Promoted Motion-Sensing Gestural Interaction by Adapting to Group Users' Spatial Movements

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Abstract: Large displays are weak in providing sufficient access efficiency and input precision in gestural interaction. In particular, in multi-user situations when equal access efficiency and high precision are required, the weak of large displays becomes more obstructive. In order to address access efficiency and precision issues in both single- and multi- user situations, a walk-to-point technique is proposed. To evaluate the effectiveness, the new technique is compared to the traditional laser pointing method in terms of efficiency, precision and usability. The results showed that the new pointing technique outperformed the traditional laser pointing in both efficiency and precision, the smaller target size the more obvious superiority of the new technique. The new technique is also verified to be effective in providing equal access efficiency and precision to group users. Furthermore, the new technique achieves good result in usability evaluation.

1. Introduction

Due to fast drop in manufacture cost and rapid development in display technologies, large-scale displays with high resolutions have become prevalent equipment in wide applications [1]. For example, large displays in working spaces [10]; large displays in public sites [24]; and large displays in collaborative work [6].

With large physical size and high resolution, large-scale displays afford users to operate detailed information in close distances but have a global view of the whole content and interact at remote distances. For example in [3], with a common large display, one user operates by touching in close while another one interact by controller at a distance. Some particular situations also require large displays to be interacted at a distance. Like displays in hospital, for sterile demand, are always mounted out of reach [1].

Among remote interaction techniques, free hand gestural interaction is more preferred by users, not only for its naturalness in use but also because it does not rely on any device in operation, thus make the transition from distant operation to up close touch more fluid [26]. Regardless of its strength, usability issues are also concerned. On one hand, when the size of large display is far larger than the traditional sized screens, users spend more time to reach distal targets [9]; on the other hand, be limited by the camera's recognition precision and hand motion accuracy, interaction in front of large displays performs weak in accessing small targets [14].

In multi-user situations, space for each user is more limited. It becomes more difficult for users standing aside to reach the other side of display [2]; furthermore, the distribution in users' standing position incurs inequity in access efficiency and precision between users [25]. In public interactions, it has been demonstrated that users standing in central positions have priority to the other users in interaction efficiency and precision on large displays [20,24]. It has been verified that laser pointing interaction had a higher precision in central position than in peripheral position [19].

To satisfy the interaction efficiency and precision demands in gestural interaction with large displays, in particular to provide equal interaction efficiency and precision for parallel users, we propose a new pointing technique. The new technique captures the user's position information to coarsely define a focus area on the large display, then transforms the user's gestural motions to fine-grained interactions within the focus area. Be limited by the research scope, this paper is not aimed to exhaust all interaction types, thus only pointing interaction is concerned in this research and we named the new technique as "walk-to-point" technique.

Compared to other interaction techniques, the new technique specialises as follows: (1) settles the contradiction between access efficiency and pointing precision. It permits accessing any areas of large display meanwhile providing adequate precision in gestural interaction; (2) implements a free-hand precise pointing technique without other devices aided; (3) not only settles access efficiency and precision issues in individual context but also provides equal access efficiency and sufficient precision for parallel users in group collaboration.

2.   Related Work

2.1.   Access Efficiency on Large Displays

Because of the extra physical size and wide visual field, large displays are applied in broad types and diverse situations, from individual immersive working table to public exhibition platform [1]. In different situations, different interaction approaches are adopted, including direct touch, mouse interaction and Kinect-based gestural operation [1]. No matter what approaches are adopted, accessing difficulty is a common issue, especially in large display (e.g. size in $3m \times 5m$) environments [5]. For example, in direct touch on large table screens, users can only interact within an arm reachable region at one time while have to move around the table to reach farther areas or interpret others to collaborate [1]. In mouse-based interaction with large displays, a subtle movement in mouse generates cursor's rapid movement, which results in more difficulties in windows' and layouts' management [21]. In interaction with large displays, because the majority of interaction techniques are derived from typical-sized display interactions, access problem is prevalent [9].

