Body Cyberization by Spatial Augmented Reality for Reaching Unreachable World

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ABSTRACT

This paper presents a novel body cyberization technique, in which we visually extend the length of a user's arm by projected imagery to allow the user to reach unreachable objects. We thoroughly design the body cyberization model such as graphical representations, action components, and interaction techniques. Through a psychophysical experiment, we investigate if a user can feel a sense of ownership for a projected hand. We also conduct a user study to make it clear that projection-based visualization of extended arm provides users with better usability. We build various application systems and demonstrate the feasibility and effectiveness of the proposal.

CCS CONCEPTS

•**Human-centered computing →Mixed / augmented reality;** *User interface design; Accessibility technologies;*

KEYWORDS

Spatial augmented reality, projection mapping, augmented human, body ownership, cybernetics, body extension

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1 INTRODUCTION

The hand is significantly important in human-human communication, by which we can express rich non-verbal information using various gestures. In addition, from the user interface point of view, it is obvious that direct manipulations by our hands and fingers are the most natural and intuitive way to manipulate machines and devices in many cases. However, such rich communications and natural/intuitive manipulations are achieved only within a limited space defined by the reaching ranges of the hands. We can keep benefiting from the advantages by moving our bodies to close to the communication partners or the manipulating devices so that these targets are within the reaching ranges. However, moving our bodies is in some cases impossible due to aging or disease. In this paper, we apply the reverse solution, i.e., extending our reaching ranges so that they include the targets.

Previously, the arm extension was achieved straightforwardly by mechanical approaches [8, 12, 21]. However, these techniques are still difficult to be used in our daily life, because users need to be tightly held by robotic arms, and the safety issue must be cleared. In addition, the size and degree-of-freedom (DOF) of the extended arm is mechanically fixed in advance, and consequently, cannot be flexibly changed at run-time. Thanks to the recent trends in connecting things in our daily environment to the internet (or simply speaking, IoT: internet-of-things), we can manipulate many devices through the internet. Furthermore, most non-verbal information of hand gestures is visually delivered. Therefore, a physical contact by a mechanically extended hand is not necessary both in device manipulation and human-human communication.

In this paper, we propose a novel body cyberization approach, which visually extends our hands and arms by a spatial augmented reality (SAR) as the extension of our prior works [1, 11] (Figure 1). Basically, we measure the slight movement of a user's hand, spatially amplify it to decide a new hand location, and visualize the amplification by projecting a synthesized hand image at the location which is connected with a synthesized arm image extended from the user's physical body. Gestures of a physical hand are almost directly mapped to those of the projected hand. Leveraging the flexible nature of our computer graphics-based approach of body extension, users can adaptively change the length of the projected arm at run-time. Furthermore, we can stabilize undesirable shakes of projected hand caused by hand tremors due to aging or disease, while amplifying the intended hand movement. In this paper, we describe the proposed body cyberization model, including what kind of action components are prepared, how to implement them,

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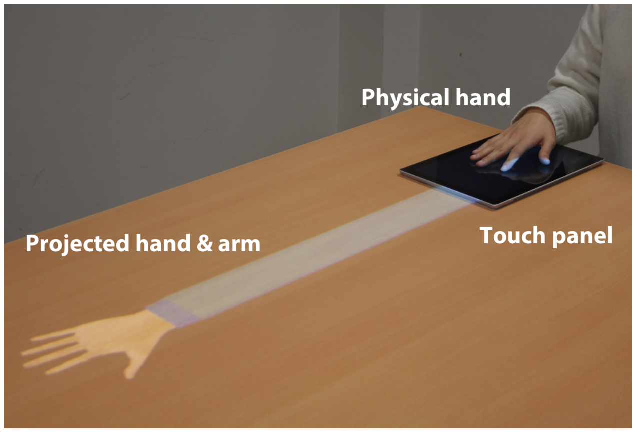

Figure 1: Proposed body cyberization visually extends the length of a user's arm by projected imagery to reach the unreachable world.

and what kind of interaction techniques are realized by combining them.

The proposed technique seamlessly connects the physical and cyber spaces, and allow users to control unreachable things via projected body images. This is designed such that the users can communicate/manipulate unreachable partners/devices by the extended hands as if they use their own physical hands. However, because the projected hand loses most of the volumetric information and the appearance of arm extension is physically impossible, it is unclear if users feel that the projected hands are their own hands. Because this is an important factor for the usability of the proposed technique, we investigate the sense of ownership for the projected hand in a psychophysical study. Then, we investigate the usability of the proposed technique through a user study and show that it provides better usability than conventional laser-pointer-based interfaces. Finally, we build several application systems to show the potential effectiveness of the proposal in a wide range of usage scenarios, such as the manipulation of electric devices including service robots, and face-to-face collaboration in an interactive tabletop system.

