Weak Perspective Shadow Interface for Seated User's Pointing on Large Wall Display

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Abstract— **Shadow is widely researched as a user interface for manipulating graphical information on large displays. The shadow of one's fingertip is used as a pointing cursor whose position and size (i.e., gain and reaching area) can be intuitively adjusted, because one thoroughly comprehend the shadow's perspective projection behavior. The goal of this research is to allow a seated user, who cannot sufficiently move his/her fingertip, to manipulate the shadow cursor. We achieve this by relaxing the perspective constraints, i.e., applying weak perspective projection model. Through an experiment, we confirmed that the pointing performance of seated users is improved in the proposed method compared with the conventional method. Specifically, the users completed pointing tasks 25.1 % faster with 54.2 % fewer errors when the target size was small, 34.5 % faster with 64.2 % fewer errors when the target size was medium, and with 58.3 % fewer errors when the target size was large.**

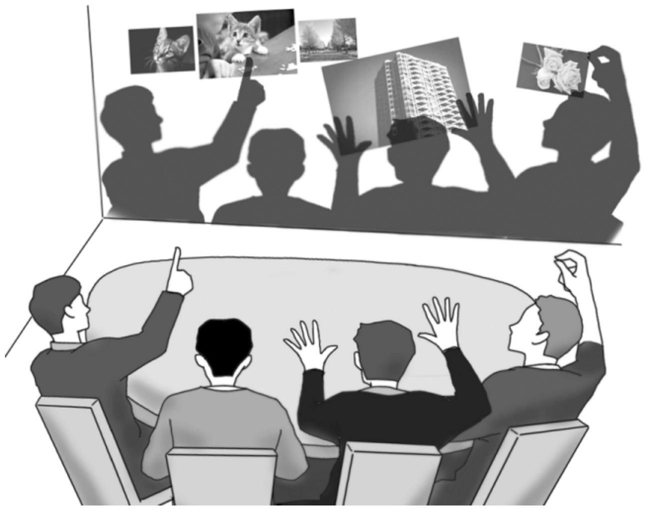

Fig. 1. Example of the proposed shadow interface.

I. INTRODUCTION

Shadows are natural extensions of our bodies with high embodiment [1], and we know how shadows move according to the movement of our bodies. Recently, a shadow interface that uses the shadow metaphor has been proposed for operating graphical information on large displays. A user interacts with a computer by using the shadow cast on a screen from a light source behind the user. In particular, the user uses his or her shadow finger point as a pointing cursor. The shadow appears as the perspective projection of the user on the display. Consequently, the user can move the cursor by moving his or her fingertip on a plane parallel to the display, and adjust the size of the shadow (i.e., gain and reaching area of the cursor) by moving the fingertip along the normal of the display [2].

The advantage of the shadow interface is that a user can easily understand the correspondence between his or her fingertip movement and the shadow cursor because people normally comprehend the shadow's perspective nature. On the other hand, the disadvantage is that a user needs to move in between the display and the light source in order to change the size of his or her shadow. In particular, this leads to a serious problem when a user is seated. In such a case, the user can not change the body position and consequently can not satisfactorily adjust the gain and reaching area of the shadow cursor.

We aim to realize a projection-based shadow interface shown in Fig. 1, in which users can easily operate graphical information on a large projection display while staying seated. To achieve this goal, we relax the perspective constraints of the shadow metaphor, i.e., we apply the weak perspective model to the shadow interface. We set a virtual screen within a user's reachable range between the user and the real screen. The shadow cast on the virtual screen is, without any modification, copied and displayed on the real screen, so that the user can sufficiently adjust the size of his or her shadow while staying seated. We conducted a pointing experiment to examine the usability of our proposed interface.

II. RELATED WORK

Various shadow interfaces have been proposed. Conventional shadow interfaces fall into the following two categories. In the first category, the real shadow geometry is faithfully reflected to the displayed shadow interface. In the second category, a geometrically tweaked shadow is applied. In this section, we introduce these previously proposed shadow interfaces, and then, explain how the proposed interface is different from them.

