_{cR}, I_{cG}, I_{cB} and I_{cBK} are reflections from a wall surface, then we can calculate the transfer function of the PROCAMS model. Using the calculated transfer function of the PROCAMS model, the brightness of reflection on the surface can be estimated. The system compares this estimated brightness and a captured brightness by camera, to judge the existence of an outlier. Only some projection rays are used to calculate because comparing all of the projection rays increases computational complexity.

Figure 4 (a) is one of outlier image. This image has noise from shadow and defocus. To recognize the hand area, outlier image is processed with labeling operation and the result is shown in Figure 4 (b). When it is assumed that an input action must enter the projection area, the hand area has captured-screen edge. Therefore, the area that has not captured-screen edge, is considered noise. In addition, the largest area that has captured-screen edge is recognized as a hand area.

(a) (b) (c) (d)

Figure 4. *Detect finger-tip pointing position from outlier image. (a) one of outliner images, (b) the result of labelling operation, (c) the outlier's edge, (d) finger-tip pointing position.*

3.5 Estimation of the Finger-tip Position

The recognized hand area image is processed with edge detection. Then, a distance from image-screen edge is calculated along the hand area outline, as shown in Figure 4 (c). Furthest point on the outline is estimated to finger-tip direction, as shown in Figure 4 (d). Finally that same point is defined as finger tips position.

4. EVALUATION EXPERIMENT

The prototype system is developed and the usability of the tapping input interface is evaluated through user testing with elderly people. The performance evaluation was also verified to confirm an input response time, resolution and available environment.

4.1 Prototype System Configuration

The prototype system consists of a projector (3M^{TM} Micro Professional Projector MPro110, SVGA), a camera (Logitech QuickCam Vision Pro, 960x720 pixels), an accelerometer (ATR-Promotions WAA-006), and a computer (Lenovo ThinkPad X61, 271g), whose weight is 271g excluding the computer. Figure 5 shows an appearance of the prototype system and a user interface design on the system. At first, the camera is calibrated using Zhang's method (Zhang, 2000) to get undistorted images. The projection image has a colour marker at left-upper side to detect a hand area. The colour marker consists of 4 colours; Red (255, 0, 0), Green (0, 255, 0), Blue (0, 0, 255) and Black (0, 0, 0) in RGB colour space. Using this colour marker, the system calculates RGB colour transformation matrices in each frame. Then, four points at corners of a projection image are used to calculate a homography matrix.

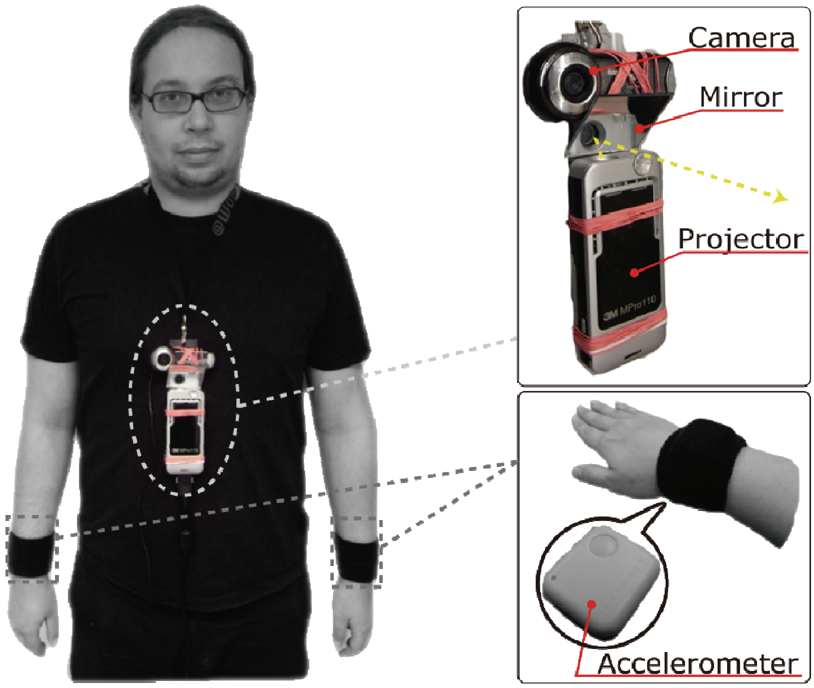


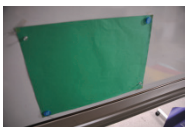
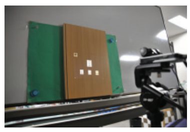
Figure 5. *Prototype system overview. A projector-camera unit is hanging on user's neck. An accelerometer is worn on user's wrist by wristband.*

4.2 Evaluation of System Availability

To confirm available environments of the system, the projection experiment was executed for some surfaces. In this experiment, five materials were chosen as projection monotone wall surface. These surfaces properties (material and Lab colour space) are as follows; drawing red paper (56.26, 61.98, 29.59), drawing green paper (97.75, 3.86, 89.56), drawing yellow paper (61.48, -38.4, 16.98), mat surface wood (112.4, 8.03, 17.74), and shiny surface wood (73.88, 13.06, 43.08). These colour properties are measured by a chroma meter (KONICA MINOLTA CS200).

