



HAL
open science

E-Pad: Large Display Pointing in a Continuous Interaction Space around a Mobile Device

Cagan Arslan, Yosra Rekik, Laurent Grisoni

► **To cite this version:**

Cagan Arslan, Yosra Rekik, Laurent Grisoni. E-Pad: Large Display Pointing in a Continuous Interaction Space around a Mobile Device. DIS 2019 : Designing Interactive Systems Conference 2019, Jun 2019, San Diego, United States. pp.1101-1108, 10.1145/3322276.3322284 . hal-02432474

HAL Id: hal-02432474

<https://hal.science/hal-02432474>

Submitted on 8 Jan 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

E-Pad: Large Display Pointing in a Continuous Interaction Space around a Mobile Device

Cagan Arslan
Univ. of Lille,
CNRS UMR 9189, CRIStAL,
Villeneuve d'Ascq, France
cagan.arslan@univ-lille.fr

Yosra Rekik
Univ. Polytechnique
Hauts-de-France,
LAMIH, CNRS UMR 8201,
Valenciennes, France
yosra.rekik@uphf.fr

Laurent Grisoni
Univ. of Lille,
CNRS UMR 9189, CRIStAL,
Villeneuve d'Ascq, France
laurent.grisoni@univ-lille.fr

ABSTRACT

Relative pointing through using tactile mobile device (such as tablets or phones) on a large display is a viable interaction technique (that we call *Pad* in this paper) which permits accurate pointing. However, limited device size has consequences on interaction. Such systems are known to often require clutching, which degrades performances. We present *E-Pad*, an indirect relative pointing interaction technique which takes benefit of the mobile tactile surface combined with its surrounding space. A user can perform continuous relative pointing starting on the pad then continuing in the free space around the pad, within arm's reach. As a first step toward *E-Pad*, we first introduce *extended continuous relative pointing gestures* and conduct a preliminary study to determine how people move their hand around the mobile device. We then conduct an experiment that compares the performance of *E-Pad* and *Pad*. Our findings indicate that *E-Pad* is faster than *Pad* and decreases the number of clutches without compromising accuracy. Our findings also suggest an overwhelming preference for *E-Pad*.

Author Keywords

Pointing; mobile devices; extended gestures; continuous interaction; large display

CCS Concepts

•**Human-centered computing** → **Pointing devices**; *Touch screens*; *Mobile devices*;

INTRODUCTION

Large displays are increasingly popular and well adapted for public settings. Ray casting methods [5,8,14,18,19] and tablet based gestures [13] are usually used to interact with these displays. However, although these techniques perform well for targeting and tracing [8], they can lead to major issues. For instance, using only ray casting methods can be limited due to hand jitter and can entail fatigue; lack of supporting

surface may decrease user performance [14]. Another important design element is that pointing task when interacting with large displays differs from desktop and mobile. In this context, either using absolute mapping or relative ones can be problematic. For example, absolute mapping suffers from difference in screen sizes [15]. Meanwhile, while relative pointing is a viable technique enabling precise pointing, the nature of a small screen requires a careful calculation of the cursor transfer function. In addition, the small size of touch pad requires clutching to move the cursor, which degrades the performance [4].

To overcome such limitations, we propose to combine touchscreen with surrounding space to perform *extended continuous relative pointing gestures* which enable transitioning from the mobile touchscreen to mid-air. These gestures permit the creation of the *Extended-Pad* (hereafter referred as *E-Pad*), that first takes into account a unified interaction space composed of device space and surrounding space, and second, uses a modified control function for the correspondence of the user movement to cursor display to perform large cursor movements while being less tiring than direct pointing and faster than the on-device pointing techniques.

Our contributions are as follows: (1) we introduce *extended continuous relative pointing gestures* and conduct a preliminary study to determine how the hand diverges upwards from the smartphone's plane as the motion continues around it, (2) we propose *E-Pad*, a novel technique for relative pointing on large displays, (3) we conduct an experiment to compare the performance of *E-Pad* with *Pad*, and (4) we derive three guidelines for pointing on large displays. We hope that *E-Pad* and our results will prove useful to designers and practitioners interested in indirect pointing on large display designs.

RELATED WORK

Ray casting methods are largely used to interact with the large displays. *Laser pointing* [5,18] and *image-plane pointing* [19] are the principal applications of ray casting methods. Although these techniques perform well for targeting and tracing [8], hand jitter, fatigue and lack of supporting surface decrease their performance [14]. Kopper et al. [9] also state that the performance of distal interaction systems depends largely on angular movements and sizes. Therefore, if the target and the user are at opposite ends of the display, the target is very

difficult to acquire. In order to attack the precision problems, Vogel and Balakrishnan investigated gestural pointing techniques in air and concluded that ray casting may be faster, but less accurate than relative pointing [26].