A. Geometrically Correct Shadow Interface

Regarding the shadow interfaces falling into the first category, a number of works had been presented in the field

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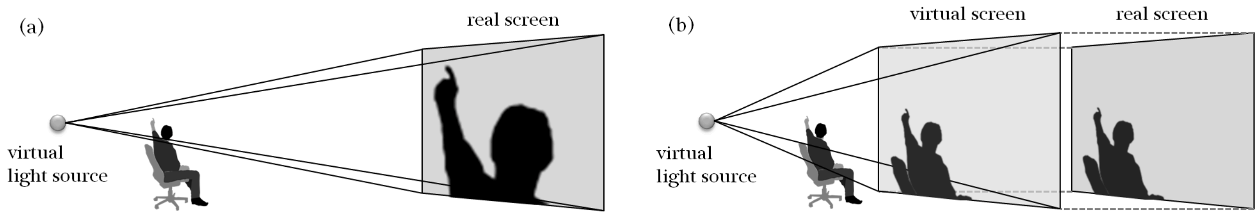

Fig. 2. Geometrical shadow models for (a) the conventional shadow interface and (b) the proposed interface.

of interactive art since 1970s [3], [4], [5], [6]. For example, Minomo *et al.* realized a real shadow art installation in which colorful graphics in the area of a shadow of user's body [6].

Shadow pointing interfaces have been also proposed in the first category. These pointing interfaces used the shadow of a user's fingertip as a pointing cursor for large display. Shoemaker *et al.* proposed "Shadow Reaching" [2] in which users operated information on a display by changing the size and scale of their shadow. It used a real shadow as a cursor and the user could intuitively operate the cursor by utilizing the perspective constraints of shadow. Xu *et al.* [7] and Yamamoto *et al.* [8] proposed similar interfaces with synthesized shadows which were generated by extracting the silhouette of a user's body from a captured image sequence. Tsukitani *et al.* [9] found that Fitts' law, which is well known pointing performance characteristics in conventional pointing device such as a mouse cursor, can also be applied to pointing operation in such shadow interfaces.

Isogawa *et al.* proposed another type of shadow interface in which a user can browse a graphical in a shadow area which is different from that in a non-shadow area [10]. Naemura *et al.* proposed a shadow interface in which a user can change the position of a light source by moving a hand held light source device [11]. In this interface, a user can change the position or scale of shadow more quickly than when a light source is fixed.

In the above mentioned shadow interfaces, geometrically correct shadows, which are either real shadows or synthesized virtual shadows, are applied. Therefore, a user can intuitively operate the shadow interface because they can easily expect the movement of the interface based on his or her own experience.

B. Geometrically Tweaked Shadow Interface

There are some shadow interfaces which are geometrically tweaked from real shadows. Miwa *et al.* developed the system in which the delay time of shadow could be changed according to user's action and investigated the effect of spatiotemporal operation of shadow on user's sensation [12]. Yamamoto *et al.* proposed a volume adjustment interface in which a user can rotate a widget by a palm rotation gesture. The shadow of the user's palm is displayed in the widget and the movement of the palm shadow is not continuous as real shadow but discretized so that the user feel clicking sensation as a Pseudo-Haptics effect [13].

In the above mentioned interfaces, the shape or movement of real shadow is changed. Therefore, a user can not intuitively operate the interface compared with the geometrically correct shadow interface. On the other hand, these interfaces can improve the flexibility of manipulation by relaxing the geometrical constraints of real shadow.

C. Proposed Shadow Interface

The geometrically correct shadow interfaces, i.e., falling into the first category, allowed a user to intuitively change the position, scale and gain of moving speed of shadow. Tsukitani *et al.* proved that the interface using a shadow metaphor is reasonable as a pointing interface [9]. On the other hand, a user needs to move his/her body position between a light source and a screen to change the position or scale of shadow. Therefore, there is a problem that the user can not satisfactorily adjust the gain and reaching area of the shadow cursor when he/she is seated or cannot move his/her position.

To solve this problem, we propose a shadow pointing interface which relaxes the perspective constraint of real shadow to reduce the moving distance required to change the size of his or her shadow. In particular, we applied a weak perspective model to our shadow pointing interface to improve the usability of pointing operation for seated users.

III. Shadow Interface with Weak Perspective Model

The geometrical model of the proposed interface is shown in Fig. 2. To realize the weak perspective model, we apply a virtual shadow method. We generate a virtual shadow by computing the shadow of a user illuminated by a virtual light source, which is cast on a virtual screen placed between the user and the real screen. The virtual shadow is displayed on the real screen by a video projector.

