Natural Use Profiles for the Pen: An Empirical Exploration of Pressure, Tilt, and Azimuth

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ABSTRACT
Inherent pen input modalities such as tip pressure, tilt and azimuth (PTA) have been extensively used as additional input channels in pen-based interactions. We conducted a study to investigate the *natural use profiles* of PTA, which describes the features of PTA in the course of normal pen use such as writing and drawing. First, the study reveals the ranges of PTA in normal pen use, which can distinguish pen events accidently occurring in normal drawing and writing from those used for mode switch. The *natural use profiles* also show that azimuth is least likely to cause false pen mode switching while tip pressure is most likely to cause false pen mode switching. Second, the study reveals correlations among various modalities, indicating that pressure plus azimuth is superior to other pairs for dual-modality control.

Author Keywords
Pen input; tip pressure; tilt; azimuth; natural use profiles.

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces - Interaction styles; I.3.6 [Methodology and Techniques] - Interaction techniques.

General Terms
Design; Experimentation; Human Factors.

INTRODUCTION
Pen input has been widely adopted as a major interaction modality for slate computers, handheld devices, and large format electronic whiteboards, due to its portability, outdoor availability, short learning curve, and ease of manipulation. Despite these advantages, pen input suffers from its low communication bandwidth: typically, only a single point, the x-y position of the pen tip, is used for interaction. To expand the communication bandwidth and offer users more interaction flexibility, researchers have explored using additional pen characteristics, including tilting, tip pressure, rolling, and azimuth, as auxiliary interaction modalities [2, 6, 10, 11, 13, 14].

One big benefit of adding extra interaction modalities is that a user can select different pen modes by simply adjusting the added modality, without moving the pen tip away from the interaction focus. For example, Ramos el al. [7] proposed applying pen tip pressure beyond 60% of the maximum value to invoke a magnified lens; Bi et al. [2] and Xin el al. [12] utilized different rolling or tilt angles to select different pen modes.

To effectively switch pen modes via extra modalities, the designers need to choose appropriate thresholds for triggering the mode switch process. Otherwise, the mode switch might be falsely activated because normal pen use, such as drawing or writing, also affects the values of these modalities.

Using values that are unlikely to occur in normal pen use would help prevent false activations. For example, research [2] shows that the rolling angles of a pen range from -10º to +10º in normal pen use. Therefore, the ±10º was used as the threshold for triggering a rolling menu to avoid accidental activation. The *natural use profiles* of a pen, which describe the features of various modalities during the course of normal pen use, provide hints for the thresholds of other modalities.

Besides suggesting thresholds for mode switching, *natural use profiles* reveal the correlations among various modalities. A loose correlation pair means that the two modalities are unlikely to interfere with each other, indicating that a user can independently control each modality. These modalities are highly recommended for multi-degree-of-freedom control tasks, e.g., curve manipulation [2], or 3D objects manipulations [5, 12].

Overall, an understanding of *natural use profiles* will provide pen-based interface design with a proven foundation. However, prior work (e.g., [8] on pressure and [2] on rolling) mostly addressed the use of a particular dimension for enriching pen-based interaction. The profiles about tip pressure, tilt and azimuth (PTA) still remain unknown. In this paper, we, conduct a study to fill this gap.

EXPERIMENT

Participants and Apparatus

Twenty volunteers (3 females, 17 males), age from 21 to 33, participated in the experiment. All of them were right-handed. The experiment was conducted on a Wacom Cintiq 21UX interactive LCD display (resolution 1280 x 1024, 96 dpi) with a digital stylus. The hardware can detect the tip pressure range [0, 1023], corresponding to the force range [0, 4] (Newton), tilt angle range [22º, 90º] (90º means that the pen is perpendicular to the tablet display), and azimuth angle range [0º, 359º] (0º is the north direction). The experimental program was developed in Java and ran on a 2.13 GHz Intel Core2 CPU PC with Windows XP.