In parallel, other researchers advocated for using tablet devices as a touchpad when interacting with large displays. These endeavours have led to a number of orthogonal designs. For example, hand-held touch screens based on absolute mapping of the touch screen to the display have been employed to interact with large displays [11,20]. However, an absolute mapping is problematic due to the difference in screen size. Other researchers proposed using relative pointing [15] or combining both absolute and relative mapping by tapping to jump to the corresponding location on the screen, and then invoking relative motion with any finger movement [13]. Siddhpuria et al. conducted an experiment on distal pointing with everyday smart devices [22] and concluded that using smartphone with two hands as a relative trackpad in landscape orientation gives the best results. Relative pointing on a touchpad is a viable technique which permits precise pointing, but the nature of small screen requires a careful calculation of the cursor transfer function. Pointer acceleration (PA) functions dynamically adjust the control-display gain, but they are implemented for desktop use in major operating systems [3]. Also, increasing the gain may deteriorate the performance due to hand tremor and quantification errors [7]. Additionally, according to Casiez et al. [4], significant clutching to move the cursor degrades the performance. We should also state that, Nancel et al. [16] found that clutch-less movements were harder to perform and were not faster than clutch-enabled movements on touchpads.

Multimodal interaction techniques such as gaze and touch are used to increase the performance of pointing with mobile devices. [23] [24]. Mixing touch and mid-air gestures is another approach to control large displays. In [2,10,28], authors benefit from switching between touch and air interaction for large tactile displays, but there is no continuity between the two modes. Yet, there exists a rich interaction space trapped between touch and air. Marquardt et al. [12] propose transition techniques that start on a touch surface and end in the air, and vice-versa. They generalize these types of gestures as *Extended Continuous Gestures*. Following this, the community has started to employ the extended continuous gestures. For example, DeAraujo et al. [6] proposed an on-and-above-the-surface interaction techniques for creating and editing 3D models in a stereoscopic environment. Rateau et al. [21] proposed Talaria, a drag & drop technique on a big wall display. Takashima et al., [25] introduced *Boundless Scroll* to decrease the number of clutches while performing scroll gestures on a touchscreen. *E-Pad*, the technique that we propose in this paper, builds upon this previous work to insure large display pointing in a continuous interaction space around a mobile device.

EXTENDED CONTINUOUS RELATIVE POINTING GESTURE

Marquardt et al. defined *Extended Continuous Gestures* [12] as “a gesture that a person starts through direct touch on the interactive surface can continue in the space above the surface

to avoid occlusion of the digital content visible on the tabletop display”. We propose an extended continuous gesture that continues in the space *around* a small hand-held touchscreen device. *Extended continuous relative pointing gestures* are complementary to regular pointing gestures, meaning that they intervene when the limited physical surface of a hand-held touchscreen is insufficient to perform large cursor movements. These gestures start on the touchscreen and end in mid-air while the cursor is attached to the relative motion of the finger (Fig. 1.)

Preliminary Study: Finger Motion

During the implementation stage of *E-Pad*, we realized that in mid air, the dominant hand diverged upwards from the smartphone’s plane as the motion continues. This observation is parallel to the findings in *Boundless Scroll* [25]. Consequently, we decided to study the approximate imaginary surface on which the user performed the gestures when being around the smartphone surface. Thus, we conducted a preliminary study to observe the user’s ability to interact spatially on and around a smartphone’s touchscreen when pointing on a large display. Our main interest is in determining the boundaries of the interaction volume and the pointing path in mid air.

Participants

Six men; average age 28. All participants were right handed and regular users of smartphone.

Apparatus

The preliminary experiment was conducted on two concatenated displays with a total resolution of 3840×1080 pixels resulting in a screen size of 130×37 centimeters. Participants were standing 2 meters’ away from the projection surface. We used a 5.8” Galaxy S8 smartphone (14.8×6.7 cm) to send the touch inputs via TUIO protocol. Additionally, four Optitrack cameras operating at 150Hz were in charge of tracking reflective markers on the pad and the user’s hand as seen in Figure 2. The experiment was implemented in C++ and ran on two PCs (one for tracking and one for the display, each running on Windows 10.)

Procedure

We told participants that we were interested in determining users’ performances when pointing on and around the smartphone surface to control large displays. This was intentionally misleading, since the main study objective was how they unconsciously move their finger and the dominant hand around the smartphone surface, as well as how they hold the smartphone. We then equipped our participants with reflective markers to create rigid bodies for the smartphone, the index finger and the dominant hand. This allowed us to obtain the position and the orientation of the smartphone, the finger’s position with respect to the smartphone to move the cursor and the finger’s position with respect to the hand to implement a reliable clicking technique independent from the smartphone’s plane.

In the experiment phase, the participants were asked to stay standing while holding the smartphone comfortably using their non-dominant hand, and perform the gestures quickly using



Figure 1: E-Pad functions: (a) Coordinates of E-pad; (b) pointing on the pad; (c) continuing in the air; and (d) releasing the cursor.

