Reflective Haptics: Enhancing Stylus-Based Interactions on Touch Screens

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Abstract. In this paper, we introduce the prototype of a low cost haptically augmented stylus for pen computing on touch screens. The stylus supports human-computer interaction through a dynamic haptic feedback. This reflective feedback is generated by a magnetically operated brake system. The feedback actuator is integrated in the stylus. Therefore, the pen supports the use of multiple styli on a single touch screen. The pen provides a broad scale of feedback – especially for the display of haptic surface cues. Hence, it is predestined for stroke gestures, as they are commonly used in crossing-based pen interfaces.

Keywords: stylus, pen computing, haptics, interface, HCI, haptic feedback, magnetic, brake, crossing-based interface

1 Introduction

Touch screens are increasingly important for human-computer interaction systems. They can be found in various electronic devices, ranging from large tabletop interfaces to small mobile phones. One reason for this importance is the intuitive access to digital content that they provide. By joining the locations of input and output, they enable the user to manipulate digital content at the same spot where it is displayed. This joint location can strengthen the connection between action and reaction. Yet, there are still some limitations to these technologies: for example, the occlusion of content by the finger, called the “fat finger problem”. Especially on small screens, as they are used in PDAs or mobile phones, this is a emergent issue. There are several software-based solutions for this problem, such as the “Shift” system [1]. By shifting the covered interaction area besides or above the users fingertip, the occlued information is moved into a visible area. However, this shift is occluding other parts of the interface, and is thus separating the position of input and output. Another solution is the use of a stylus to minimize the contact area and therefore the occlusion of content. Generally, by touching objects – for example, the key of a keyboard – the user has to cover the contact area, but still receives haptic information about their action. Since the perceived haptic feedback of a touch screen is limited to the properties of the screen itself and does not correspond to the properties of the virtual content, the user receives no distinct information about their actions.

According to Wigdor et al., [2], this feedback ambiguity can reduce a user's confidence in a device. Therefore, a context-corresponding haptic feedback can improve the touch screen interaction with respect to speed and accuracy. Brewster et al. [3] confirm that haptic feedback can significantly improve the performance of text entry tasks on a touch screen. In order to solve these inherent problems, we developed a simple and low cost stylus-based interface that provides a wide range of haptic feedback. We integrated a feedback-actuator into this pen which cannot only be applied to any kind of touch screen, but that also supports multi-user situations. This setup enables the use of multiple pens on one screen, which is important for multi-user applications.

2 Related Work

In recent developments, haptically enhanced pen interfaces have become an active field of research. The "Haptic Pen" by Lee et al. [4] is a low-cost device that generates a haptic feedback through solenoid-based actuation. In combination with a pressure-sensitive tip, it allows a variety of haptic click feedback, for the interaction with point and click GUIs. Another approach is the "Ubi-Pen" by Kyung and Lee [5]. It combines a compact tactile display for texture simulation and a pancake motor that provides vibration and texture stimuli.

Both prototypes – as well as the system presented in this paper – are designed for being used on touch screens. In contrast to these two systems, we focus on the display of lateral forces, as they appear in stroke gestures. In 2004, Poupyrev et al. [6] conducted a study about haptic feedback for pen computing in which they argued that most users prefer haptic feedback in combination with an active input gesture. They presume that this fact refers to Gibson's active touch paradigm [7]. Forlines et al. [8] confirm that tactile feedback improves selection times, especially for gesture-based crossing tasks.

3 Pen Prototype using Reflective Haptics

One possibility to provide a realistic feedback in two dimensional stroking gestures is increasing the force that a user has to apply, dragging a stylus across a surface and therefore simulating a higher friction of the virtual content. In order to display such a force, we developed a pen setup that is similar to a conventional ball pen. It consists of three functional components: A high-precision steel ball, an electromagnetic coil and a pen housing (Fig. 1).

When the pen is moved over the touch screen surface the steel ball is rolled in consequence. The steel ball is partly guided by the electromagnetic coil. When voltage is applied to the coil, it magnetically attracts the steel ball and the dynamic friction between these two parts increases. As a result of a higher friction between these two parts, it is more difficult to spin the steel ball. Thus, the user has to apply a greater force in order to move the stylus. To ensure that the friction between the steel ball and the touch screen surface is high enough, we applied a soft PVC film to the touch screen (Fig. 2).