2 RELATED WORKS

Followed by a pioneering work by Poupyrev et al. [14], extending arm for reaching far objects has been well researched in virtual reality (VR) research field. Though such *Go Go Interaction* achieves a flexible extension of the reaching range of the user's hand, it only works in VR spaces. In this paper, we extend this concept to the physical world by applying an AR approach.

AR researchers have also investigated human body augmentation. For example, researchers have attempted to change the perceived body size to offer extraordinary experiences. Nishida et al. proposed a system that captured scenes using cameras located at the waist of a user and displayed them on a head-mounted display (HMD), in which the user felt as if she/he became a child [9]. In an opposite manner, Furukawa et al. offered a giant experience to a user by displaying aerial images captured by a drone-mounted camera floating above the user [3]. These showed that it is possible to let a user feel as if her/his body becomes smaller/larger than usual just by changing the viewpoints in HMD-based AR systems. However, the viewpoint modification approach does not change the reaching range of the user.

In SAR research field, human body augmentation was mainly investigated through projecting textures onto human bodies. Ho et al. studied the effect of hand color on the judgment of a touched object's temperature, by changing the color of the hand to red/blue by projection [4]. Punpongsanon et al. proposed to manipulate the perceived softness of non-rigid surface by changing the color of a fingertip applying a force to the surface [15]. On the other hand, there are few types of research applying body image projection. An example is a telepresence system [17], where hand images of a distant user are projected to make it easy for a communication partner to understand where the distant user is pointing. However, these previous SAR works also did not attempt to make her/his reaching range wider.

Reaching range extension was previously tried by utilizing the shadow of user's hand and arm [2, 19, 23]. Through a psychophysical study, it was shown that the shadow is perceived as a natural extension of our body [13]. Thanks to the strong body ownership sensation for the shadow, the shadow-based body extension can be intuitively manipulated. However, as pointed out in [20], the usability of the shadow is limited due to the geometric constraints. The size and position of a shadow are not flexibly controlled but is dependent on the position of a light source.

Seifried et al. proposed an interface for manipulating electrical devices spread in a room without extending the reaching area of a user [18]. This system applied a tabletop-sized touch screen on which the captured top view of a room was displayed. Users can manipulate each device by touching it on the screen. On the other hand, our proposed technique extends the length of a user's arm to visually reach each unreachable device and manipulates it by a projected hand connected on top of the arm. The proposed technique is also useful in human-human communication, which is out-of-scope of this previous work [18].

Recently, fingers extension was proposed by Ogawa et al. [10]. In their work, the extended fingers are displayed on a flat surface placed above the user's fingers, which covers the real fingers and shows virtual ones only. In our work, we focus on arm extension rather than fingers in SAR environment where a user can observe both augmented and real hands.

3 BODY CYBERIZATION MODEL

The proposed body cyberization model is described in this section. First, we show its graphical representation. Second, we explain action components realized in the proposed technique. Third, we show a simple solution to suppress undesirable shakes of projected hand due to hand tremors. Finally, we explain interaction techniques of the proposed system by combining the action components.

3.1 Graphical Representation

The proposed cybernetic body graphically consists of two connected parts, a hand and extended arm as shown in Figure 2. For the hand, we prepare a three-dimensional (3D) polygon mesh on which a real

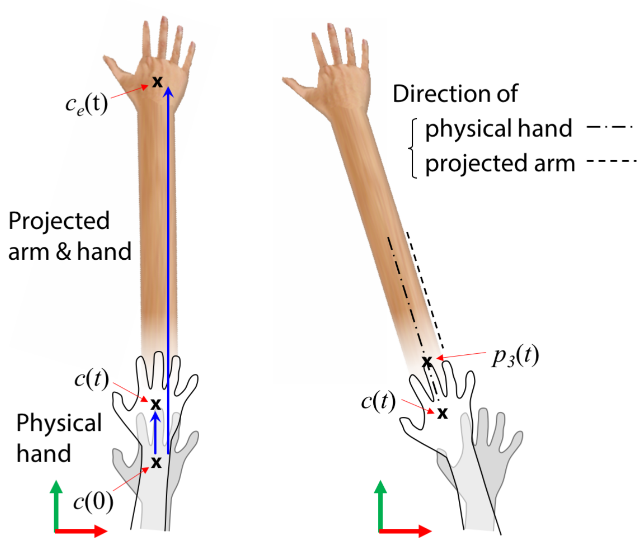

Figure 2: Body cyberization model: (left) translation and (right) ad-/abduction of projected hand with an extended arm. Gray and white hands represent the initial and current physical hands, respectively.

hand texture is mapped. Each finger consists of two (thumb) or three (other fingers) rigid parts connected by joints. Thus, the hand can open and close the fingers. For the arm, we prepare a polygon mesh elliptic cylinder, and different textures including the human skin and several kinds of sleeves, so that users can change them. The arm is extended only towards the direction of the hand, not towards its orthogonal direction.