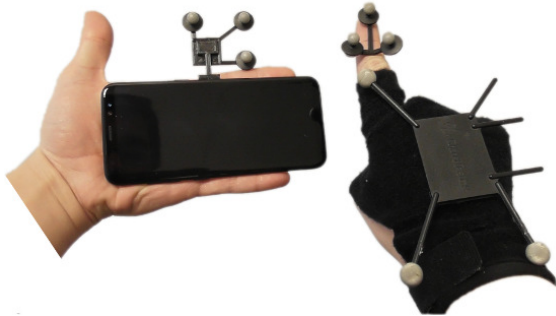


Figure 2: 3d printed markers on the smartphone and the user's dominant hand and the index finger.

their index finger from the dominant hand. They were shown a start target they selected by tapping on the touchscreen. Once the start target was selected, an end target was displayed on the opposite side of the screen. The participants were required to select the end target with an air-click as a result of a continuous gesture (Figure 1). To simulate the motion on the cursor on the screen, we used the standard Windows 10 transfer function for both the finger position on the touchscreen and in mid-air. 3D finger positions were projected on the *Pad's* plane to obtain 2D coordinates. In order to prevent the click gesture from moving the cursor, we blocked the cursor when the finger accelerates away ($>1\text{cm/s}$) from the hand's plane. However, a click is performed only if the finger reaches 15° from the hand. This threshold was empirically chosen.

The experiment was a 6×3 within-subjects design with two factors: pointing direction (east to west, north-east to south-west, north-west to south-east, west to east, south-west to north-east) and block (block1, block2, block3). We used a fixed amplitude (117 cm, with the amplitude corresponds to the distance between the start target and the end target on the screen) and a fixed tolerance (2.54 cm, with tolerance corresponds to the target circle radius). The experimental trials were administered as 3 blocks of 36 trials. Inside each block, 36 trials (6 directions \times 6 repetitions) were randomly presented to each participant – a total of 108 trials per participant. The average duration of the experiment was 30 minutes.

Data collection

We recorded the position of the rigid bodies placed on the smartphone, the index finger and the dominant hand at 120Hz.

We isolated the 108 extended relative pointing gestures per participant between the start target and the end target. The finger position captured by the Optitrack cameras was translated to the smartphone's coordinates. We did not log the finger position on the touchscreen as it can also be obtained from the Optitracks using the markers on the finger and the smartphone.

Results

First, each participant held the smartphone almost parallel to the ground, holding it from the back in order not to block the movements on different directions.

We constructed a point cloud of index finger positions from 648 trials. All the points were constrained in an imaginary box that exists between -63cm and 71cm on the x -axis, -12cm and 25cm on the y axis and -33cm and 22cm on the z axis.

We then fitted two fourth order polynomials to the point cloud on the x -axis (see Fig. 3a) and on the z -axis (see Fig. 3b) to represent the average paths used by participants. The equations of the curves are as following:

On the x -axis:

$$y = 0.03 + 0.01x + 0.23x^2 + 0.05x^3 + 0.12x^4$$

On the z -axis:

$$y = 0.02 - 0.008z + 6.38z^2 + 27.07z^3 + 33.45z^4$$

These curves confirm the hypothesis that the index finger deviates from the ideal smartphone plane as it moves away in mid-air. The deviation is similar on the dominant and non dominant hand sides, but as expected, the user has a larger reach on the dominant hand side. Because of the limited distance between the user and the smartphone, there is limited reach when user move downwards on the z -axis. On this direction, the finger deviates quickly.

Design implications.

Informed by our experimental findings, we outline two relevant guidelines for designing pointing techniques on and around a smartphone's touchscreen for large display:

- *Interaction volume.* The imaginary box obtained by the experiment shows that it's important to define an interaction volume rather than an interaction plane to perform the extended relative pointing. It is not important to limit the size of the interaction volume on the x and z axes as these dimensions depend heavily on the arm's length. However,

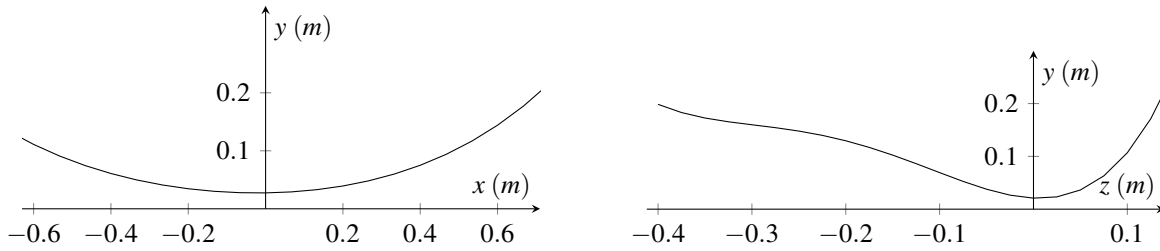


Figure 3: Estimated paths of the finger. (a) on the x axis, (b) on the z-axis. Y-axis corresponds to the average orthogonal distance between the finger and the *Pad*.

limiting the *depth* of the volume on the y-axis, we can present the users a mechanism to release the cursor, or to perform clutches in the air. Based on the extremities of the point cloud we obtained, this depth can be chosen as 37cms, 12cms under and 25cms over the *Pad*.

- **Curved motions.** The curved nature of the obtained surface has to be taken into account in the control to display transfer function. On one hand, if the transfer function only uses the projected positions on the xz plane, the user wastes physical motion performed on the y axis while moving the cursor. On the other hand, we cannot directly add the y component of the motion into the equation. If the user deviates even more than the proposed curves, y component of the motion weighs heavily, causing stability issues. Additionally, using y component on both x and z axes result in interdependence between horizontal and vertical cursor motion. Therefore, we propose projecting the finger position on the xz plane, then using the length of the displacement vector on the curves (Figure 4).

