Exploring pressure as an alternative to multi-touch based interaction

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ABSTRACT
Pressure is a useful medium for interaction as it can be used in different contexts such as for navigating through depth in 3-D, for time-series visualizations, and in zoomable interfaces. We propose pressure based input as an alternative to repetitive multi-touch interactions, such as expanding/pinching to zoom. While most user interface controls for zooming or scrolling are bidirectional, pressure is primarily a one-way continuous parameter (from zero to positive). Human ability to control pressure from positive to zero is limited but needs to be resolved to make this medium accessible to various interactive tasks. We first carry out an experiment to measure the effectiveness of various pressure control functions for controlling pressure in both directions (from zero to positive and positive to zero). Based on this preliminary knowledge, we compare the performance of a pressure based zooming system with a multi-touch expand/pinch gesture based zooming system. Our results show that pressure input is an improvement to multi-touch interactions that involve multiple invocations, such as the one presented in this paper.

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General terms: Design**,** Human Factors

Keywords: Pressure, Multi-touch, Bi-directionality

INTRODUCTION
Generally people apply different amounts of pressure in doing mundane tasks like pushing, pulling, and twisting. Many devices also support pressure input, such as the IBM track point joystick [1], Sony's dualshock2 controller for Sony PS2 gaming console, Synaptics touchpad (not exactly pressure but based on area of contact) and stylus based digitizing tablets. Additionally, researchers have proposed utilizing continuous pressure input in addition to the standard x-y input position obtained from other input channels such as a pen or mouse. Ramos et al [2] propose different visualizations for navigating through pressure menus. Zelzenik propose using a two-pressure state input [3]: a soft press or hard press for new user interactions. Cechanowicz et al. [4] presented a mouse with its buttons replaced with two pressure sensors. Pressure has also been proposed for high precsision parameter manipulation [5] or for automatic selections while making pen strokes [6].

Although several point-designs of pressure-based input are emerging, a factor that has limited its uptake is the human motor ability to control pressure from a positive to zero [4, 7]. Rekimoto et. al [7] propose a solution where the contact area of the finger applying pressure is used to discriminate between increasing and decreasing pressure values. Cechanowicz et. al [4] use two sensors one for each direction are used to overcome the problem of pressure bi-directionality while the IBM track point joystick [1] uses 4 sensors to control cursor rate in all four directions.

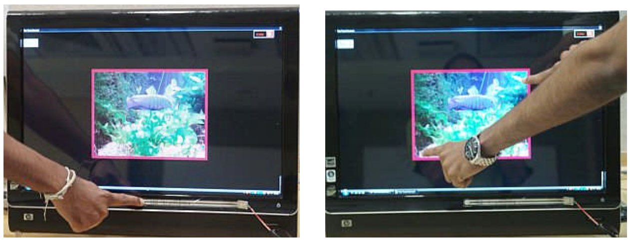

Figure 1: Pressure based zooming (left) and multi-touch based zooming on a HP TouchSmart PC (right).

Here we first investigate through a controlled user-study the differences in human motor function in pressure control in both directions, with four different mapping functions. Our results show that the fish-eye function, proposed in [9] results in best pressure control for both directions.

We then put our newly designed fish-eye based pressure input to test against the ever popular multi-touch solution for zooming multiple levels of a photo in a photo application. The two-handed pinch/expand gesture used for zooming is one of the most frequently used multi-touch interaction demonstrations. We designed an application that uses key insights from our first pressure bi-directionality study but with pressure for zooming in and out of a scene, and compared the performance of the pressure based interaction with multi-touch based zooming. Results show that pressure input is significantly faster than multi-touch zooming. We discuss our results and present some design guidelines.

The main contributions of this paper are

- Show through a user study that fisheye mapping enables bi-directional control of pressure

- Show that pressure based zooming is significantly faster than its multi-touch counterpart
- Show that pressure can potentially be used as an alternative to multi-touch

The rest of the paper is organized as follows: we first describe or experiment to identify the best bi-directional mapping, we then design our pressure-zoomable photo application interface and finally describe our experiment comparing pressure zoom with multi-touch.