We apply the orthographic projection to the 3D models to synthesize a projection image. The size of the projected hand can be adjusted by users. Unless otherwise noted, we apply the same size of a physical hand to the projected hand.

3.2 Action Components

The action components of the proposed technique are the translation of a projected hand, adduction/abduction of projected arm, and projected hand gestures. To avoid the fatigue in gestural user interfaces, we design the action components so that a user can use them while laying her/his hand on a flat surface. The 2D movements of a user's finger on the surface are mapped onto the action components. Real-time measurement of user's fingertip positions can be easily achieved by using a touch panel. We can also apply other sensing technologies such as computer vision using infrared cameras to avoid visual interference between projections and touch detection [6, 7, 22]. Without loss of generality, in the following explanation, we assume that fingertip positions are measured using a touch panel.

According to the 2D translation of a user's hand on a touch panel, projected hand translates towards the same direction with an amplified translation distance (Figure 2(left)). We define a period of time from when a finger touches on the panel till when it releases as a **session**. Suppose that measured fingertip positions and their centroid are represented as $p_i(t)$ ($i = 1, \ldots, 5$; 1: thumb, …, 5: little finger) and $c(t)$, respectively, where t is the time in a session. Then, the translated position of the projected hand centroid $c_e(t)$ is computed as $c_e(t) = K(c(t) - c(0)) + c(0)$, where K represents the amplification factor. The length of the projected arm is $|c_e(t) - c(0)| - |c(t) - c(0)|$. The rotation of the projected hand corresponds to the rotation of the user's physical hand on the touch panel. The projected arm is adducted and abducted according to the hand rotation (Figure 2(right)). We incline the projected arm so that it directs the same direction of the user's middle finger. The direction of the middle finger is computed from $p_3(t) - c(t)$.

In this paper, we prepare four gestures for a projected hand, **opening**, **closing**, **clicking**, and **pointing**. The graphical representations of the four gestures are as follows. All projected fingers are stretched out and completely bent in the opening and closing gestures, respectively (Figure 3(a)(b)). In the case of the clicking gesture, only the index finger is slightly bent and the other fingers are stretched (Figure 3(c)). On the other hand, in the case of the pointing gesture, the index finger is stretched and the others are completely bent (Figure 3(d)).

When a session starts, the projected hand is open regardless of the fingertip positions on a touch panel (Figure 3(a)). When all the fingertips move close to the centroid, the hand gesture becomes closing (Figure 3(b)). In particular, we compute the ratio $r_i(t)$ of the current distance between each fingertip position $p_i(t)$ and the centroid $c(t)$ to the initial distance. Thus, $r_i(t) = (p_i(t) - c(t))/(p_i(0) - c(0))$. If the ratios of all the fingers become smaller than predefined thresholds $s_i(t)$, we regard that the hand gesture becomes closing. The clicking gesture is triggered when the ratio of the index finger $r_2(t)$ becomes smaller than the threshold $h_2(t)$, while the other ratios do not (Figure 3(c)). Finally, the pointing gesture is triggered when only the index finger touches on a touch panel (Figure 3(d)).

3.3 Stabilization

As described above, the proposed technique amplifies the user's hand movement on a touch panel. However, in such a naïve method, it also amplifies undesirable fluctuations due to a hand tremor from which many people suffer due to aging or disease. We propose to stabilize the undesirable tremor by applying temporal filters. In particular, we apply a Kalman filter for this purpose. Although the filter successfully stabilizes the fingertip positions over time, a delay occurs in the filtered result for the fingers' sudden, large movements. Thus, we also apply a Hysteresis filter so that we accept raw fingertip positions when a large movement occurs.

Suppose an estimated fingertip position at the previous frame and a stabilized fingertip position by a Kalman filter at the current frame are represented as $\hat{p_i}(t-1)$ and $p_i{}'(t)$, respectively. Then, we estimate the fingertip position at the current frame $\hat{p_i}(t)$ by applying a Hysteresis filter as:

$$\hat{p_i}(t) = \begin{cases} p_i{}'(t), & |\hat{p_i}(t-1) - p_i{}'(t)| \le s_l \\ \hat{p_i}(t-1), & s_l < |\hat{p_i}(t-1) - p_i{}'(t)| \le s_h \\ p_i(t), & s_h \le |\hat{p_i}(t-1) - p_i{}'(t)| \end{cases},$$

where s_l and s_h represent thresholds of the filter. If a user needs the filter, we replace raw fingertip position $p_i(t)$ with the estimated one $\hat{p_i}(t)$ in computing the actions of the projected hand and arm described above.