E-PAD DESIGN

E-Pad is designed to overcome the limitations of indirect relative pointing system with a mobile device for large displays. We were inspired by extended continuous interaction techniques [12] that start the interaction on touch and continues in the air and we named our technique Extended-Pad (*E-Pad*). *E-Pad* is an indirect relative pointing system composed of a touch surface (smartphone) and the space around. A person can perform *extended continuous relative pointing gestures* starting on the pad, then continuing in the free space within arm's reach.

The preliminary study we conducted allowed us to define the following functions for *E-Pad*:

Starting pointing on pad.

E-Pad contains the regular use of a trackpad (see Figure 1.b). Relative movements of the finger on the touch screen are mapped into the motion of the cursor on the screen with a conventional control to display transfer function. We use Windows' native pointer acceleration function to control the cursor [3].

Exiting the *Pad* and creating the Imaginary Interaction Space (*IIS*). When the size of the pad is not sufficient to move the cursor through a long distance, *E-Pad* permits the user to exceed the *Pad*'s frame. To enable the relative mid-air pointing,

the finger should leave the touchscreen with a high velocity and should continue parallel to the smartphone's surface. The velocity threshold and the maximum angle between the direction of the finger on exit and the smartphone's plane were empirically chosen as 8 cm/s and 15° respectively. Once the transition to mid-air is completed and an *Imaginary Interaction Space (IIS)* is created, its origin and orientation corresponds to that of the smartphone (see the axes in the Figure 1.a). The position and the orientation of the *IIS* are then fixed. This prevents variations of the coordinate system of the finger while it is in mid air and provides a better stability for the cursor on screen. *IIS* is open ended on the smartphone's plane, but it has a height of 37cms (see 3.2). *IIS* encompasses an optimal surface for the finger motion while permitting deviations from the optimal path.

Pointing in mid-air. In order to maintain the continuity between the *Pad* and around the *Pad*, we use Windows' native pointer acceleration function with the same gain multiplier for pointing in the mid-air. However, in the light of the preliminary study, instead of taking the planar components of finger's motion as the input displacement vector, we used the displacement on the obtained curves. More precisely, we first obtained the displacements on the x-axis and the z-axis (1.a) as if the user was moving on an invisible plane overlapping the *Pad*, and then used the length of the curve corresponding to those displacements. Taking the y-component of the motion would create a dependence between the x and z axis, meaning any explicit gesture to create an horizontal cursor motion would result in a vertical cursor motion and vice-versa. Yet, using the direct projections of the displacement on the x and z axes would mean that only a part of the user's physical effort was used to move the cursor. Thus, the polynomials we obtained in the preliminary study permits us to compromise between the two approaches (Figure 4).

Clutching in mid-air. The height of the *IIS* ensures that user's hand stays in the interaction volume without the guidance of a physical surface in mid-air. If the user wants to perform a clutch, in air, they can quickly leave the *IIS*, clutch and re-enter *IIS* in 2 seconds. The user can also land on the *Pad* once they re-enter the *IIS*. The cursor control method we described above permits the user to lift their hand without disturbing the cursor. By doing so, contrarily to a clutch on a physical device -in our case the smartphone- the users can make a clutch by lifting their hand over the upper limit but also by lowering it under the bottom limit of the *E-Pad* space, *i.e.*, the *IIS* limits.

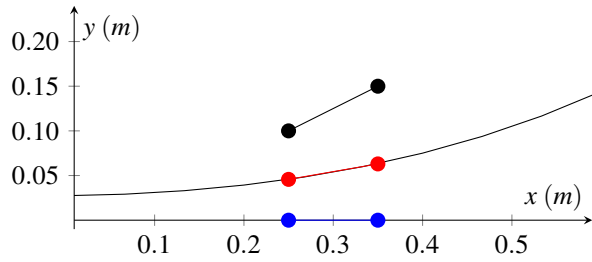


Figure 4: An example of displacement vector estimation on the x axis. Black: Displacement of the finger. Blue: Projected displacement. Red: Displacement obtained by our method.



Figure 5: Clutching in the air

Clicking in mid-air. The air click technique we described in the procedure of the preliminary study can be used anywhere in the *IIS*.

Releasing the cursor. In order to detach the cursor from the hand, the user simply leaves the *IIS*. The user can also lower the smartphone to invalidate the *IIS* and end the interaction. If the user needs then to use the *E-Pad* again, they can create a new *IIS* that corresponds to the position and orientation of the device when the user exits the *Pad* condition.

EXPERIMENT

We conducted an experiment to compare performance between *Pad* and *E-Pad* techniques. Based on the theoretical ability (*i.e.*, the limited surface) of *Pad* technique to point on the large display, we hypothesize that *E-Pad* will **(H1)** improve selection speed while **(H2)** decreasing the number of clutches. The third hypothesis **H3** is that *Pad* will be more accurate than *E-Pad* as the touch click should more precise than mid-air click.

Participants

12 participants (1 female) volunteered to take part in our experiment. Participant ages varied between 24 and 32 years (mean age 26.66, $sd=2.67$ years). All participants were right-handed. All participants except one were regular users of smart phones or tablet devices with multi-touch screens, and 4 participants were regular users of Kinect games.