In conventional methods applying physically correct perspective constraint, illustrated in Fig. 2(a), a user sits on a chair at a distance from a real screen; and, a virtual point light source illuminates user's body from behind the user. The virtual shadow of the user on the real screen is generated by interrupting a virtual optical path derived from the virtual light source. In our proposed model, illustrated in Fig. 2(b), we set a virtual screen, whose size is same as the real screen, placed closer to the user than the real screen. We relax the perspective constraint and enable users to change the size of

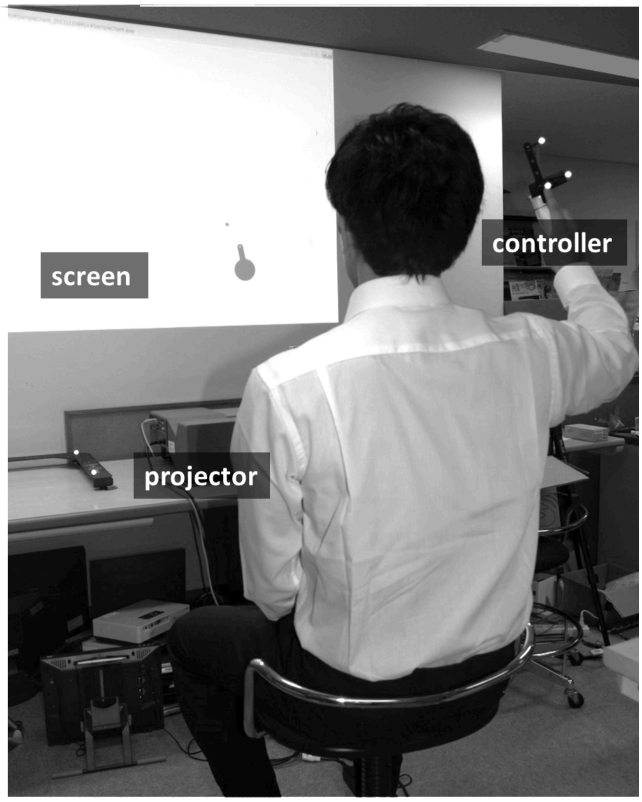

Fig. 3. Outlook of experimental setup.

Fig. 4. Hand held device attached by three MoCap markers.

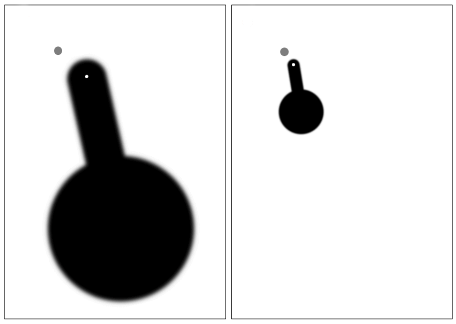

Fig. 5. Virtual shadow and target when a subject's hand is close to the virtual light source (left) and the virtual/real screen (right). The gray dots are the targets.

their shadow with less hand movements than the conventional methods.

In general, one of the advantages of shadow interface is that a user can change the size of shadow by moving between the light source and the screen. When the size of the shadow is large, a user can do rough but fast pointing. On the other hand, when the size is small, a user can do precise but slow pointing. In the conventional model, a user needs to move his/her position close to the real screen in order to change the size of virtual shadow to the same size as a real shadow for precise poiting. On the other hand, in the proposed model, a user can make the small virtual shadow only by moving close to the virtual screen nearer to user than the real screen. Therefore, when the virtual screen is set within the moving range of user's hand, the user can utilize both the large and small shadows while staying seated. However, there is a possibility that the usability of the proposed interface becomes worse because the shadow in the proposed interface is not geometrically correct shadow which is familiar to us.

IV. POINTING EXPERIMENT

We conducted a user study to validate the pointing performance of the proposed method.

A. Purpose

In the proposed model, a user can move his or her hand close to the virtual screen with a little movement while staying seated. It is consequently thought that the user can easily conduct detailed tasks because the user easily change the gain of moving speed of a cursor. Therefore, the proposed model has the possibility that the user complete pointing tasks quickly with less movement and fewer error than the conventional model. On the other hand, the virtual shadow in the proposed interface has no geometric consistency with real shadow due to relaxation of the perspective constraints of shadow. Therefore, there is a possibility that the usability of proposed interface is less than the conventional interface because intuitively operation become difficult in proposed interface. We conducted a pointing experiment in which we compare the proposed model and the conventional model in order to validate the usability and property of the proposed pointing interface.