Design

Our basic objective is to investigate the *natural use profiles* of PTA, which describe the features of PTA and correlations among them in normal drawing and writing. Therefore, besides the common symbols and English letters, we also included Chinese characters in the experiment, which contain most basic strokes in daily drawing and writing such as points, lines, turns, crosses, and arcs. In particular, the following characters are involved in the experiment:

- Symbols (@,☆, &, ×),
- Letters (S, E, M, B),
- Chinese characters which were classified by structure and complexity (see Table 1).

Structure / Complexity	Left-to-right	Mixed	Top-to-bottom
Simple (1~5 strokes)	人 (2 strokes)	中 (4 strokes)	之 (3 strokes)
Medium (6~10 strokes)	如 (6 strokes)	我 (7 strokes)	宜 (8 strokes)
Complex (beyond 10 strokes)	橘 (16 strokes)	幾 (12 strokes)	蜜 (14 strokes)

Table 1. Chinese characters classified by structure and complexity.

Task and Procedure

Subjects were seated in front of the display tablet which was placed on the horizontal plane [1]. Subjects were instructed to write and draw three types of characters in seven sizes (50, 100, 200, 400, 600, 800, and 1000 pixels in length, which equates to 1.67, 3.33, 6.67, 13.34, 20, 26.67, 33.34 cm respectively). At the beginning of each trial, a character appeared on the upper left corner of the display in the font size 36. In the meantime, a translucent green square was displayed at the center of the display, the length of which was one of the seven tested sizes. Subjects were instructed to write/draw characters as large as the square size. By pressing the spacebar on the keyboard the user proceeded to the next trial. Each character appeared twice in total. All characters were mixed and counterbalanced in random order. In summary, the experiment consisted of:

20 participants ×
17 characters ×
7 sizes ×
2 repetitions
= 4760 trials.

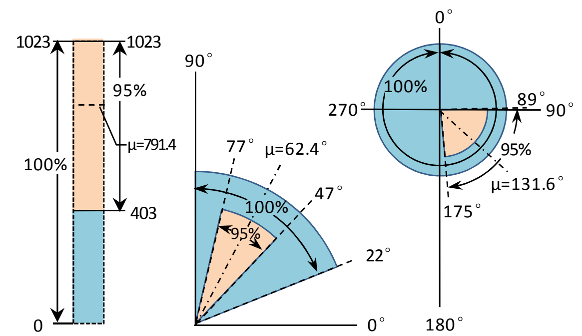

Figure 1. Means and 95% ranges of tip pressure (left), tilt (middle), and azimuth (right).

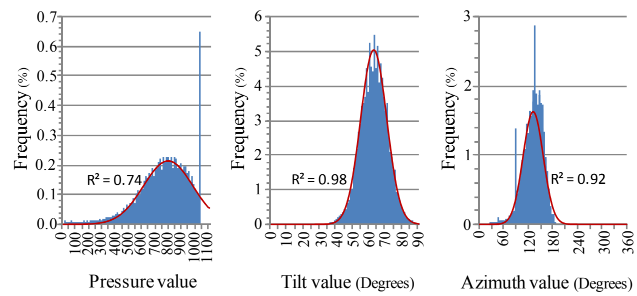

Figure 2. PTA Distributions and Gaussian regressions.

Results

PTA Distributions. Means (SD) across all the trials are 791.4 (194.1), 62.4° (7.52°), and 131.64° (21.53°) for tip pressure, tilt and azimuth, respectively (Figure 1). Figure 2 shows the distribution for each of them. R-squares of Gaussian distribution regression were 0.74 (pressure), 0.98 (tilt), and 0.92 (azimuth), indicating that the tilt and azimuth data well fit Gaussian distributions. The frequency of pressure value 1023 was extraordinarily high, probably because pressures above 1023 were also recorded as 1023. Excluding it (level 1023), the R-square of Gaussian distribution regression is 0.98, also showing a strong fit of Gaussian distribution.

Size Condition. Figure 3 illustrates how character size affects PTA modalities. A repeated measure ANOVA revealed significant main effects for character size on pressure ($F_{6, 114} = 308.75$), tilt ($F_{6, 114} = 5.75$) and azimuth ($F_{6, 114} = 4.393$), all $p < .001$. *Post hoc* pair-wise comparisons showed significant differences for all pairs in pressure, and 50 vs. other sizes in tilt, and 100 vs. other sizes in azimuth.