Apparatus

The experiment uses the same apparatus as in the preliminary study.

Task, Procedure and Design

We used a reciprocal two dimensional pointing task (Figure 6) on 6 targets (only one visible at a time) that were positioned on an imaginary circle). The participants were instructed to stay standing while holding the smartphone with their non-dominant hand. The participants were then instructed to click on the targets in random order to complete a clicking sequence of 6 motions in different directions. Each direction consisted of a *start target* and an *end target*. Each trial began after the start target was successfully selected with a click on the touchscreen. The trial ended with the selection of the end target with a touchscreen click in the case of the *Pad* technique and an air click in the case of the *E-Pad* technique. The touchscreen click is possible with *E-Pad* if the user does not leave the pad surface. After a *start target* was selected, it disappeared and the corresponding *end target* was displayed. In case a participant missed the *end target*, it disappeared and the start target was displayed again, logging an error for the trial. Participants had to successfully select the *end target* before moving to the next *start target*, even if it required multiple attempts. Each pointing sequence was repeated 3 times.

Dependent measures are analyzed using a $2 \times 3 \times 3 \times 6$ repeated measures within-subjects analysis of variance for the factors *Technique* (*Pad* and *E-Pad*), *Block* (1–3, with the first block serving as opportunity for learning the new method), *tolerance* (*L*: 75px (5.08cm); *M*: 38px (2.54cm) and *S*: 13px (0.85cm), with *tolerance* corresponding to the target circle radius), *direction* (east to west (*EW*), north-east to south-west (*NE-SW*), north-west to south-east (*NW-SE*), west to east (*WE*), south-west to north-east (*SW-NE*) and south-east to north-west (*SE-NW*)).

The amplitude (*i.e.*, the distance between the start target and the end target) was kept constant at 117 cm. We decided on this longer single distance because we think that the issue of clutching when using a smartphone is more recurrent when the target distance was longer even if we think that the benefits of *E-Pad* still consistent with short distance as *E-pad* can be used as *Pad* for short amplitude. This decision was taken to reduce the duration of the experiment and to highlight the effect of the proposed technique. The rationale was also that if no effect was found with these settings, it would be likely that no such effect exists.

In the experiment phase, the two *techniques* were randomly presented to the participants. Inside each *technique*, participants completed three *blocks*. Inside each *block*, the three *tolerances* were randomly presented to the participants. For each *tolerance*, the pointing sequence (*i.e.*, the six directions) were repeated 3 times. The initial direction of each pointing sequence was randomized – a total of 324 (=2 techniques \times 3 blocks \times 3 tolerances \times 6 directions \times 3 repetitions) trials per participant. After each block of trials, participants were encouraged to take a break.

After each technique, participants respond to 5-point Likert-scale questions (strongly disagree to strongly agree): i) I performed well, ii) I accomplish the task rapidly, iii) I need a lot effort to finish the task, iv) I need to concentrate to accomplish

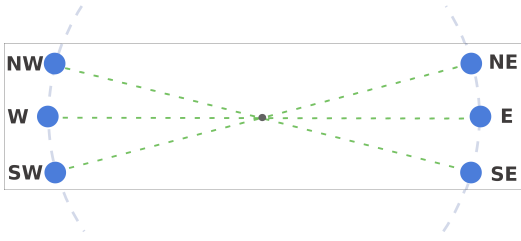


Figure 6: Target positions and movement directions.

the task; v) I feel frustrated/stressed/irritated/annoyed; vi) I felt confident in my ability to hit the target; vii) I enjoyed interacting with the device(s)." At the end of the experiment, participants were asked to rank the two techniques according to their preferences. The average duration of the experiment was 1 hour and 10 minutes.

RESULTS

The dependent measures are *movement time*, *number of clutches* and *error rate*. We also analyze the subjective responses. All analyses are multi-way ANOVA. Tukey tests are used post-hoc when significant effects are found.

Movement time

Movement time is the main dependent measure and is defined as the time between the click on the start target and the click on the end target.

Repeated-measures ANOVA revealed a significant effect of *block* on *movement time* ($F_{2,22}=4.76$, $p<.0001$). Post-hoc tests showed a significant decrease in the time between the first block and the two remaining ($p<.05$; block1: 3630 ms, block2: 3439ms, block3: 3359ms) due to a learning during the first block. As we are concerned with user performance after familiarization, the remaining analysis discards the first block.

There were significant main effects of *technique* ($F_{1,11} = 12.48$, $p = .0047$), *tolerance* ($F_{2,22} = 142.92$, $p < .0001$) and a significant *technique* \times *tolerance* interaction ($F_{2,22} = 16.10$, $p < .0001$) on *movement time*. Post-hoc tests revealed that *E-Pad* was significantly faster than *Pad* for the medium and the large tolerance sizes ($p < .05$) by respectively 14.78% and 19.06%, supporting partially **H1**. We also, found that with *Pad*, *movement time* is significantly higher with small tolerance size than both medium and large tolerance sizes ($p<.05$). Meanwhile, with *E-Pad*, *movement time* increased significantly as the *tolerance* decreases ($p<.05$). There were no significant *technique* \times *direction* \times *tolerance* ($p=.33$) interaction, suggesting that the benefits of *E-Pad* with the medium and the large tolerance are consistent across directions.