A projection and a tapping input that were the fundamental system operations were done to each material surface. As the results, shown in Table 1, there were problems for drawing green paper and mat surface wood although the system operated normally for other materials. The result for drawing green paper shows that the acquisition radiance value of the colour marker was low, and the reflection from the wall was judged as a hand area. Mat surface wood interferes in the distinction between the wall and the hand area.

Table 1. *Results of evaluating system availability for five materials.*

Appearance of Material	 Drawing red paper	 Drawing green paper	 Drawing yellow paper	 Mat surface wood	 Shiny surface wood
Chroma meter value in Lab colour space	(56.26, 61.98, 29.59)	(61.48, -38.4, 16.98)	(95.75, 3.86, 89.59)	(112.4, 8.03, 17.74)	(73.88, 13.06, 43.08)
System availability	Available	Not available	Available	Not available	Available

4.3 Evaluating Reactions

In this usability test, a senior citizen subject is given a simple task, which is to select the projected images. The senior citizen has no previous experience or training in the use of the system. The senior citizen subject is 84 year-old man and never tested dementia level. The subject cannot raise his arms much above shoulder height because he has shoulders slightly sore. Figure 6 shows the user interface design of the experiment.

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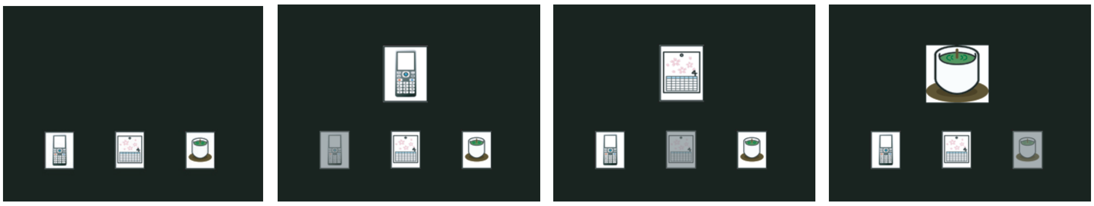
There are three selectable pictures in the bottom of the screen, and the user taps one of these pictures. Then, the system presents at the top area of the screen the tap-selected picture. The experiment consists of two steps. The first step is to confirm that the projected images allow the subject to tap them like a button without previous training. The second step is to confirm that the senior subject could use the interface and what issues they had in using the interface. After the tapping tasks, the subject answers three questions.



(a) (b) (c) (d)

Figure 6. *User interface configuration. (a) Initial screen, there are three selectable pictures in the bottom, (b, c, d) The top bigger pictures is presented according to user selection.*

Through an active observation of the senior citizen subject in step 1, it can be seen that he can touch projected images as the input action without an explanation on how to use it. After training, the tap task of 40 trials is given to the subject for calculating tap recognition rate. In the result, there were 22 successes (55%), the false detection of 9 times, and 9 no detection. The following are answers to the questionnaire.

- *Does wearing the device feel strange or uncomfortable to you?: Not really. The device is not heavy and I can imagine wearing it throughout the day. The device does feel a bit loose, though. It should be more stable. The picture displayed swings around the wall as the device moves.*
- *When inputting with the device, do you feel any strange or difficult points?: Not really, but I would imagine that if I will use the system whole day, my fingertips might become sore. I thought that maybe I will need some kind of protection for may fingertips.*
- *Anything else about the system?: All the icons did not look like what they supposedly were representing. Teacup looked like a candle and the cellphone looked like a door. The calendar icon, however was easily recognized.*

5. DISCUSSION

The performance of this system and its user interface was confirmed through two experiments. In this section, the usability of the system and the effectiveness of the user interface for senior citizens are discussed by the experimental results.