In order to address the access issues, a number of methods have been put forwarded. For example, in body-centric interactions [22,23], users' body shadows projected on the large display areas were adopted as interactive areas, and users can use gestural behaviours to extend their reachable region. In interaction with desktop screens, Banerjee et al. [4] developed *Pointable* technique to reach out-of-reach targets. All these techniques were aimed to handle the difficulty in accessing out-of-reach targets, but how efficiently and accurately interact with those distant targets were seldom concerned. Additionally, in multi-user interactions, how large displays are interacted by parallel users has still not be sufficiently investigated.

2.2.   Precise Interaction

Except for the difficulty in accessing distant targets, low interaction precision is another issue of large displays [10], especially in interacting with rich data on large-scale user interfaces [7]. In

order to remedy this weakness, Malik et al. [17] used a touchpad to aid interaction with large displays. The touchpad is designed in two parts: Gestural motions in the left part were transformed to coarse selection and the gestures in the right part were translated to precise interaction. Likewise, Zhou et al. [27] developed *Javelin* to realise precise mouse-based interaction in large displays. Mäkelä [15] proposed a technique called *Magnetic cursor* to automatically wraps the cursor to the targeted object, thus the object could be more easily selected.

In addition, another kind of *Dual-Precision* (DP) pointing technique has been proposed to aid interaction with large displays. The DP pointing technique refers to a combination of absolute (coarse-grained) positioning and relative (fine-grained) pointing [18,26]. Among the DP pointing techniques, mobile devices integrated with large displays are the dominant configurations because mobile personal devices held by users have strengths in flexibility, non-interference and privacy [5]. In DP interactions, the orientation of the device is often tracked to determine the position of interest area while the relative movements of the device and touch-based input on the touchscreen are transformed to fine-grained interactions within the interest area [11,12,16].

3. Walk-to-Point Technique

In earlier research, user's spatial dynamics such as user's standing position and movement are captured to generate responsive interfaces in proxemic interaction and ambient interface [3,25], but to our knowledge, such dynamics have never been used as input in precise interaction with large displays. In this paper, these spatial dynamics are explored to promote access efficiency and precision in gestural interaction with large displays, both in single- and multi- user situations.

Unlike earlier research relying on sensitive floor [3] and precise motion-tracking systems [26], our technique implements a more flexible and affordable method, only needs a commercial depth camera. It captures the user's movement in horizontal and the head-to-display distance to implement walk-to-point technique. The new technique has two modes: In coarse mode, the user's position determines the coordinate of a focus area. The focus area is a rectangular frame hovering on the interface, cursor's movement is confined within this frame. In precise mode, the user's gestural motion is tracked to determine the cursor's position within focus area. The whole process of two modes is illustrated in Figure 1.
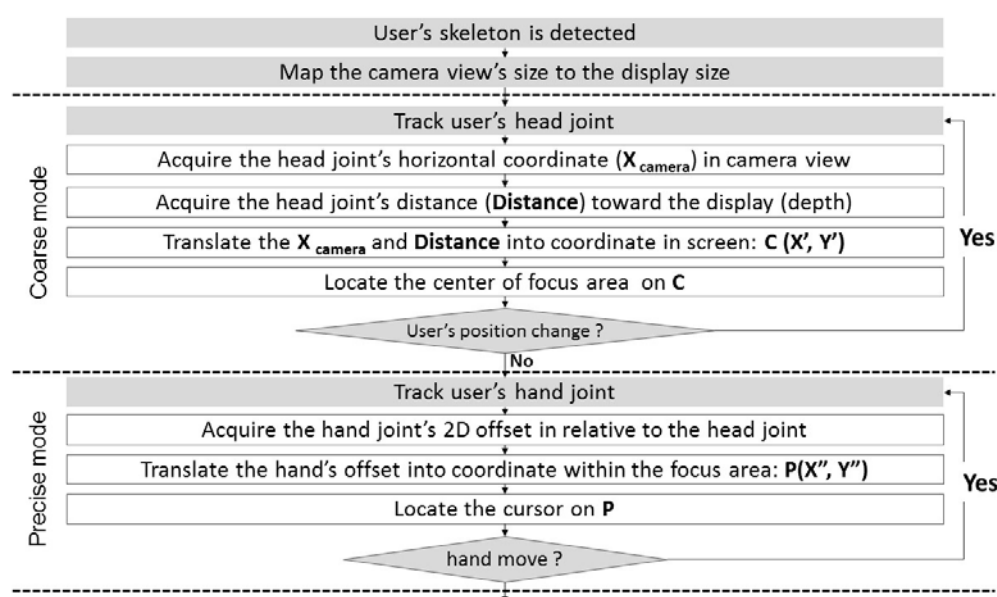

Figure 1. The whole process of two modes in walk-to-point technique.