Clutching

We analyzed the *number of clutches* used on the pad surface, assuming that frequent clutching indicates high physical workload. Repeated measures ANOVA showed significant main effects of *technique* ($F_{1,11}=1067$, $p<.0001$) and a significant *technique* \times *tolerance* interaction ($F_{2,22}=3.88$, $p=.0360$) on

	<i>Pad</i>		<i>E-Pad</i>		<i>Wilcoxon</i>
	Mean	s.d	Mean	s.d	Z
Performance	3.83	.47	3.5	.61	.96
Rapidity	3.08	.37	3.66	.65	-1.41
Physical	2.58	.65	2.41	.70	.32
Concentration	2.66	.81	2.83	.79	-.41
Frustration	2.41	.78	2	.59	.89
Confidence	4.41	.50	4.16	.63	1.73
Enjoyment	3.25	.48	4.16	.53	-2.75

Note: Wilcoxon-Signed-Rank tests are reported at $p=.05$ (*) significance levels. The significant tests are highlighted.

Table 1: Mean and s.d questionnaire responses, with 1=strongly disagree, and 5 = strongly agree.

number of clutches. As *E-Pad* (mean .09, s.d .01) allows continuous pointing to be maintained without movement, it is unsurprising that they have significantly less clutching than *Pad* (mean 4.97, s.d .06) with the three tolerance sizes ($p < .05$), supporting **H2**. Additionally, for *Pad* technique, Post-hoc tests revealed that the number of clutches increased significantly as the *tolerance* decreases ($p<.05$). Interestingly, we found that there was no significant *technique* \times *direction* ($p=.31$) nor *technique* \times *tolerance* \times *direction* ($p=.45$) interactions, suggesting that the benefits of *E-Pad* over *Pad* are consistent across the different *tolerances* and *distances*.

In the *E-Pad* technique, even though both the upper and lower limits could be used for a clutch, participants were observed making the clutch only by lifting their hand/finger using the upper limit of the IIS.

Error Rate

Targets that were not selected on the first attempt were marked as errors. There were no significant main effects nor interaction ($p>.05$) on *error rate* with *Pad* (mean 9.25%, s.d. 1.82), *E-Pad* (mean 10.26%, s.d. 1.95), suggesting that there was no significant difference between *Pad* and *E-Pad* and so leading to rejection of **H3**.

Subjective Results

We recorded that participants were asked to rank the two techniques conditions after completing the experiment. Overall, *E-Pad* was ranked 100% first.

Participants were also asked to rate each technique. Overall, questionnaire responses (Table 1) show that mean ratings for *E-Pad* were mostly more appreciative, but only significantly for enjoyment.

We correlate these findings with comments from participants who felt that the PAD technique was “*boring*” and “*repetitive*”. Multiple participants stated that swiping continuously on the screen forced their wrists. One participant said: “*this really hurts my wrist*”. Besides multiple participants felt that the friction on the touchscreen hurts the finger in the long term. One person said: “*I don’t feel my fingertip anymore*”.

In contrast, participants stated their satisfaction with *E-Pad*. Some quotes are: “*I’m happy... the precision is not an issue*”.

while my finger is in the air” and “I definitely prefer this technique”. Most of the participants affirmed, also, that clicking in mid-air was not difficult. One participant said: “This is much easier than I imagined”. However, some participants stated a few concerns about the E-PAD. Two participants said that distinguishing the y-axis and the z-axis was difficult in the beginning. One of them said: “How do you go upwards again?”. Three participants declared that pointing to their non-dominant side was more difficult. However, as discussed above, we did not find a significant effect of *direction* on the *movement time*.

DISCUSSION AND DESIGN GUIDELINES

Our key finding is that *E-Pad* improved selection speed, decreased the number of clutches and increased enjoyment over conventional *Pad*, without compromising accuracy. The performance benefits were consistent across different *tolerances* and *directions*. Our analysis also suggests an overwhelming preference for *E-Pad* instead of the *Pad*.

Informed by our experimental findings, we outline relevant guidelines for designing pointing techniques on large displays:

- Touchscreen of the smartphone should be used prudently for selecting distant targets on large display. Our participants often expressed dissatisfaction when making distant target selections, feeling that it requires longer selection time and bigger number of clutches.
- Users should be provided with a physical reference when making mid-air indirect pointing on large displays, as our participants insisted on the confidence brought by having the smartphone as a reference when switching to mid-air modality.
- Designers should conceive flexible input that allow users to continue pointing in the space around the smartphone when the surface of the pad is not sufficient to continue the pointing task.