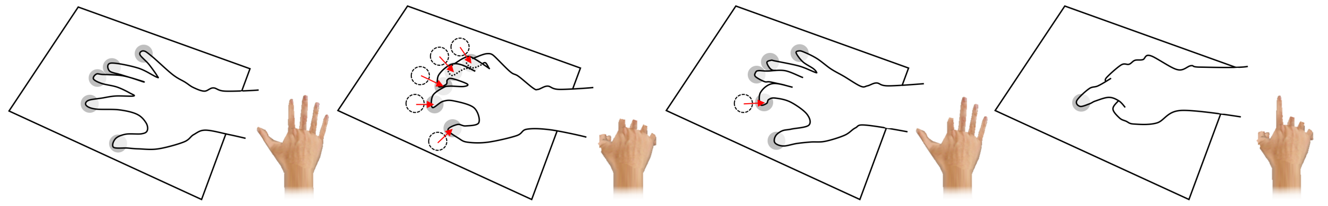

Figure 3: Correspondences between (left) physical hand gestures on a touch panel and (right) resulting projected hand gestures: (a) opening, (b) closing, (c) clicking, and (d) pointing.

3.4 Interaction Techniques

We realize various interaction techniques by combining the action components. When a projected hand is on an either virtual or physical object, the hand grabs it with the closing gesture. A user can bring it by moving the projected hand while keeping the closing gesture, and then, the object is released at any places with the opening gesture. We call this interaction as **grab-and-release**, which can be used in various situations such as bringing unreachable items to a reachable area in an interactive tabletop system, sending a photo data from a smartphone to TV to share it on a large screen, or bringing a cleaning robot to a place to be cleaned up.

The clicking gesture can be used in manipulating home appliances such as a room light or TV. In this interaction, a user extends her/his arm to reach a target appliance and performs the clicking gesture directly on it or virtual buttons/menus projected around the appliance.

The pointing gesture is mainly useful in human-human interaction. For example, when a user would like to take an unreachable object such as a book stored on a bookshelf which is too high for her/him, the user can ask a taller person to take this book by extending her/his arm and performing the pointing gesture to indicate the target. Because there are many books on a bookshelf in general, it is hard to specify a particular book by a physical finger pointing and oral explanation. On the other hand, the projected hand can visually and directly specify the desired book, which is much more understandable.

4 SENSE OF OWNERSHIP FOR PROJECTED HAND

The sense of ownership for a projected hand is essential for the usability of the proposed system. If users can feel as if their extended hands are their own hands, they can intuitively use them. We conducted a psychophysical study to investigate the sense of ownership for a projected hand, based on a procedure applied in a rubber-hand illusion research [?]. In particular, we measured the proprioceptive drift, a well-known phenomenon in which the perceived position of a real fingertip is shifted towards its rubber hand. The proprioceptive drift is elicited when a person feels as if a rubber hand is her/his own body.

4.1 Method

Each participant laid the right hand on a table. The hand was hidden from the participant's observation by a black box (D: 400 mm, W: 200 mm, H: 150 mm). We placed a ruler on the box in parallel to the edge of the table. We projected a hand image on the table 200 mm away from the physical hand, as shown in Figure 4. When all the fingers were opened, the depth (from the wrist to the middle finger) and width (from the thumb to the little finger) were 200 mm and 180 mm, respectively.

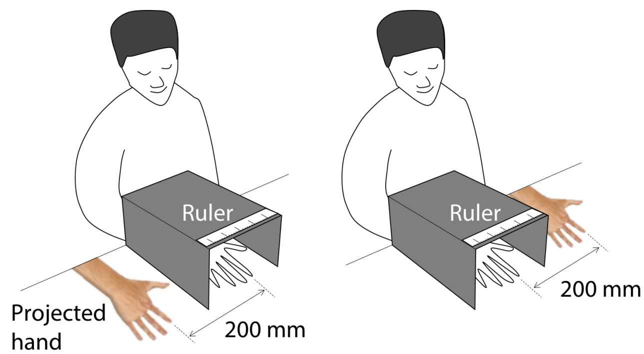

Figure 4: Experimental setup in the investigation of the sense of ownership. A synthesized hand image was projected on (a) the right or (b) the left of real hand which was covered by a black box.

We recorded the perceived position of the hidden index fingertip in the combination of two hand conditions and two projection conditions (i.e., four conditions in total). In the hand condition of **LS** (or **RS**), the hand image was projected on the left (or right) side of the real hand. In each hand condition, we conducted the study as follows. First, without projecting the hand image, we asked a participant to read aloud the scale of the ruler under which the participant perceived her/his index fingertip laid. In this manner, we obtained the perceived index fingertip position in this **without projection** condition. Second, we projected the hand image on the table according to the hand condition. We provided tactile stimuli using a paint brush to the hidden index finger for 240 seconds, while synchronously touching the projected index finger with another paint brush. We asked the participant to focus on the movement of the paint brush on the projected hand. After the stimulation, we asked the participant to read aloud the scale of the ruler in the same manner. Then, we obtained the perceived index fingertip position in the **with projection** condition. Each participant repeated the above process five times.