As shown in Figure 1, to detect users in space and to track user's head and hand, a skeleton detecting method is utilized in walk-to-point technique. In prepare stage, it firstly detects user's skeleton to confirm how many users interact simultaneously, so as to determine how to map camera view's coordinate to display's coordinate.

Figure 2 illustrates the rationale of coarse mode in single-user situation. As shown in Figure 2, when the user is sensed within the camera's perspective, user's horizontal position (i.e. X_{camera} in Figure 1) and distance towards display (i.e. "Distance" in Figure 1) can be calculated. By mapping camera's coordinate to display's coordinate, X_{camera} is used to calculate the cursor's central X coordinate value; by mapping space's distance range to display's height, "Distance" is used to calculate the cursor's central Y coordinate value. In this way, user can move left and right to change focus area's horizontal position while steps forward and backward to move focus area higher and lower on display. Note that be limited by the depth camera's recognition resolution, the distance range is confined within the 800 - 3500 millimetres [14].
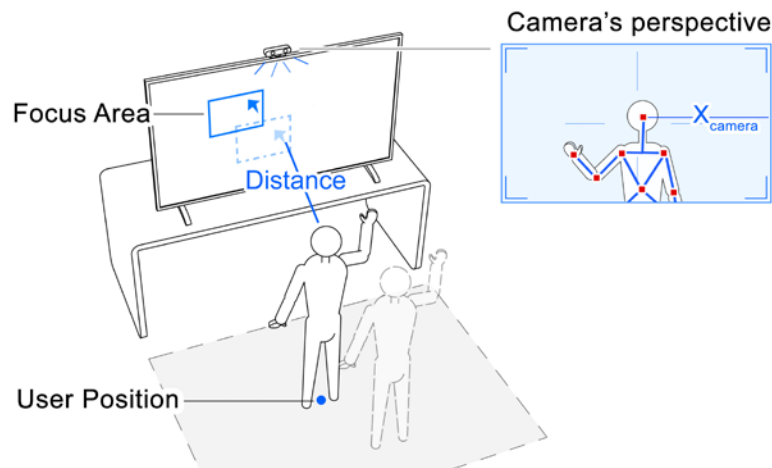

Figure. 2. Interpretation of coarse mode in single-user situation.

When multiple users interact simultaneously, the space in camera's perspective is separated into sub-space in horizontal direction. To ensure each user has an equal access efficiency to the whole display, space needs to be separated equally and each sub-space should be mapped to the whole size of display. This explains why the technique detects user number in preparation stage. Figure 3 illustrates how focus areas are positioned in multi-user situation.
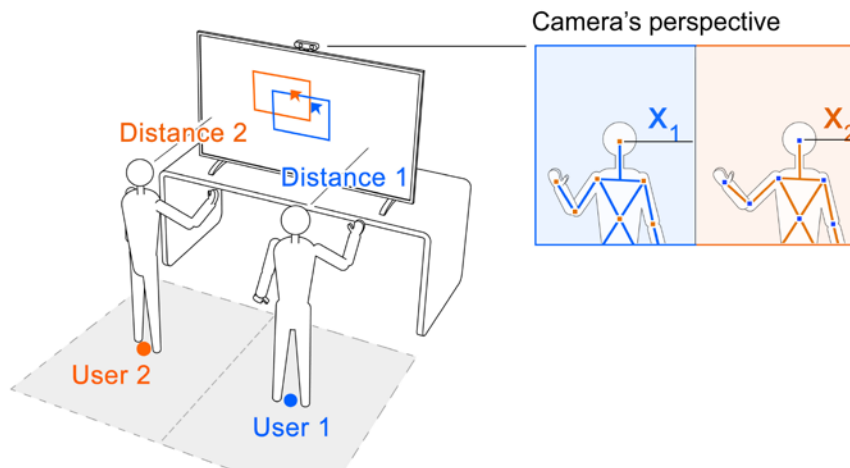

Figure 3. Interpretation of coarse mode in multi-user situation.