B. System Configuration

Fig. 3 shows the outlook of the experimental system. In both the conventional and our proposed models, each subject sat on a chair. We used a white wall as a real screen and projected the shadow of subject and the target to point by a short focus projector (SANYO PLC-XL51). The size of the

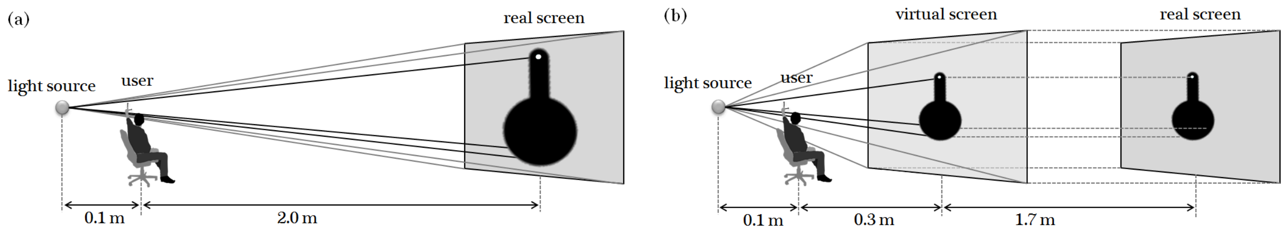

Fig. 6. How to calculate a texture of shadow; (a)conventional model, (b)proposed model.

real and virtual screens was 1.5×1.2 meters.

We measured the subject's hand movement by an optical motion capture (MoCap) system. Each subject was asked to hold a hand held device on which a button and MoCap markers were attached (Fig. 4). The position of the virtual shadow of the hand and finger was computed from the MoCap data.

The virtual shadow and target circle to point are projected onto the real screen as shown in Fig. 5. The color of background is white, the virtual shadow is black and the target circle is red. We simplified the shape of the virtual shadow in order to reduce the influence of individual variation of hand shape. This virtual shadow did not lose the generality because it reflected the scale and rotation of the subject's hand computed by either proposed or conventional model.

C. Optical Model

Fig. 6 shows our proposed optical model. We conducted a preliminary experiment to decide the positions of virtual light source, real screen, and virtual screen, so that subjects of the experiment can reach the whole projected image space by their shadows. We fixed a virtual light source at 0.1 m behind the subject and placed a real screen at 2.0 m in front of the subject. In the proposed model, we set a virtual screen at 0.3 m in front of the subject. We regarded the scale and rotation of the MoCap markers as those of subject's hand. The marker furthest from the hand held device was considered as a fingertip of the subject. In the conventional model, we computed a displayed virtual shadow as a shadow of subject's hand cast on the real screen by the virtual light source (Fig. 6(a)). In the proposed model, we calculated the scale and rotation of the virtual shadow of subject's hand which was cast on the virtual screen and copied the virtual shadow on to the real screen (Fig. 6(b)).

D. Procedure

We recruited 20 subjects from the local university. Each subject performed 30 pointing tasks in both the conventional and proposed models. Before the experiment, we told the subjects the positions of the real screen, the virtual screen, and the virtual light source. We instructed the subjects to perform each pointing task as quickly as possible while minimizing errors and to stay seated during the experiment.

The pointing task was conducted as follows. After a target appeared on a screen, each subject tried to point it by moving his or her hand holding the device. Once the fingertip of the virtual shadow pointed the target, the subject pressed the button on the device. When the distance from the shadow cursor and the target circle was within a predefined threshold, the task was finished. Otherwise, the number of errors in the task was added. The position of each target was randomly chosen from 50 predefined target positions. We prepared three different target sizes (small, medium, and large) each of which appeared 10 times for each subject, i.e., 30 tasks in totals. We evaluated the task completion time, the pass ratio (i.e., the ratio of the length of subject's hand trajectory to the distance between the position of the present pointed target and the prior target), and the number of errors. Moreover, we measured 3D hand movements of 6 out of 20 subjects.

E. Result

Figures 7, 8, and Fig. 9 show the experimental results of average and standard deviation of pointing time, pass ratio and error. Tab. I shows the experimental results of the hand movement of the 6 subjects; standard deviation of hand movement and moving range of subject's hand along the normal of the real or virtual screen. Fig. 10 shows the movement of subject 1's hand along the normal of the real or virtual screen.

