ClearPen: Improving the legibility of handwriting

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ABSTRACT

We describe the application of a pen model, and sub-pixel addressing (ClearPen), to render handwriting on an LCD display. This technique is shown to improve the legibility of handwriting. ClearPen can increase the viability of working with handwriting on a computer. This has direct significance to TabletPC applications such as note taking or annotating documents.

Keywords

Handwriting, legibility, pen model, sub-pixel addressing

INTRODUCTION

Traditionally, pen-based computing applications have implemented a strategy of recognizing handwritten script and displaying this input as typed text. This style of interface can be cumbersome and difficult to use. A number of recent research projects[1, 2, 3, 6] have argued that preserving handwritten input is, in certain situations, more preferable to recognition. They have all demonstrated applications which highlight this. As pen-based computers, such as TabletPCs, become more widespread[1] we are likely to see similar applications become mainstream products.

Handwriting is an ideal mode of communication for numerous tasks. Tasks that are traditionally performed with pen and paper. These tasks are typically characterized by capturing loosely structured ideas, immediately expressing thoughts, or forming representations of important concepts without specifying intricate details. For example: note taking[1, 6]; annotating slides or documents[3]; or design work[2].

Despite the benefits computer assistance can bring to pen-based tasks, the general acceptance of such applications is hampered by many things. Not least, the legibility of handwritten script on a computer screen. Computer screens that are too small with insufficient pixel resolution result in script that is either barely legible, or too large to warrant reading any significant amount.

In this light we have chosen to investigate the effect of horizontal resolution enhancement on the legibility of handwritten script. Horizontal enhancement was chosen because it is likely that the definition of salient features in handwriting[4] will be improved by horizontal resolution enhancement.

METHOD

Resolution enhancement in one direction can be achieved by exploiting sub-pixel addressing on LCD displays, which are typically used in TabletPCs. Sub-pixel addressing gives a three-fold resolution enhancement in the direction of the scanlines of the LCD display. This technique is common knowledge, but has not been applied to handwriting before, only type fonts[2].

As well as employing sub-pixel addressing techniques, we have implemented a pen model that mimics the characteristics of real pens. These algorithms are used together to produce handwritten script on a computer screen, similar to its appearance on paper. We call our enhancements ClearPen.

ClearPen Model

Our pen model algorithm is model based on observation, similar to the work of Sousa and Buchanan[5], except that we are modeling a fountain pen alone rather than pencil, paper, and other artistic materials.

The pen model algorithm operates at a geometric level by modeling the volume of ink flowing from the pen nib to the page. The ink volume is represented by an "intensity" value. The more ink, the higher the intensity of the pen trace.

The volume of ink deposited on the page depends both on the speed the pen is moving at, and the pressure applied to the tip. The pen model generates a series of consecutive line segments describing the path of each pen stroke at a resolution far higher than that of the computer screen.

ClearPen Rendering

ClearPen rendering recognizes that on an LCD panel, scanlines are composed of individually addressable colour com-

[1] http://www.microsoft.com/windowsxp/tabletpc/

[2] http://grc.com/cleartype.htm

ponent pixels (sub-pixels) in an ordered sequence, usually red–green–blue. Each screen pixel is formed from a triplet of adjacent sub-pixels.

The assignment of sub-pixels to pixels is static, however as each sub-pixel is individually addressable, any three adjacent sub-pixels can be combined to give the appearance of a full pixel. This technique allows us to position "perceptual pixels" at three times the normal precision of the LCD display.

Instead of being rendered directly onto the screen, each line segment is rendered onto a grid at nine times the display resolution. The intensity values are interpolated along the line segment. Each grid point along the line segment becomes the centre of a "Tip-Filter". The Tip-Filter is a two-dimensional filter representing a hemi-ellipsoidal pen tip. At each point along the line the intensity value is dissipated over the area covered by the filter. The filtered line segment is then mapped onto an "Intensity Grid". An Intensity Grid is three times the display screen size. It is populated by summing each square of nine intensity values from the first grid into the corresponding cell of the Intensity Grid.

Finally, columns of three intensity values are averaged and converted into sub-pixel colour components. Each group of three sub-pixels forms one coloured pixel. That colour is finally rendered onto the corresponding screen pixel.

The result of ClearPen rendering is a sharp image of a fine line pen strokes. When viewed at a normal distance the colour components in adjacent pixels combine to form a smooth black line. The ClearPen model and rendering is simple enough to process and render handwriting in real time, on a 750MHz Pentium III PC, with no discernible lag.

EVALUATION

Two experiments were conducted. The first experiment assessed the relationship between horizontal rendering resolution and legibility, by measuring the recognition rate of individual tachistoscopically displayed words. The second experiment assessed user preference for reading ClearPen against two alternative rendering methods, anti-aliasing and a "nearest pixel" plot, using a questionnaire. All three methods used the same pen model.

The first experiment showed a strong correlation between pixel width and recognition rate ($F(4, 80) = 5.481, p = .001$). A quadratic relationship ($p < .001$) depicted a recognition threshold of ≈ 80%, reached at an equivalent of 170 dpi viewed from 450mm, which dropped off rapidly as screen resolution decreased. This was in agreement with formal and informal observations. The second experiment clearly showed that subjects perceived a difference in the three different rendering methods ($p < .05$), and that their preference followed increasing resolution ($p < .001$).

CONCLUSION

ClearPen is capable of improving the legibility of handwritten script displayed on an LCD screen. The technique improved the horizontal resolution of the 85 dpi display used in the experiment to around 250 dpi, well within the recognition rate threshold. This enhancement increases the viability of reading handwritten script on a computer, including both Tablet-PCs (≈ 120 dpi) and Handheld PCs (≈ 100 dpi).

ClearPen does however have a number of limitations. Firstly, script must be written along the direction of a scan-line. Informal observation has shown that legibility is not greatly impacted by vertical resolution enhancement. Secondly, the technique involves sacrificing colour for resolution. In applications where colour or freedom of orientation are important, ClearPen may not be suitable.

The legibility of handwritten script displayed on an LCD computer screen is improved by ClearPen. People are able to perceive, and prefer, this improvement. Reading handwriting on a computer is as feasible as it is on paper and need not be hampered by poor script legibility.

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