PRESSURE BI-DIRECTIONALITY EXPERIMENT

The main objective of the experiment was to determine the dependency of bi-directional pressure control on different discretization functions and identify the best discretization function for each direction of pressure control.

Based on what has been proposed in the literature we used four discretization functions: linear discretization function [2, 8], fish eye discretization function [9], a multi-stage non linear discretization function employed in the rate control track-point joystick [10] and a two sensor discretization function (as adopted in [4]), where one sensor is used to increase the parameter value by increasing pressure and other sensor is used to decrease parameter value by increasing pressure.

The experimental setup is similar to that described in [2] but in the form of a game, to maintain the participants' interest in the study. The act of increasing pressure was mapped to the metaphor of increasing water level of a container and decreasing pressure was mapped to a decrease in water level. The user had to increase pressure to the right amount to fill a container with water and decrease the right amount of pressure to water the plant. The container is divided into discrete levels based on the discretization function and the number of levels. In each trial participants are required to increase the pressure so that the water level reaches the particular red colored band, select that band by dwelling and are required to controllably reduce the pressure to reach a lower band and select that particular band by dwelling. The boundary of the band turns green when the user is in the expected band. The trial ends when both the top band and bottom band are selected. The dwell duration for selecting a band was set to 1000 ms.

Pressure sensor model # 08713 from FlexiForce was used in the study. The pressure sensor was placed on a flat worktop and the users were asked to operate the sensor with their index finger to increase/decrease pressure. We used this method to simulate the situation of users manipulating pressure on a pressure sensitive touch screen (like those proposed by Smith et. al [11]).

The study used a 2×4×3 within-participants factorial design. The factors were:

- Pressure directions (increasing-pressure and decreasing-pressure),
- Discretization function (Linear, Fisheye, Multi-st, 2Sensors)
- Number of levels (4, 6 and 8).

Users performed 24 trials per factor resulting in a total of 288 trials per user. The experiment took approximately 1 hour per participant. The experiment was partially balanced for pressure direction and discretization function.

14 participants (9 males and 5 females) between the ages of 20 and 40 were recruited from a local community. All participants had previous experience with graphical interfaces and were right handed. Most of them had seen or used a tabletPC before but had no extensive experience with pressure sensors.

Results and Discussion

The total number of trials with errors was 857 out of 4032 trials. The average trial completion time over all trials completed without errors was 2649 ms (s.d.=2433 ms). A Univariate ANOVA test with users as a random factor showed a significant effect of transfer function on trial completion time ($F_{3,31} = 100.1$, $p<0.001$) and no significant effect of direction on trial completion time ($F_{1,23} = 0.318$, $p=0.6$). Post-hoc pairwise comparison (Tamhane) of transfer functions showed a significant difference between all pairs except (Linear and Fisheye). Figure 2 (left) shows the average time per direction for each transfer function.

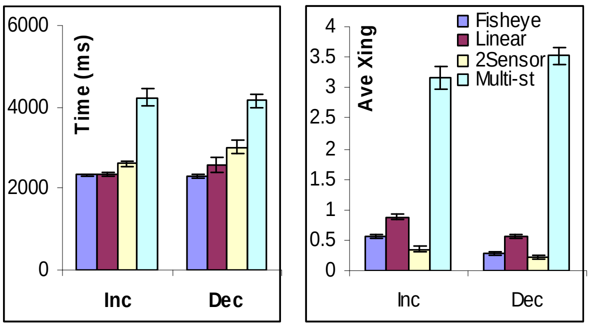

Figure 2: Average time (left) and number of crossings (right) for pressure direction and transfer function.