Fig. 7 shows that the average of pointing time in proposed model was shorter than the conventional model with significant difference ($p < 0.01$) when the target size was small and medium. There was no significant difference ($p = 0.12$) between the averages of pointing time in the conventional model and the proposed model when the target size was large.

Fig. 8 shows that the average of pass ratio in proposed model was larger than the conventional model with significant difference ($p < 0.01$) regardless of the target size. Therefore, the users need to move their hands widely in proposed model than the conventional model.

Fig. 9 shows that the average of error in proposed model was shorter than the conventional model with significant difference ($p < 0.01$) when the target size was small and medium. There was also significant difference ($p = 0.04$) between the averages of error in the conventional model and the proposed model when the target size was large.

Table I shows that the standard deviation of hand movement and moving distance of 4 subject's hand was larger in the proposed model than the conventional model. There

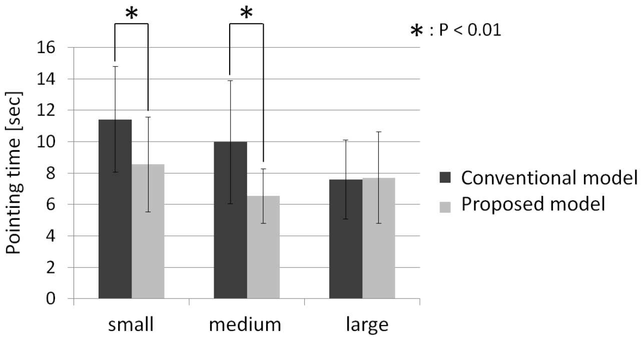

Fig. 7. Average and standard deviation of pointing time.

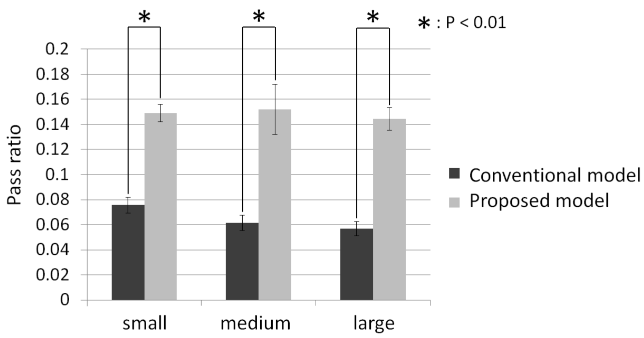

Fig. 8. Average and standard deviation of pass ratio.

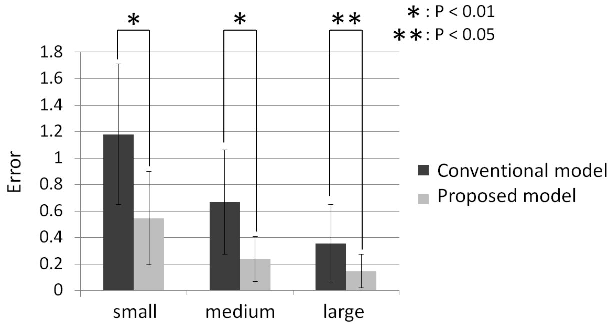

Fig. 9. Average and standard deviation of error.

TABLE I
STANDARD DEVIATION (SD) AND MOVING RANGE (MR) OF SUBJECT'S HAND MOVEMENT.

	conventional model		proposed model	
	SD [mm]	MR [mm]	SD [mm]	MR [mm]
subject 1	24	119	**65**	**324**
subject 2	26	115	**93**	**325**
subject 3	**89**	**366**	83	352
subject 4	48	225	**61**	**277**
subject 5	**62**	**278**	54	269
subject 6	61	268	**94**	**443**

was no significant difference between the both model in the results of other 2 subjects. Therefore, the subjects tend to move their hands along the normal of the real or virtual screen widely in the proposed method compared with the conventional method.

Fig. 10 shows that the subject 1 moved her hand around 0.1m in front of her (1.9m from the real screen) in the conventional model. On the other hand, the subject moved her hand widely from front to rear between the sitting position (2.0m from the real screen) and the virtual screen (1.7m from the real screen) in the proposed model.