Unlike single-user utilization, in two-user situation the camera's view space is separated into horizontal two parts, each corresponds with a whole coordinate axis. Thus each user's horizontal position (X_1, X_2) in sub-space can be determined, as shown in Figure 3. From depth data, two users' distance (Distance1, Distance2) toward the display can be calculated. Using these four values, the coordinate of two focus areas can be determined. The formula of defining focus area's central coordinate can be represented as:

$$X_c = a \times X_{camera}, \; Y_c = b \times Distance \tag{1}$$

where *a* and *b* are mapping-factors that translate distance values in real world to display coordinate: *a* is determined by both user number and the rate between screen resolution and camera resolution in horizontal. For example in our study, the display resolution is 3840×2160 while the camera resolution is 640×480, thus the a value is 4.5 (2160/480); *b* is the rate between screen's Y-axis height and camera's sensed depth range (e.g. 800 to 3500 millimetre). X_{camera} refers to the user head's horizontal position in camera view. As we explained in Figure 2 and 3, it is differently calculated in single- and multi-user situations. Distance refers to the head-to-display distance.

In precise mode, the interacting hand's position relative to the head is translated to the cursor's coordinate within the focus area. To provide a precise translation function, a pointing technique based on the cursor-to-display transferring ratio (i.e. CD gain) is adopted [19]. CD gain refers to a ratio between cursor movement and input variation. A high CD gain generates a large extent of the cursor's movement, but it is weak in precision; while a low CD gain represents the cursor can be precisely controlled, but it is limited in accessible scope [19]. In walk-to-point, we use a CD value of 0.5, which has been demonstrated to be suitable in precise interaction [21]. Given hand's movement span is larger than 500 millimetres, we design focus area's side length as 250 millimetres. The formula of defining cursor's coordinate can be represented as:

$$X_p = X_c + 250 \times (X_{hand} - X_{head}) \times RH_{dis} / (W_{dis} \times RH_{cam}) \tag{2}$$

$$Y_p = Y_c + 250 \times (Y_{hand} - Y_{head}) \times RV_{dis} / (H_{dis} \times RV_{cam}) \tag{3}$$

where (X_c, Y_c) is the central coordinate of focus area, (X_{hand}, Y_{hand}) refers to the coordinate of hand joint in camera's perspective and (X_{head}, Y_{head}) is the coordinate of the user's head joint in camera's perspective. Other factors are determined by configurations: RH_{dis} and RV_{dis} are display's horizontal and vertical resolution; W_{dis} and H_{dis} are display's physical size in width and height; and RH_{cam} and RV_{cam} are camera's horizontal and vertical resolution. In this study, a 1560mm $\times$ 877.5mm display was used, and the camera's resolution is 640×480. So the coordinate of cursor can be simplified as $(X_c + 0.96 \times (X_{hand} - X_{head}), Y_c + 1.28 \times (Y_{hand} - Y_{head}))$. Note that the cursor's movement is limited within the focus area, so that only targets within the focus area can be accessed by cursor. In this way, targets located near the focus frame's sides are more easily reached. Besides, a threshold of 200 millimetres is added to eliminate those occasional movements.

4. Hypotheses Development

Unlike laser pointing operates by holding a laser emitter in hand and directly pointing to targets, walk-to-point technique relies on user's movement and hand motions to perform dual-mode pointing. It has been demonstrated that user's spatial movement is less efficient than gestural movement in interaction [13], thus we raise hypothesis 1 as follows:

- *(H1) In comparison to the traditional laser pointing method, walk-to-point technique has a higher pointing precision but is lower in access efficiency.*

In laser pointing, visual angle determines the laser's direction range [12], thus users stand on the edge face more limited pointing angle than those stand in central front of large displays. But in walk-to-point technique, users' movement and gestural motions are equally mapped to the coordinate of display no matter where users stand. In this regard, we raise hypothesis 2 as follows:

- **(H2)** *In multi-user interaction, walk-to-point technique shows less discrimination in access efficiency and precision among users than the laser pointing method.*

5. Methods

The objective of this study is to evaluate the effectiveness of walk-to-point technique. In this study, laser pointing is selected as control technique, and it is compared to the new technique in terms of precision, efficiency and usability evaluation. In particular, the study aims to demonstrate that walk-to-point technique can provide equal access efficiency and precision for group users in multi-user interaction. Based on this, we conducted studies in both single- and multi- user situations.

5.1. Participants

The study recruited 12 participants (7 males and 5 females; Mean Age = 24, SD = 4.5). These participants are employees and undergraduate students from local companies and universities, all have experience of using large displays for searching and interacting with information. And all participants have normal or correct-to-normal eyesight without body impairments. Participants were paid $10 for their participation.

The study adopted within-group design in evaluation. In single-user study, each participant was required to complete the tasks by two interaction methods; while in multi-user study participants were separated into 4 groups (two groups have 4 participants in each while other two groups have 2 participants in each), each group completed the tasks by two methods.

5.2. Apparatus

Studies were conducted in a laboratory with work stations, tables and adequate space provided. A 70-inch (1560mm × 877.5mm) flat screen was used as large display. The screen was connected to a work station (Windows 7, 32 GB memory, and 4.0 GHz Intel 32-core processor) and it displayed the task interfaces from the workstation. An ASUS Xtion PRO^{TM} depth camera was mounted on middle top of the large screen. Figure 4 shows the task interface and the study scenario.
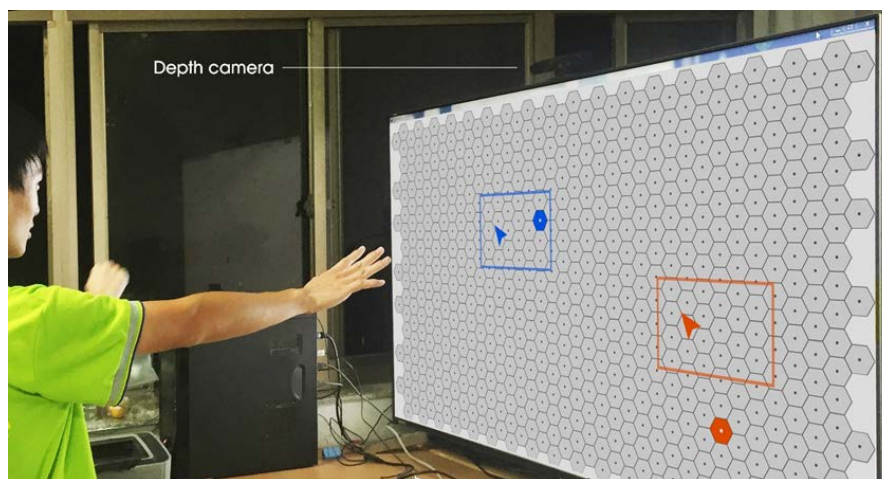

Figure 4. Study scene: two participants were completing tasks by wall-to-point technique.

Based on [26], 48mm and 24mm were selected as target size variables in this study. As a consequence, two interface variables were developed, each having different sized targets: interface one exhibited 627 hexagonal targets, each target had a diameter of 48mm; interface two exhibited 2460 targets, each having a diameter of 24mm. Except for targets, cursor(s) and focus area(s) were shown in interface with discriminative colours: (a) single-user: blue colour in cursor and focus area's frame; (b) two-user group: blue for participant one, orange for participant two; (c) four-user group: blue for participant one, orange for participant two, green for participant three, purple for participant four. In control group, four converted Sharp^{TM} remote controllers were used as laser pointers in laser pointing. The same task interfaces were used in two technique conditions.