[1] Our pilot studies indicated that the preferred display-table angle varied for different users. Thus, we decided to place the tablet horizontally to eliminate potential effects caused by different display-table angles. The horizontal plane is also a common tablet usage, e.g., where a user flattens a tablet laptop and places it on the lap or on a desk.

Figure 3 also shows that pressure is susceptible while tilt and azimuth are robust to the change of character size. Along with the increase of character size, pressure increased rapidly and remained stable at around 763 when character size reaches 800 pixels. However, tilt and azimuth did not undergo drastic changes: the gaps between the lowest and highest values were 2.77º for tilt and 3.23º for azimuth.

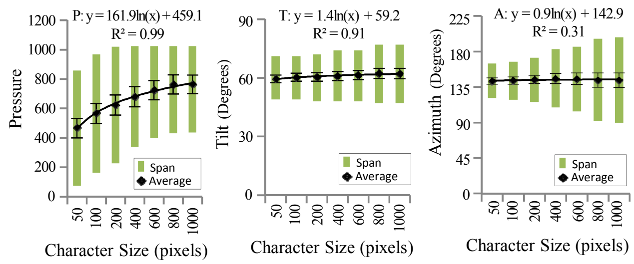

Figure 3. Mean (Std. Error) of PTA per character size. The green spans represent 2 × Std. Dev intervals.

The susceptibleness of pressure is probably due to the following two reasons. First, users tend to control a pen mainly by the muscle groups of fingers and palm when drawing/writing small-sized characters, while muscle groups of the arm are involved for large-sized characters. Using different muscle groups to control the pen probably leads to the large variation in pressure. This finding also concurs with the literature [1, 3, 4]. Second, research literature [9] shows that human mechanoreceptors in a person's fingers (responsible from sensing isometric force/pressure) adapt after a few milliseconds. In other words, users become less aware of the absolute amount of pressure they are applying with a pen. This is one of the reasons why the user's grip gets tighter as time goes by, and also a possible explanation as to why pressure is greater while drawing larger characters, which require more drawing/writing time.

Combination Distribution between PTA. The combined distributions for each pair of PTA as well as the correlations among them were also investigated (Figure 4). Two-tailed Pearson Correlation Analyses revealed small correlations between pressure and tilt ($r = 0.24$), tilt and azimuth ($r = -0.37$), and a very minor correlation between pressure and azimuth ($r = -0.09$), all $p < .001$.

DISCUSSION

Mode Switch

During the course of normal pen use, 95% of pen events fall within the ranges of [403, 1023] (pressure), [47º, 77º] (tilt), and [89º, 175º] (azimuth). We suggest using the PTA values outside these ranges to trigger pen mode switching in order to prevent false activation.

Our study also shows that the azimuth is least likely to cause accidental pen mode switching while tip pressure is most likely to cause accidental pen mode switching. The range of azimuth in normal pen use takes only 24% of the full range [0º, 359º]. The remaining 76% of full range, [0º, 88º] and [176º, 359º] is available for activating different modes. Moreover, the azimuth value remains relatively consistent regardless of the change of character size. In contrast, the pressure modality is the opposite: the range of tip pressure in normal pen use [403, 1023] takes 61% of the full range [0, 1023] and it is susceptible to the change of character size. Also, as the pen pressure always starts from the level 0 when the pen tip lands on the tablet, the values outside the normal use range, which are [0, 402], still occasionally occur in normal drawing and writing, especially when the pen tip just lands on the tablet. Therefore, tip pressure is not recommended for triggering pen mode switch.

Our experiment shows that plenty of pen events exceeded the maximum tip pressure, 1023 (see Figure 2), suggesting that the manufactures should enlarge the detectable range to accurately capture tip pressures.