The following is a summary of the above. The subjects pointed more quickly with fewer errors using the proposed model than the conventional model when the target size was small (25.1 % faster and 54.2 % fewer errors) and medium (34.5 % faster and 64.2 % fewer errors). On the other hand, when the target size was large, the task completion time was same in both models and the number of errors was fewer in the proposed model (58.3 % fewer errors). Therefore, the usability of the proposed model was improved compared to the conventional model. We also observe that in our proposed model, the user moved his or her hand 25.6 % more along the normal of the real screen. This indicates that users changed the size of their shadows during their pointing operations more frequently in our proposed model.

V. DISCUSSION

We discuss the results of the pointing experiment.

A. *Effectiveness of Proposed Interface*

In our proposed interface, there is a possibility that the shadow metaphor is lost since we relax the perspective constraint of shadow and apply weak perspective model. Note that in this paper we regard the shadow metaphor as that the scale of shadow changes according to the movement of hand from front to rear between a screen and a light source. If the distance between user's hand and a virtual screen is too short, the shadow metaphor does not effectively work in the proposed model because the optical model is close to the parallel projection model and the movement of hand is almost equal to of virtual shadow. Moreover, if a user moves his or her hand within a parallel plane to a real or virtual screen, the virtual shadow moves like a mouse cursor because the effect of the hand movement along the normal of the real or virtual screen is weakened. In the pointing experiment, we observed that the user moved his or her hand along the normal of the real screen 82.9 % of the distance between the virtual screen and the virtual light source in our proposed model. This indicates that the shadow metaphor was effectively utilized in our proposed model under the experimental setup in this paper.

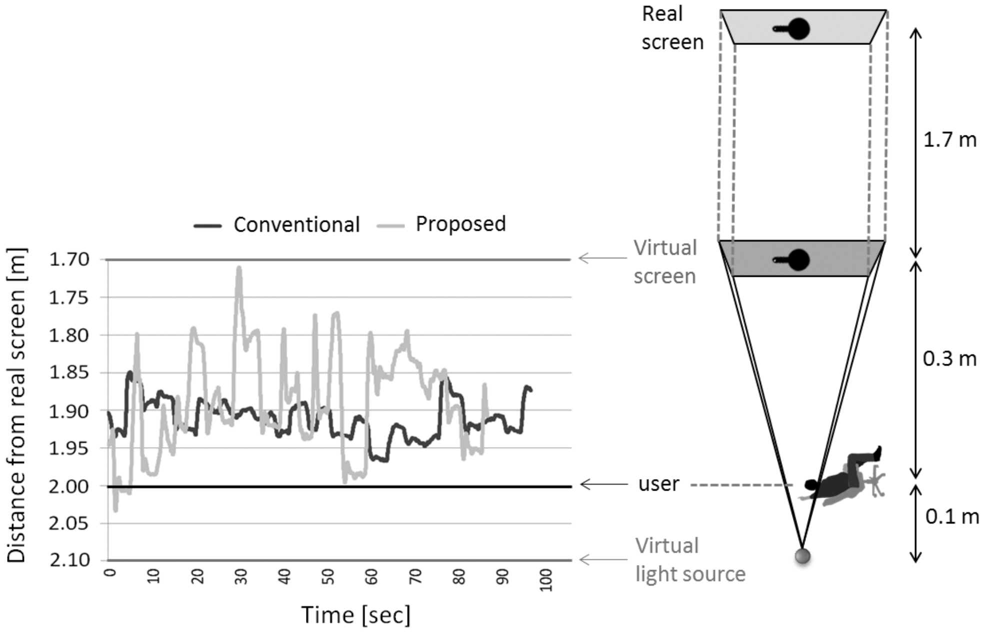

Fig. 10. Movement of subject's hand along the normal of the real or virtual screen

B. Usability of Proposed Interface

Comparing the conventional model with the proposed model, the subjects finished the pointing tasks more quickly with fewer error in the proposed model than the conventional model when the target size was small and medium even though the users needed to move their hand wider. Therefore, we conclude that the proposed interface allowed a sitting user to perform better pointing tasks than conventional interface because of relaxation of the perspective constraint of shadow.

On the other hand, the movement of hand was much larger in the proposed model than the conventional model. This indicates that the proposed model is unfavorable from the perspective of fatigue in pointing operation compared with the conventional model. In future work, we need to consider the system design to reduce fatigue, for example, users can select the proposed or conventional model according to target size.

VI. CONCLUSION

In this study, we proposed a novel shadow pointing interface that relaxes perspective constraint and applies weak perspective model. Through the pointing experiment where subjects were seated, we confirmed that the performance of pointing tasks was improved in the proposed interface.

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