CONCLUSION AND FUTURE WORK

We introduced Extended Continuous Relative Pointing Gesture; a complementary pointing gesture to perform large cursor movements by allowing users to continue the pointing gesture in the air around the touchscreen when the physical surface is limited. We conducted a preliminary study to determine how users articulate the Extended Continuous Relative Pointing Gesture. Our findings indicate that when switching to the air space, the hand motion deviate from the touchscreen plane and follow a curved trajectory. We then used our new findings to design *E-Pad* a novel pointing technique on large display where the pointing task starts on the smartphone and continues around it. We conducted an experiment to evaluate and compare our technique with *Pad*. Our findings indicate that *E-Pad* is faster than *Pad* by up to 19.06% and decreases the number of clutches, without compromising accuracy. Our findings also suggest an overwhelming preference for *E-Pad*. From our experience, we derive three guidelines for relative pointing on large displays. It is our hope that this work will advance our knowledge for large display pointing and that *E-Pad* technique

will prove useful by integrating it on the interaction techniques that use smartphones to interact with large displays.

In our experiments, we randomly chose the participants on availability basis to construct the interaction space. To further explore the shape of the *E-Pad*, we consider studying the effect of physical traits such as age and sex on the average path and the acceleration profile of the finger motion. During the experiments, our participants were standing while taking the smartphone with their non-dominant hand which can increase the fatigue and change the behaviour of the user when compared to having the smartphone on a desk and the users set down. Thus, future work will investigate the effect of having the smartphone on a desk on both Extended continuous relative pointing gesture behaviour, the design of *E-Pad* and then on the performance of *Pad* and *E-Pad*. Additionally, one potential usability issue of our techniques is that when switching to the midair modality, there was no visual feedback for the pad’s extended surface. To assist the user, the technique could add a visual feedback of the extended pad using revealed virtual objects [1]. To omit the dependency on external cameras, future work will explore the use of magnetic sensing [27] and microphone arrays [17] for the *E-pad*. After the aforementioned improvements, we will be able to compare *E-pad*’s performance with ray casting methods.

REFERENCES

- [1] Florent Berthaut, Cagan Arslan, and Laurent Grisoni. 2017. Revgest: Augmenting Gestural Musical Instruments with Revealed Virtual Objects. In *NIME '17*. Copenhagen, Denmark. <https://hal.archives-ouvertes.fr/hal-01518579>
- [2] Andrew Bragdon, Rob DeLine, Ken Hinckley, and Meredith Ringel Morris. Code Space: Touch + Air Gesture Hybrid Interactions for Supporting Developer Meetings. In *ITS '11, ACM*. ACM, New York, NY, USA, 212–221. DOI: <http://dx.doi.org/10.1145/2076354.2076393>
- [3] Géry Casiez and Nicolas Roussel. No More Bricolage!: Methods and Tools to Characterize, Replicate and Compare Pointing Transfer Functions. In *UIST '11, ACM*. ACM, 603–614. DOI: <http://dx.doi.org/10.1145/2047196.2047276>
- [4] Géry Casiez, Daniel Vogel, Qing Pan, and Christophe Chaillou. RubberEdge: Reducing Clutching by Combining Position and Rate Control with Elastic Feedback. In *UIST '07, ACM*. ACM, 129–138. DOI: <http://dx.doi.org/10.1145/1294211.1294234>
- [5] Duncan Cavens, Florian Vogt, Sidney Fels, and Michael Meitner. Interacting with the Big Screen: Pointers to Ponder. In *CHI '02, ACM*. ACM, 678–679. DOI: <http://dx.doi.org/10.1145/506443.506542>
- [6] Bruno R. De Araújo, Géry Casiez, and Joaquim A. Jorge. 2012. Mockup Builder: Direct 3D Modeling on and Above the Surface in a Continuous Interaction Space. In *GI '12*. Canadian Information Processing Society, Toronto, Ont., Canada, Canada, 173–180. <http://dl.acm.org/citation.cfm?id=2305276.2305305>