Controlling Dual Degrees of Freedom

If a user needs to control two PTA modalities to manipulate multiple degrees of freedom (e.g., control the scale of an object by tip pressure and adjust its rotation angle by azimuth), the best option is pressure & azimuth. The combined distribution of PTA shows that pressure & azimuth is the most loosely correlated pair, with the correlation coefficient of -0.09, which is substantially lower than pressure & tilt ($r = 0.24$), and tilt & azimuth ($r = -0.37$). This loose correlation is probably caused by different muscle groups controlling pressure and azimuth: a user usually adjusts the pen tip pressure by changing the

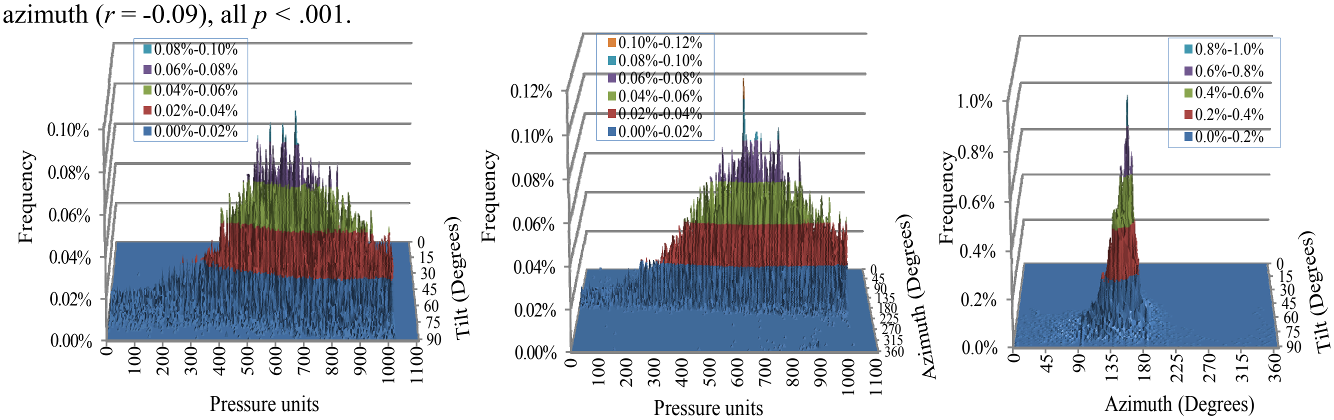

Figure 4. Distributions of pressure & tilt (left), pressure & azimuth (middle), and azimuth & tilt (right).

downward force of the fingers gripping the pen; the user alters the azimuth angle by rotating the wrist.

The minor correlation shows that pressure and azimuth almost never interfere with each other in normal pen use, in which a user does not even consciously avoid interference between different modalities. This suggests that pressure and azimuth are promising candidates for dual-modality control: they can be independently controlled without causing interference.

Our study focuses on natural pen use, which means the results revealed the correlations among PTA in a natural usage scenario. Correlations among PTA in intentional control applications (e.g., deliberately control variables using PTA modalities) are also worthy of exploration. We will investigate these in future work.

Other Applications

Besides providing specific ranges for trigging pen mode switching and for dual-modality control, understanding PTA profiles can also benefit the following applications:

(1) *Adaptive mode switching based on personal PTA use profiles.* As PTA profiles vary across different users, thresholds for mode switching may be designed for different users.
(2) *Signature verification*. Personal PTA profiles can serve to distinguish different users.
(3) *Reducing the dependence between PTA.* Understanding the correlations among PTA allows designers to better leverage these modalities used in tandem.

CONCLUSIONS

We have conducted a study systematically investigating the natural use profiles of pressure, tilt and azimuth (PTA). Our study reveals that the ranges of PTA during the course of normal pen use are [403, 1023] (pressure), [47º, 77º] (tilt), and [89º, 175º] (azimuth). Detailed analysis shows that using azimuth is least likely to cause accidental activation while tip pressure is most likely to cause false activation for pen mode switching, and that pressure plus azimuth is the best option for dual-modality control due to their loose correlation.

This study is the first one that investigates the natural profiles of pen pressure, pen tilt, and pen azimuth simultaneously and their mutual relationships as well. It might open up a promising new field of research on multiple pen modalities. Furthermore, comparing prior studies on pen input modalities which mainly focused on the human ability to control pen input modalities, this work focuses on *natural pen use* and thus reflects the spirit of human computer interaction. The results of our study provide guidelines on how to use multiple degrees of freedom which are intrinsic to a pen in realistic pen usage situations.

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