Univariate Anova also showed a significant effect of transfer function on number of crossings (($F_{3,29} = 247.1$, $p<0.001$) and no significant effect of direction on number of crossings ($F_{1,31} = 3.16$, $p=0.09$). Post-hoc pairwise comparison (Tamhane) of transfer functions showed a significant difference between all pairs. 2Sensor had the least number of crossings closely followed by Fisheye. Multistage resulted in the most number of crossings.

Our results show that there is no difference in user performance when increasing or decreasing pressure and that the Fisheye function performs best. This adds to the earlier results from Shi et. al [9] by showing that the Fisheye function works well when both, increasing and decreasing pressure.

The multi-stage function did not work well in our case. This is primarily because this function was designed by IBM for their track-point where users control the speed of a cursor (and always in the positive direction) and not really designed for pressure control.

Contrary to some of the prior literature on pressure suggesting that pressure is a unidirectional channel, the main result of this study suggests that pressure can be controlled in a bi-directional manner. Furthermore, our results reaffirm that the Fisheye function works well for both directions of pressure input.

COMPARING PRESSURE BASED INPUT TO MULTI-TOUCH

Multi-touch based interaction has become notorious with the introduction of the iPhone. Many interactive tasks designed with multi-touch could also be enabled using pressure based input. We developed a photo browsing application that works with both pressure and multi-touch gestures for zooming. We conducted an experiment to compare the performance of pressure based interaction with multi-touch in this application context.

The objective of the experiment was to determine the performance difference in terms of time and the number of crossings made in achieving a certain zoom level using pressure and multi-touch. In the case of multi-touch, users had to achieve a certain zoom level using a two-handed expand/pinch gesture where the user had to move his fingers by 100 pixels apart/closer (as per the default setting on the device) to go to the next zoom level.

In the case of pressure input users had to press or release pressure to zoom. We used the Fisheye transfer function which was found to be optimal in the earlier study for pressure discretization. We conducted the experiment on a HP TouchSmart PC and the pressure sensor was stuck to the bottom bezel of the device. Pressure sensor model # 08713 from FlexiForce was used in the study.

Task

In this task the participants were asked to achieve a particular zoom level by using multi-touch gestures and by applying pressure. The task had different levels with each level representing the number of discrete zoom levels possible in that application. In each level participants were required to zoom an image to a particular level and dwell there for selection. The image border turned red when the user was in the expected zoom level. The dwell duration was set to 1000ms. Each trial started at zoom level 1 and the user had to zoom to a higher level. In the case of pressure, trials always started with a pressure of zero and the pressure had to be increased to reach the appropriate zoom level. Bi-directional pressure was used when the user overshot the required zoom level and had to reduce pressure to come back to the appropriate level. Each level had four trials. The study used a 2×3 within-participants factorial design. The factors were:

- Input modality : Pressure or Multi-touch
- Number of zoom levels per level : 4, 6, 8

24 trials were collected from each user. Ten participants (8 males and 2 females) between the ages of 20 and 35 were recruited from a local community. Five participants started with pressure first while the others started with multi-touch first. All participants had previous experience with graphical interfaces and were right handed. Most of them had seen or used a tabletPC before, few of them had prior experience with multi-touch but none of them had extensive experience with pressure sensors. All participants used two hands to perform the multi-touch pinch/expand gesture.

Results and Discussion

Users were not able to continue to the next trial without completing a trial accurately and so there were no errors for the system to record. The average trial completion time across all levels and input type was 5414ms (s.d = 2062). We excluded 10 trials (4 from multi-touch and 6 from pressure input) that took beyond 9500 ms from further analysis.

Trial Completion Time: A Univariate ANOVA test with users as a random factor showed a significant effect of input modality ($F_{1,10} = 5.6$, $p<0.05$) and zoom level ($F_{2,19} = 3.94$, $p<0.05$) on trial completion time. Our results also showed an interaction between modality and zoom level ($F_{2,20} = 5.135$, $p<0.02$). Pressure based input was significantly faster than multi-touch. Post-hoc pairwise comparison (Tamhane) of levels showed a significant difference between levels (0, 2) and (1, 2). Our results also showed that at level 4 Multi-touch was significantly faster than pressure whereas at both level 6 and 8 pressure based zooming was significantly faster than multi-touch. Figure 3 (left) shows the average time per input modality for each zoom level.