5.3. Procedures

Participants were given an introduction of tasks and a trial use of the large display before study. Once study started, a target turned colour (e.g. blue) in a random position on interface. Participants were required to move the cursor to the highlighted target, keep the cursor hovering on the target 1000ms to complete selection. Then the target disappeared and another target showed in a random position. After the participant completed 200 target selections, the interface exited automatically. Note that when pointing a target, if the cursor move away without sustaining 1000ms, it represents one pointing error. The pointing error number was recorded by interface program. During the task process, the interval from a target showed to it was accessed by cursor was defined as access time, the access time for each selection was also recorded. After the interface exited, the pointing error number and all access time were written into a text file and stored.

The single-user study was carried out in prior to the multi-user study. In single-user study, each participant completed four task rounds. Each task round is explained as follows:

- Task round 1: using laser pointing method to point 48mm targets;
- Task round 2: using laser pointing method to point 24mm targets;
- Task round 3: using walk-to-point technique to point 48mm targets;
- Task round 4: using walk-to-point technique to point 24mm targets.

The order of task rounds be conducted was randomly selected by Latin square design. Between two task rounds, participants were given 10 minutes to relax. The participants took approximate 58 minutes (SD = 6.30) to finish four task rounds. At last, 48 data files were collected in single-user study.

In multi-user study, four groups completed the task one by one, each group also completed four task rounds with random order. During tasks, participants were guided to stand from left to right without overlapping in front of display, and they were told what colour each one corresponded before task started. According to different numbers of participants attended, different numbers of focus areas and cursors showed on interface in different colours. Between two task rounds, groups were given 10 minutes to relax. In each task round, each participant needed to complete pointing 200 targets. After all participants completed task, interface exited automatically. Each group took almost 54.5 minutes (SD = 5.75). Finally, 16 data files were collected in multi-user study, each file included all group users' access time and error number data.

After study, participants were given two questionnaires of System Usability Scale (SUS) [8] to evaluate two pointing methods. The SUS questionnaire is a 5-point Likert scale containing 10 items of description, each item can be scored from 1 to 5, 1 represents "strongly disagree" while 5 represents "strongly accept". Furthermore, after each task round participants were encouraged to discuss their experience of using large display and evaluate on the pointing technique. Their comments were recorded.

6. Analysis

For each data file, mean access efficiency and pointing precision were calculated. The access time data that were 3 standard deviations more than the mean value were treated as the outliers and removed.

6.1. Single-User Performance

For each pointing technique, mean access time in two target sizes were calculated. Figure 5 shows the access time result in single-user study. In accessing 48mm target, the new technique has 29.7% longer access time than laser pointing (*Two-tailed independent T-test, $T_{22} = 3.14$, p = 0.012*). While in accessing 24mm wide target, by contrast, the new technique performs 8.7% less access time than laser pointing ($T_{22} = -7.82$, p = 0.023).
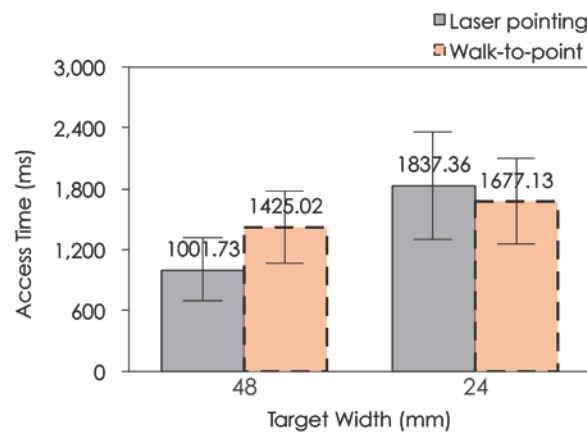
Figure 5. Access time result in single-user study.