The first experiment that was to confirm system availability, it was clarified that the system had weak points according to the surface condition. On the surface of green drawing paper, the system cannot process the necessary calculations for projection because the radiance value of the projected markers cannot be observed through the camera. It is thought that this material is a dark shade, and consequently it has the characteristic in which the projector light cannot be strongly reflected. One solution is to have much stronger projector light. Because a device exists that projects a much brighter light compared with the projector used in this the prototype system, the possibility that this problem can be solved is high today. On the other hand, it is one of the factors which can limit system available environment because there are generally a lot of surfaces (especially wall) in an interior of a house, e.g. like white. On the surface of mat surface wood, the system cannot distinguish the presence of a hand, as the reflection surface property of the mat surface wood is similar to one of the hand. Therefore, wooden products in the house cannot be target objects to be projected. These problems should be considered with the influence by ambient light, and cannot declare a quality of this system from this experiment result categorically. A new prototype system might be made with a bright light projector and an experiment that includes ambient light as one of its components is necessary in the future.

The second experiment in which the senior citizen subject had used the system has been set to confirm a usability of a proposal direct manipulation interface based on projection. The result of the intuitive tapping task shows that the projected icons have an affordance to let the user tap onto it naturally. A point where this training is unnecessary becomes a major plus when it is assumed that senior citizens use the proposal system in smart living environment. Therefore, it is expected that this projection-based wearable system can offer senior citizens AAC communications anytime and anywhere. After knowing the usage, the usability of the system for the senior citizens was evaluated by observation of the subject during the tapping recognition task and by a follow up questionnaire. The recognition rate decreased by up to 55% in two causes. One is the process where the tap action is extracted from a sequence of the accelerometer data. In the prototype system, it is defined that a spectrum value of a high frequency area rises to a particular threshold. It is necessary to analyse the tap action by the principal component analysis etc. to raise the tap recognition rate. Another cause is in the process of estimating a finger-tip position. The estimation method depending on a distance edge to finger-tip has the possibility of causing a gap between a true tapping position and an estimated tapping position. The gap is sometimes caused easily when two fingers or more are used to do the tapping action. To compensate for this, new solution methods will presume a tapping finger-tip and expanding the tap reaction area.

In the following, the answer to the questionnaire is discussed. From the first answer, it was shown that this system did not give a user a feeling of discomfort when wearing it. This is a great result for a wearable system. However, the subject pointed out that there is a fault that a projected image swings according to a movement of PROCAMS when it is worn about the neck. As this solution, it will be possible to fix the PROCAMS to the body so that the PROCAMS should not swing because an approach from software is difficult. The second answer shows that a user was able to use this system intuitively. It is thought that one of the reasons why subject answer about the pain of his finger-tip might be repeating strong taps because of the low rate of the tap recognition. If a user accepts attaching something to their finger-tip, better accuracy of the tap recognition is possible. It is necessary to contemplate this wearing on a finger-tip in the future. For the third question, the subject answered the visibility of icons. As the focus length of the projector is not dynamically changeable, an image out of focus is projected onto a wall surface according to a distance. The visibility of the projected images decreases by out of focus. In AAC communications, it is fatal not to be able to distinguish the projected images. Therefore, it is necessary to present the guideline for making icons on this system to keep the visibility.

Some problems were found aiming at a development in the future as discussed by the above. Basically, the user interface that became important in smart living environment through this study was able to be made wearable.

6. CONCLUSIONS

PiTaSu has provided an intuitive tapping interface on a projection-base wearable system. This prototype system could detect finger-tip position on the target surface by comparing estimated reflection with the captured reflection. Using this system might offer users with memory problem an easier to use system with its haptic and visual feedback when user taps the projected images in the ubiquitous information environment. In smart living environment offered by P-SESC, the proposal system becomes the most important interface on the user side.

In the experiment results, the available environment and the effectiveness of the system were examined. The system was unavailable on surfaces which reflects projector light weakly and on surfaces which has a texture plane near skin-colour though it is possible to use on some surfaces. There is no major problem for the reflection of the projector light because the surface of a lot of walls in the house is like white colour. As it is difficult to distinguish the surface of matted woods from a hand, it is necessary to be careful in using the system and finding an appropriate image processing technique becomes one of future works. Through the user testing, it is shown that PiTaSu helps to assist memory-impaired senior citizens without learning special skills. Additionally, the senior citizens subject had no feeling of discomfort by using a wearable system, and it was confirmed that he tapped onto the icons naturally. If the processing algorithm of the accelerometer data is improved, the accuracy improvement is expected though the success rate of the input operation was 55%.

Future work will include a more comprehensive user testing planning for the senior citizens with memory problem. This would then help to determine the viability of establishing this interface technology in future smart living environments.

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