- [7] Herbert D. Jellinek and Stuart K. Card. Powermice and User Performance. In *CHI '90, ACM*. ACM, New York, NY, USA, 213–220. DOI: <http://dx.doi.org/10.1145/97243.97276>
- [8] Ricardo Jota, Miguel A. Nacenta, Joaquim A. Jorge, Sheelagh Carpendale, and Saul Greenberg. A Comparison of Ray Pointing Techniques for Very Large Displays. In *GI'10, Canadian Information Processing Society*. Canadian Information Processing Society, 269–276. <http://dl.acm.org/citation.cfm?id=1839214.1839261>
- [9] Regis Kopper, Doug A Bowman, Mara G Silva, and Ryan P McMahan. 2010. A human motor behavior model for distal pointing tasks. *International journal of human-computer studies* 68, 10 (2010), 603–615.
- [10] Mingyu Liu, Mathieu Nancel, and Daniel Vogel. Gunslinger: Subtle Arms-down Mid-air Interaction. In *UIST'15, ACM*. ACM, 63–71. DOI: <http://dx.doi.org/10.1145/2807442.2807489>
- [11] Shahzad Malik, Abhishek Ranjan, and Ravin Balakrishnan. Interacting with Large Displays from a Distance with Vision-tracked Multi-finger Gestural Input. In *UIST '05, ACM*. ACM, New York, NY, USA, 43–52. DOI: <http://dx.doi.org/10.1145/1095034.1095042>
- [12] Nicolai Marquardt, Ricardo Jota, Saul Greenberg, and Joaquim A. Jorge. The Continuous Interaction Space: Interaction Techniques Unifying Touch and Gesture on and Above a Digital Surface. In *INTERACT'11, Springer*. Springer-Verlag, Berlin, Heidelberg, 461–476. <http://dl.acm.org/citation.cfm?id=2042182.2042224>
- [13] David C. McCallum and Pourang Irani. ARC-Pad: Absolute+Relative Cursor Positioning for Large Displays with a Mobile Touchscreen. In *UIST '09, ACM*. ACM, 153–156. DOI: <http://dx.doi.org/10.1145/1622176.1622205>
- [14] Brad A. Myers, Rishi Bhatnagar, Jeffrey Nichols, Choon Hong Peck, Dave Kong, Robert Miller, and A. Chris Long. Interacting at a Distance: Measuring the Performance of Laser Pointers and Other Devices. In *CHI '02, ACM*. ACM, 33–40. DOI: <http://dx.doi.org/10.1145/503376.503383>
- [15] Mathieu Nancel, Olivier Chapuis, Emmanuel Pietriga, Xing-Dong Yang, Pourang P. Irani, and Michel Beaudouin-Lafon. High-precision Pointing on Large Wall Displays Using Small Handheld Devices. In *CHI '13, ACM*. ACM, New York, NY, USA, 831–840. DOI: <http://dx.doi.org/10.1145/2470654.2470773>
- [16] Mathieu Nancel, Daniel Vogel, and Edward Lank. Clutching Is Not (Necessarily) the Enemy. In *CHI '15, ACM*. ACM, New York, NY, USA, 4199–4202. DOI: <http://dx.doi.org/10.1145/2702123.2702134>
- [17] Rajalakshmi Nandakumar, Vikram Iyer, Desney Tan, and Shyamnath Gollakota. 2016. FingerIO: Using Active Sonar for Fine-Grained Finger Tracking. In *CHI '16, ACM*, New York, NY, USA, 1515–1525. DOI: <http://dx.doi.org/10.1145/2858036.2858580>
- [18] Ji-Young Oh and Wolfgang Stuerzlinger. 2002. Laser Pointers as Collaborative Pointing Devices. (2002).
- [19] Jeffrey S. Pierce, Andrew S. Forsberg, Matthew J. Conway, Seung Hong, Robert C. Zeleznik, and Mark R. Mine. Image Plane Interaction Techniques in 3D Immersive Environments. In *I3D, ACM*. ACM, 39–ff. DOI: <http://dx.doi.org/10.1145/253284.253303>
- [20] Krzysztof Pietroszek and Edward Lank. Clicking Blindly: Using Spatial Correspondence to Select Targets in Multi-device Environments. In *MobileHCI '12, ACM*. ACM, New York, NY, USA, 331–334. DOI: <http://dx.doi.org/10.1145/2371574.2371625>
- [21] Hanae Rateau, Yosra Rekik, Laurent Grisoni, and Joaquim Jorge. 2016. Talaria: Continuous Drag & Drop on a Wall Display. In *ISS '16, ACM*, New York, NY, USA, 199–204. DOI: <http://dx.doi.org/10.1145/2992154.2992164>
- [22] Shaishav Siddhpuria, Sylvain Malacria, Mathieu Nancel, and Edward Lank. 2018. Pointing at a Distance with Everyday Smart Devices. In *CHI '18, ACM*, New York, NY, USA, Article 173, 11 pages. DOI: <http://dx.doi.org/10.1145/3173574.3173747>
- [23] Sophie Stellmach and Raimund Dachsel. 2012. Look Touch: Gaze-supported Target Acquisition. In *CHI '12, ACM*, New York, NY, USA, 2981–2990. DOI: <http://dx.doi.org/10.1145/2207676.2208709>
- [24] Sophie Stellmach and Raimund Dachsel. 2013. Still Looking: Investigating Seamless Gaze-supported Selection, Positioning, and Manipulation of Distant Targets. In *CHI '13, ACM*, New York, NY, USA, 285–294. DOI: <http://dx.doi.org/10.1145/2470654.2470695>
- [25] Kazuki Takashima, Nana Shinshi, and Yoshifumi Kitamura. 2015. Exploring Boundless Scroll by Extending Motor Space. In *MobileHCI '15, ACM*, New York, NY, USA, 557–566. DOI: <http://dx.doi.org/10.1145/2785830.2785884>
- [26] Daniel Vogel and Ravin Balakrishnan. 2005. Distant Freehand Pointing and Clicking on Very Large, High Resolution Displays. In *UIST '05, ACM*, New York, NY, USA, 33–42. DOI: <http://dx.doi.org/10.1145/1095034.1095041>
- [27] Sang Ho Yoon, Ke Huo, and Karthik Ramani. 2016. TMotion: Embedded 3D Mobile Input Using Magnetic Sensing Technique. In *TEI '16, ACM*, New York, NY, USA, 21–29. DOI: <http://dx.doi.org/10.1145/2839462.2839463>
- [28] Yan Zhai, Guoying Zhao, Toni Alatalo, Janne Heikkilä, Timo Ojala, and Xinyuan Huang. Gesture Interaction for Wall-sized Touchscreen Display. In *UbiComp'13, ACM*. ACM, 175–178. DOI: <http://dx.doi.org/10.1145/2494091.2494148>