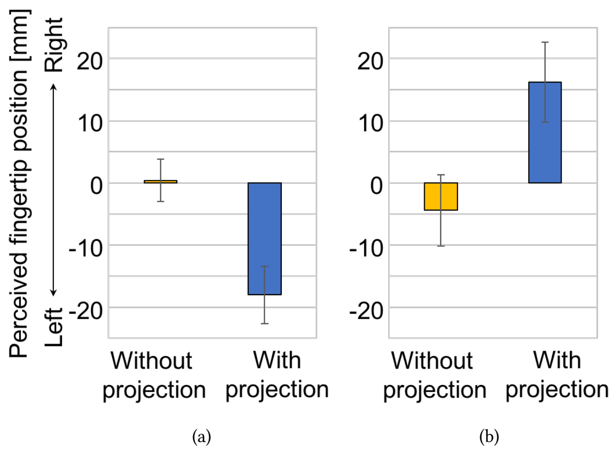

Figure 5: The average and standard error of perceived index fingertip position: (a) LS condition, and (b) RS condition.

4.2 Result

We recruited five male participants (aged from 22 to 53) from a local university. As shown in Figure 5, the averaged fingertip positions in the LS condition were 0.4 mm and -18.0 mm in the without and with projection conditions, respectively. In the RS condition, the averaged fingertip positions were -4.4 mm and 16.2 mm in the without and with projection conditions, respectively. Note that the actual fingertip position was set as 0 mm, of which the left side was minus and vice versa. The averaged drift length was 19.5 mm. We confirmed that users feel as if projected hands are their own bodies.

5 EVALUATION OF ARM EXTENSION

We evaluated the validity of the proposed visual effect of arm extension through a user study. The arm extension would provide a user with a sense of ownership for the projected hand because it shows that the projected hand is extended from around the user's physical body. On the other hand, because such arm extension is impossible in the physical world, a user might find it difficult to manipulate the projected hand. Then, as a consequence, it might be better to remove the extended arm from the graphical representation. Therefore, we compared these two visualization methods (with and without arm extension) in the study. In addition, we prepared a baseline condition where an arrow cursor used in a usual graphical user interface (GUI) was displayed instead of projected hand and arm. Thus, there were three conditions to be compared, i.e., **arm extension**, **hand only**, and **cursor** conditions.

5.1 Method

Participants were asked to perform grab-and-release interaction as quickly and accurately as possible. In each trial, two circles, which were filled with blue and yellow colors, respectively, appeared at random locations with a fixed distance. In particular, the task was to grab the blue circle and release it at the yellow one. Figure 6 shows the appearance of the user study.

Each participant sat by the short side of a table (1500×600 mm) on which a projected hand (D: 200 mm, W: 180 mm) or a cursor (D: 70 mm, W: 40 mm), and two circles (radius: 150 mm) were projected. The distance between the circles was fixed at 580 mm. The amplification parameter K was 10.0 through the study. An infrared camera (120 Hz) was used for measuring the participant's hand movement and gestures.

Participants performed fifty trials in each condition. In each trial, we measured the task completion time. Followed by the trials in each condition, participants answered a subjective question based on five-point Likert scale, which was "How easily did you perform the task? (1: difficult, . . ., 5: easy)".

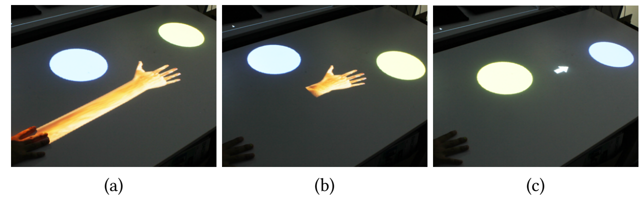

Figure 6: The appearances of the user study in the following experimental conditions: (a) arm extension, (b) hand only, and (c) cursor conditions.

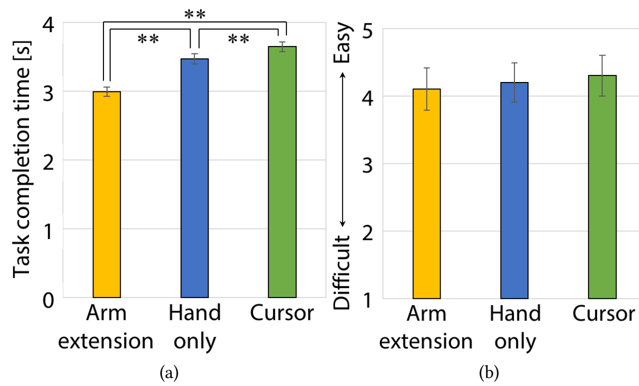

Figure 7: User study results: (a) average and standard error of task completion time, and (b) those of subjective response to the difficulty in the manipulation (**: $p < 0.01$).