The pointing error rates for two methods were then evaluated. Figure 6 shows the results of two target sizes. It can be observed that both two pointing methods had lower than 6% error rate when pointing 48mm wide targets. But when pointing 24mm wide targets, laser pointing incurs more than 60% error rate while the new technique has only about 10% error rate. It represents when pointing such small targets, traditional laser pointing method is no longer reliable in precision but the new technique is qualified to this precision demand.
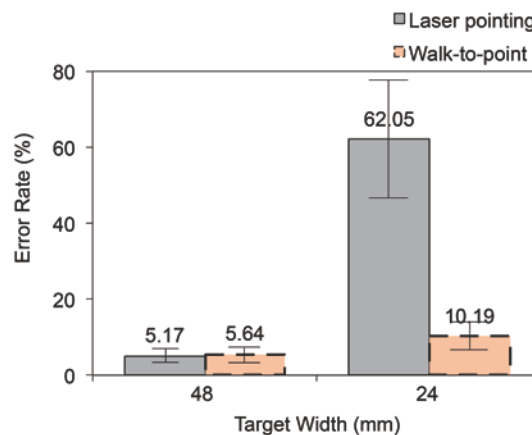
Figure 6. Pointing error rate result in single-user study.

6.2. Multi-User Performance

By the same method, we calculated four groups' mean access time in two target sizes, the result is shown in Figure 7. Difference in access time between two pointing methods maintained in multi-user study: when pointing 48mm wide targets, the new technique had a 28.3% delay in access time than laser pointing method (*Two-tailed independent T-test, $T_{22} = 5.6$, $p = 0.007$*); but when pointing 24mm wide targets, the new technique became 36.6% faster ($T_{22} = -7.12$, $p < 0.001$). We also found that group size and target size have a mixed influence on pointing tasks: In laser pointing method, larger group size generated less access time in accessing 48mm target ($p < 0.05$); but the result became opposite in accessing 24mm target, larger group size incurs lower accessing efficiency in this situation ($p < 0.05$).
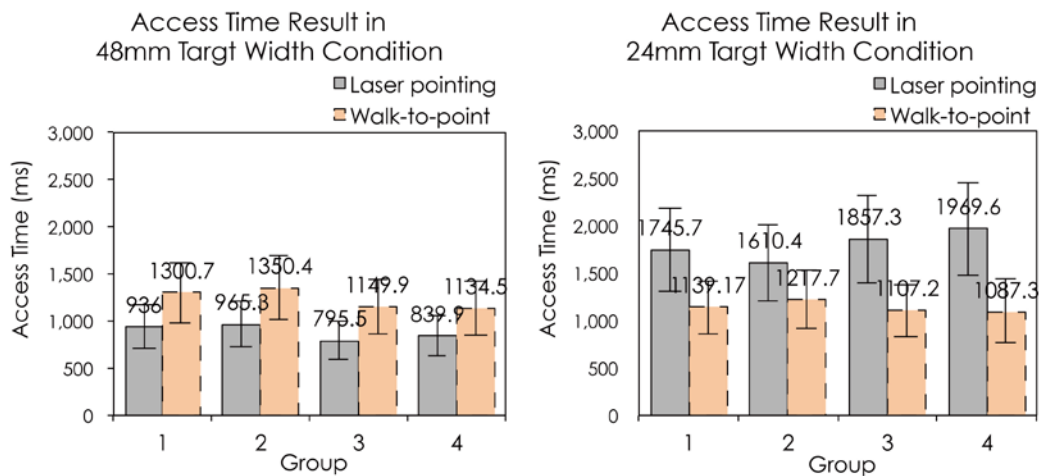

Figure 7. Access time result in multi-user study.

In order to assess how pointing techniques influence equity in access efficiency among groups, we calculated each participant's mean access time in two largest groups. Multi-ways ANOVA results show that in laser pointing method, participants standing in central front of display achieved significantly more accessing time than those standing beside (*all $p < 0.05$*); while in the new technique, such difference was not significant.