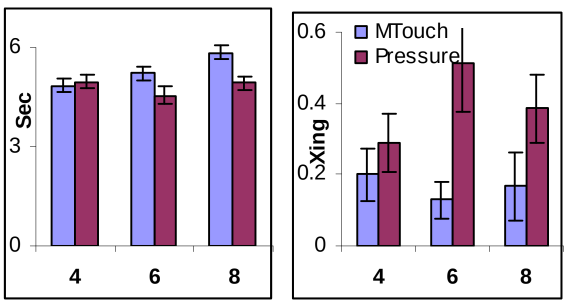

Figure 3: Average time (left) and number of crossings (right) at each zoom level for pressure and multi-touch interaction techniques.

Crossings: A Univariate ANOVA test with users as a random factor showed a significant effect of input modality ($F_{1,10} = 12.8$, $p<0.01$) on number of crossings but we found no significant effect zoom level on crossings ($F_{2,19} = 1.53$, $p=0.242$). Pressure based input resulted in significantly more crossings than multi-touch. Figure 3 (right) shows the average number of crossings per modality for each level.

Multi-touch vs Pressure: Our results show that this implementation of multi-touch results in a significantly slower interaction than pressure based zooming. The most common implementation of Multi-touch is a sequential interaction technique, that involves reiterating through the gesture several times to get to the appropriate zoom level. As can be seen in Figure 3 left, this means that as the number of zoom levels increases the time taken to complete the task increases linearly with Multi-touch (r^2=0.98 for a linear trend line with slope = 0.5). However, the time taken to complete the task with pressure is almost constant and is independent of the depth of the zoom level (r^2=0.001 for a linear trend line with slope = 0.005).

Multi-touch: We also noticed that users were much more comfortable in using the multi-touch pinch gesture than with the multi-touch expand gesture. Users were therefore careful not to overshoot as they were not confident in being able to decrease in zoom levels. Because of this and the sequential nature of Multi-touch interaction, users often completed each gesture and checked the result before moving further - resulting in a discrete form of zooming. The discrete nature of the user action results in a combination involving 'clutching' and then visual search task, particularly if users are not familiar with the task and the image. This suggests that the multi-touch zooming interfaces can be improved. One possibility is to include a rate-based mechanism, that zooms to the right level and continues based on the rate of expansion and pinching. This is analogous to flicking alternatives that are current on multi-touch systems. Another design for multi-touch zoom could involve adjusting the zoom resolution based on the use of single or pairs of fingers on each hand.

Pressure: With pressure the continuous nature of the interaction combined with the user's confidence in being able to easily release pressure to decrease levels meant that the interaction was faster despite the fact that it often resulted in and increased number of overshoots. Thus as the number of levels increases pressure-based zooming becomes more attractive than multi-touch. This is despite the fact that pressure results in significantly larger number of overshoots compared to multi-touch.

DESIGN RECOMMENDATIONS

Based on our two user studies we can offer the following design recommendations

- Users are able to control pressure in a bidirectional manner.
- Fisheye function offers users the ability to control pressure effectively in both directions
- At higher zoom levels pressure based interaction is a potentially better alternative to multi-touch interaction.
- Pressure can be used in enabling intetactions with 3D interfaces

CONCLUSION

The experiment on pressure bi-directionality did not find any difference in user performance when increasing or decreasing pressure. Results also suggest that Fisheye based transfer function performs better for both increasing and decreasing pressure. Pressure and multi-touch zooming based experiment concludes that pressure based interaction is a potential alternative to multi-touch. Also, in application contexts like zooming pressure is faster than multi-touch. We are exploring alternatives to pressure zooming for multi-touch interactions, possibly by hybridizing both input modalities.

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