5.2 Result

Ten male participants (aged from 22 to 24) were recruited from a local university. Figure 7(a) shows the averaged values of task completion time for one trial, which were 3.0 s (arm extension condition), 3.5 s (hand only condition), and 3.6 s (cursor condition). A one-way analysis of variance (ANOVA) with repeated measures showed statistically significant differences among the conditions ($p < 0.05$). Post-hoc analysis was then performed using Ryan's method for pairwise comparison. It showed that the task completion time in the arm extension condition was significantly shorter than those in the other conditions ($p < 0.01$). Figure 7(b) shows the results of the questionnaire survey. For this result, ANOVA did not show any statistically significant differences among the conditions.

In summary, we confirmed that the proposed visual effect of arm extension provided the best usability in terms of task completion

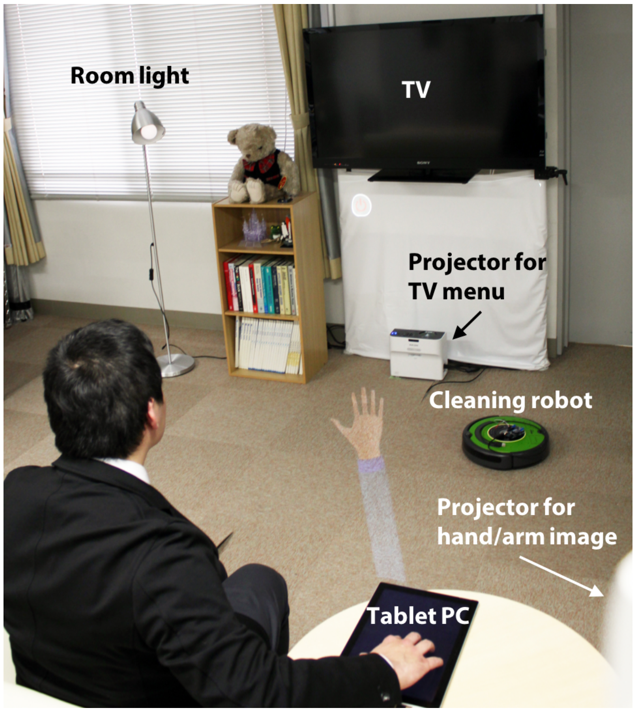

Figure 8: Experimental setup of home appliance manipulation.

time in manipulating unreachable objects. Therefore, the proposed technique provides a better usability than normal laser-pointer-based interfaces. Furthermore, even though the proposed visual effect of the arm extension was physically impossible, it did not increase the subjective difficulty of the manipulation.

6 APPLICATIONS

The proposed technique has a potential to be applied in various fields and user scenarios. In this section, we show some application prototypes. We manually found appropriate K value for each application according to the size of each target. Please refer to our supplementary video for the moving demos.

6.1 Home Appliance Manipulation

A user can manipulate her/his home appliances using the proposed technique, assuming the appliances are connected and can be manipulated via a digital network [18]. We implemented a prototype application where a user could (1) turn on/off a room light, (2) turn on/off a TV as well as adjust its channel and volume, and (3) control a cleaning robot to clean up a specified area of a floor. Figure 8 shows the experimental setup. We applied a tablet computer (Microsoft, Surface Pro 3) for measuring user's touch actions, rendering the graphics of hand/arm and sending them to a projector (NEC, NP110J), and sending control signals to the appliances. Note that $K = 29.0$ in this application.

As shown in Figure 9, a user could turn on and off the light by extending her/his arm to reach it and performing the clicking gesture on it. A LED lamp (BeauBelle, BELLED R2) was controlled

Figure 9: Room light manipulation: (left) a projected hand reached the bottom of a room light, and (right) turned it on by the clicking gesture.

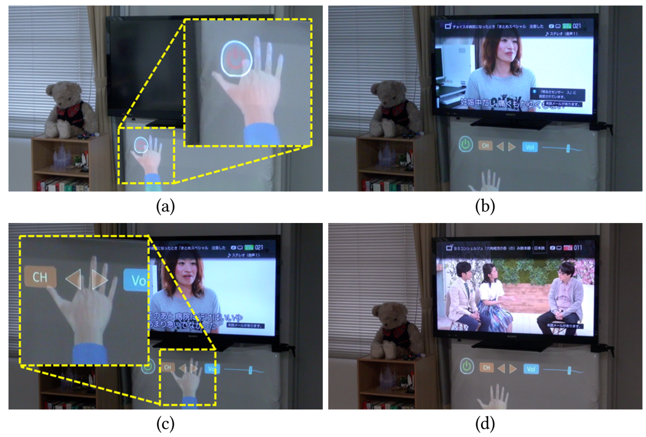

Figure 10: TV manipulation: (a)(b) the clicking gesture on the projected power button activated the TV, and (c)(d) the clicking gesture on the channel button changed its channel.