Finally, we calculated the mean pointing error rate for four groups, result is shown in Figure 8. In pointing 48mm wide targets, both two pointing methods achieved lower than 10% error rate. But in 24mm tasks, the new technique performed far lower error rate ($F_{1, 22} = 435.4$, $p < 0.01$) than the laser pointing method. Comparing between two largest groups, by laser pointing technique participants standing in central positions achieved obvious lower pointing error than those standing beside ($p < 0.05$), but such discrimination was not obvious in the new technique. In addition, precision results from different group sizes were compared. It showed that the laser pointing had a higher error rate in four-user group than in two-user group ($p < 0.05$). By contrast, the new technique showed less different error rate between two group sizes.
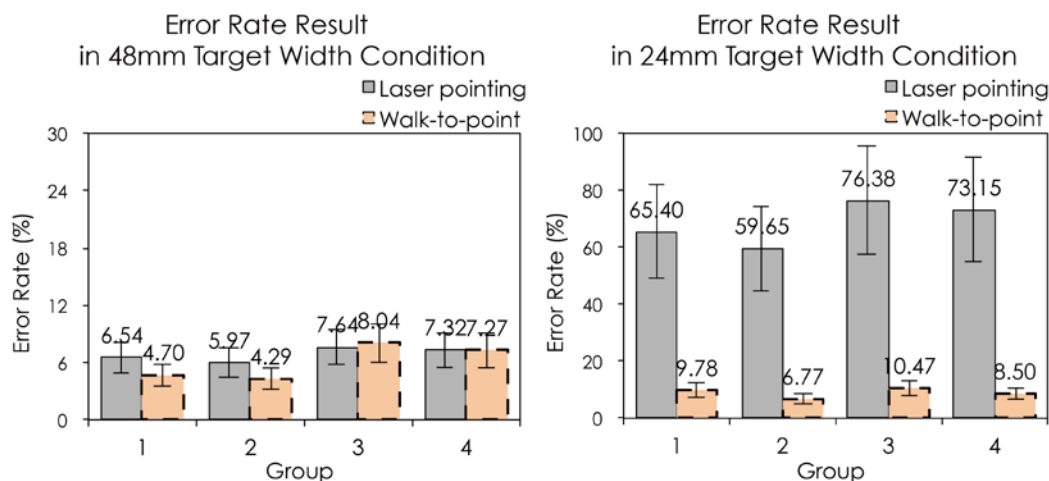
Figure 8. Pointing precision result in multi-user study.

6.3.   Usability Evaluation

Finally yet importantly, we analysed usability evaluations on two pointing methods. Using the calculation method of SUS [8], we got a mean SUS score for each technique: Laser pointing achieved a score of 63.9 while the new pointing technique was scored 78.1. A Mann-Whitney test showed that the new technique was more positively evaluated than laser pointing techniques ($U = 27.00$, *z-statistic = -2.137, p < 0.01*). In items 5, 7 and 9, the new technique was evaluated to be superior to the laser pointing in compatibility with large display environment, easiness in learning and confidence in utilization.

Participants' comments confirmed the SUS result, but also showed doubt towards the new technique: Four participants expressed walk-to-use technique is easy to learn, and one participant commented *"it is spontaneous to move here and there to change focus when watching such large display, I think this operation is more natural"*. Other two participants pointed out that frequent movement is easier to incur fatigue, especially when the task process was lasting. Another participant complained that the additional focus frame added on interface disturb his sight.

7.   Results

In analysis section, we compared walk-to-point technique with traditional laser pointing in terms of access efficiency, pointing error rate and usability evaluation, and particularly we investigated how participant number influenced two methods' performance. Results are divided: when pointing 48mm wide targets, the new technique achieved equivalent pointing precision and lower accessing efficiency than the laser pointing; but when pointing 24mm wide targets, the new technique performed both higher access efficiency and precision than the laser pointing. In this perspective, *hypothesis 1* is partially supported.

In multi-user study, analysis results showed that using laser pointing method participants standing in centre performed significantly higher pointing precision but weaker access efficiency than those standing beside. Such difference was not obvious in walk-to-point technique. These results indicated the new technique was effective in providing equality in access efficiency and precision in multi-user interactions, the *hypothesis 2* is supported.

8. Conclusion

In this paper, we proposed a walk-to-point technique to promote access efficiency and precision in gestural interaction with large displays. In particular, we conducted single- and multi- user studies to demonstrate the new technique's effectiveness. The results revealed that (i) in pointing small targets, the new technique achieves both higher efficiency and precision than the laser pointing; (ii) the new technique is effective in providing equal access efficiency and precision for group users; (iii) given fixed space, group size has an influence on the laser pointing's accessing efficiency and precision: The more participants the lower efficiency and precision. But such influence is not obvious in the new technique. Based on these findings, we concluded generalising implications for future development of large display-related applications in single- and multi- user situations.

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