Figure 11: Cleaning robot manipulation: (left) the closing gesture grabbed the robot, and (right) the opening gesture released it at the place to be cleaned up.

by a microcontroller (Arduino Uno R3), which was wirelessly communicated with the tablet computer via XBee wireless communication. For TV manipulation, a power button, channel buttons and volume slide bar were projected just below a TV (Sony, BRAVIA KDL-46HX65R). In particular, the user could turn on/off the TV and adjust the channel by performing the clicking gesture on these buttons, and adjust the volume by grabbing-and-releasing the slider (Figure 10). The TV was controlled by a custom-made remote controller consisting of an IR LED and a microcontroller (Arduino Uno

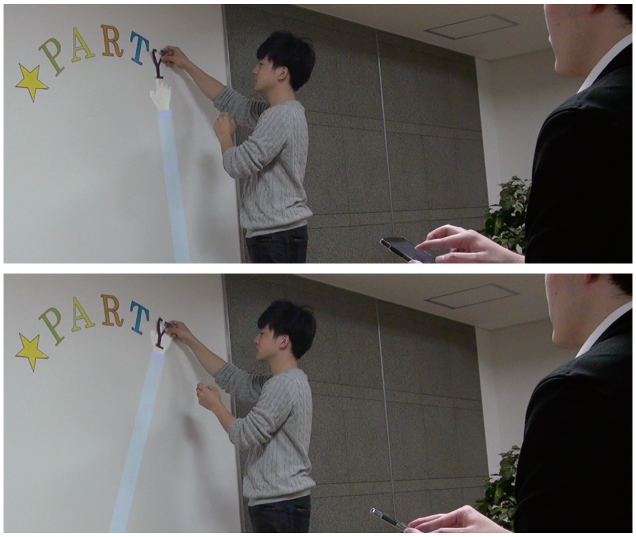

Figure 12: Human-human communication support: (a) the projected hand pointed the place where the decoration "Y" to be hanged, and (b) the projected arm indicated its desirable rotational angle.

R3), which was wirelessly controlled by the tablet computer using XBee. In addition, the user could control a cleaning robot (iRobot, Roomba) using the grab-and-release interaction to teach it where to be cleaned up, as shown in Figure 11. We controlled the robot using a microcontroller (Arduino Uno R3), which was wirelessly communicated with the tablet computer via XBee.

6.2 Human-Human Communication

The proposed technique is useful in human-human communication, especially in the communication between two users locating about 10-30 feet apart from each another. A user can convey rich information to the partner using gestures of projected hand and arm.

Figure 12 shows an example of the human-human communication using the proposed technique. In this example, a user put decorations on a wall for a party. The partner, who stood about 10 feet away from the wall, checked the spatial balance of the decorations and told the desirable place (Figure 12(a)) and rotational angle (Figure 12(b)) of each decoration using the projected hand and arm. As shown in the figure, such spatial information could be easily conveyed, which would not be achieved in a conventional laser-pointer-based communication. Note that $K = 18.0$ in this application.

6.3 Interactive Surface

We implemented an interactive surface system based on the concept of [16], consisting of a tabletop projection surface (W: 900 mm, D: 1800 mm) and a vertical LCD (iiyama, ProLite E2607WS). As an example, we implemented a photo sharing application on the system, in which users could discuss the displayed image contents. The projected hands could be used to point interesting photos located at unreachable places and spatially arrange these data by

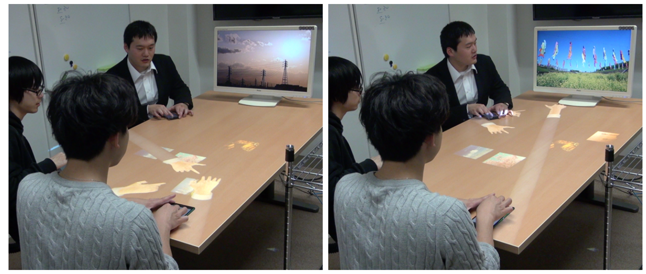

Figure 13: An interactive tabletop system with the proposed technique: (from left to right) a user performed the grab-and-release interaction technique to show an image data on the LCD unreachable from the user.

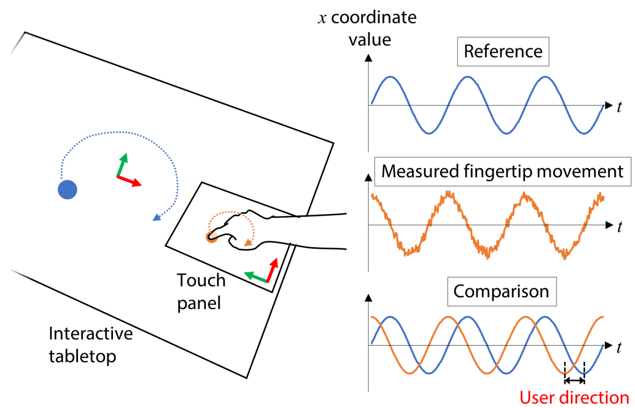

Figure 14: User direction estimation in interactive tabletop.

the grab-and-release interaction technique. In this system, users could perform various operations such as bring unreachable image data to reachable places, make small groups to visually classify the data, show a selected photo on the LCD, and so on, as shown in Figure 13. The projected hand and arm were manipulated using either a tablet computer (ASUS, Nexus 7) or smartphones (Sony Mobile, Xperia Z Ultra; LG Electronics, Nexus 5) which measured the users' touch positions and sent them to a host PC (Panasonic, Let's note CF-SX1). The host rendered all the graphics and sent them to the projector and the LCD. Note that $K = 21.0$ in this application.

The localization of each user is an important issue when using the proposed technique in such a collaborative tabletop system. In particular, each projected hand should be extended from the direction of the corresponding user. This could be solved by applying multiple human body sensors such as Kinect, which however requires additional hardware and computational costs. Instead, we developed a simple interactive solution to estimate the direction of a newly joined user without requiring any sensing devices. Figure 14 shows the overview of the technique. Once a user activates the estimation program on her/his mobile device by the side of the tabletop, a dot is shown on a tabletop, which follows a circular path around the center of the tabletop at a fixed angular frequency. Hereinafter, we call this dot as a **reference**. The user moves her/his

Figure 15: Tremor suppression technique: (left) without and (right) with stabilization technique. Three captured frames are overlaid and blended to show the tremor effects .

fingertip in a circular pattern on the mobile touch panel so that the movement of the fingertip synchronizes that of the reference as accurately as possible. We compare the x coordinate values between the reference in the interactive tabletop coordinate system and the measured fingertip position in the touch panel coordinate system. We apply the Fourier transform to the measured fingertip position to obtain the same angular frequency component as the reference. Then, we compute the phase difference between the fingertip movement and the reference, from which we estimate the direction of the user.

We conducted a user study to evaluate the accuracy of this method. Six male participants (aged from 22 to 24) were recruited from a local university. We asked the participants to perform the proposed method four times from different directions using a tablet computer (ASUS, Nexus 7). The angular frequency of the reference was π rad/s. The experimental system required each participant to perform three cycles of the circular motion. As a result, the averaged error was 11 deg. Therefore, we confirmed that the proposed method works well in an interactive tabletop system used by a small number of users, which is technically less than 16 (= 360 deg/(2 $*$ 11 deg)).

6.4 Tremor Suppression

Figure 15 shows the effectiveness of our tremor suppression technique. In this demonstration scenario, a user suffering from a hand tremor asked a partner to bring the desired book from a bookshelf. As shown in the figure, the hand tremor was amplified in the proposed technique without the stabilization. On the other hand, our simple stabilization technique could successfully suppress the effect and provided a better communication environment for the user.

7 DISCUSSION

As shown in the previous section, the proposed technique is useful in many user scenarios from machine manipulation to human-human communication. We believe that there are two important features making the proposed technique useful: (1) the visual representation of the projected hand and arm is close to our physical body, and (2) the mapping between a user's physical action on a touch panel and the behaviors of the projected hand and arm is natural. Thanks to these features, a user can manipulate machine interfaces by the projected hand as if the user manipulates them with her/his physical hands. These features also allow users to communicate each other with rich nonverbal information of projected hand gestures.

Despite the advantages discussed above, we need to consider the following issues when we apply the proposed technique to other fields. First, the proposed technique shares the same limitation with other SAR systems. More particularly, we can display hand and arm images only on surfaces, which means that we cannot display them floating in the air. Consequently, projected arm and hand are disconnected or deformed when a projection surface is not a single flat surface. The disconnection can be compensated by applying multiple projectors [5]. We can also compensate the geometrical deformation by applying a well-known user-perspective rendering technique, which however only works for a single viewpoint. Investigating a suitable rendering technique for the deformation issue is one of our future works.

The size and length of the projected hand and arm are also interesting issues to be investigated. In this paper, we fixed the size of the projected hand as almost the same as a physical hand. However, as people use a pair of tweezers for manipulating tiny objects, the size of the projected hand would affect its usability according to the size of a target. The length of the projected arm would also affect the usability. If it is too long, a user might face difficulty manipulating the projected hand displayed at a place far from the user. The amplification factor for computing the projected hand position also affects the usability. The best value of the factor would be dependent on the size of the projected hand and the length of the arm. Investigating the best combination of the parameters according to the spatial properties of the target and developing a mathematical model that can compute the best parameters in each application are important future works.

8 CONCLUSION

We proposed a novel body cyberization technique, in which users can reach unreachable objects using projected hand and arm. The paper presented the body cyberization model, including the action components and interaction techniques. Through the psychophysical experiment, we confirmed that a user can feel a sense of ownership for a projected hand. In the user study, we confirmed that a user can use the projected hand more effectively in a condition where the projected arm is extended. We showed various applications to demonstrate the feasibility of the proposal.

In our future work, we will investigate the issues raised above in the discussion section. We also plan to investigate the effectiveness and usability when different hand gestures are applied, and when both arms are extended.

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