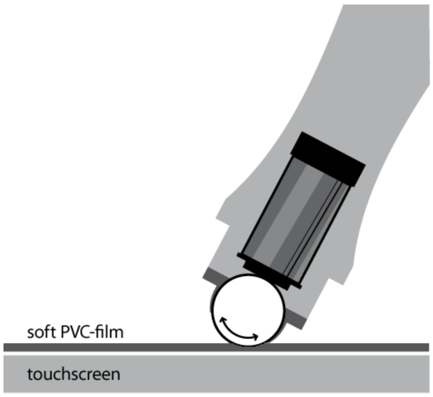

Fig. 1 Pen setup.

Fig. 2 Setup of screen, PVC film and pen.

We developed a series of different prototypes (Fig. 3), in which we tested different steel ball diameters and electromagnets of different strengths and sizes (Fig. 4 and Table 1). First informal evaluations showed that the usability of the stylus is depending on its size and weight. The final version displayed a suitable relation between friction actuation and stylus size and weight.

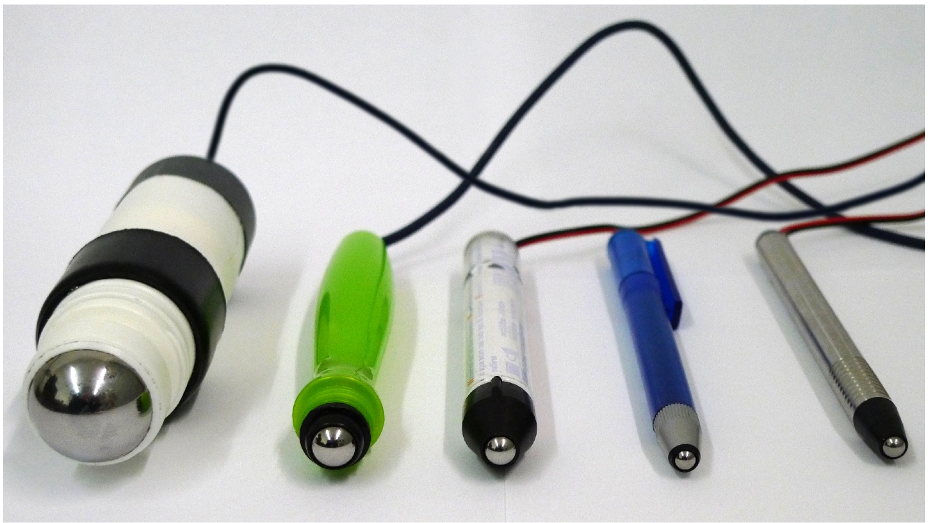

Fig. 3 Series of different prototypes.

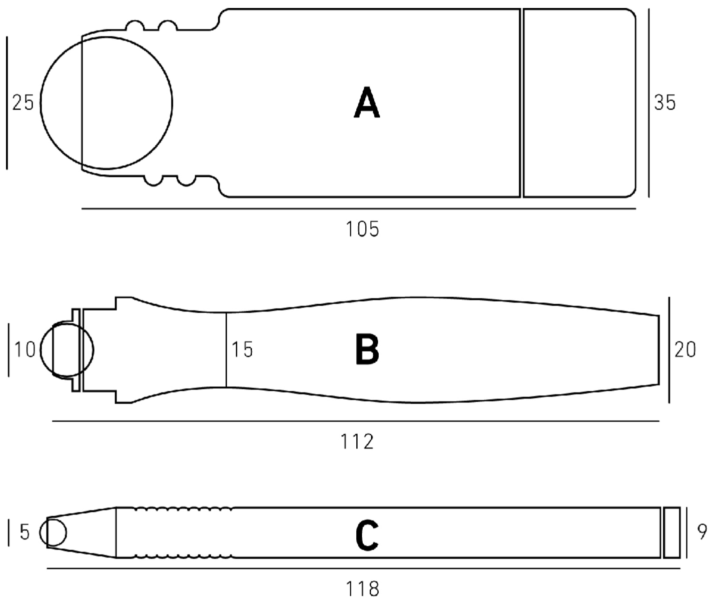

Fig. 4 Technical drawing of the tested prototypes.

Table 1 Measurements of the different prototypes.

	Prototype A	Prototype B	Prototype C
Body length	105 mm	112 mm	118 mm
Body diameter	35 mm	15 mm	9 mm
Pen weight	265 g	20 g	10 g
Steel ball diameter	25 mm	10 mm	5 mm

The operating strength of the electromagnetic coil is controlled by an ATMel ATMega328 attached to an Arduino development board. The generation of haptic effects is based on the tracking position of a 3M resistive touch sensor. These positions are relayed via USB to the Personal Computer for further processing. After calculating the effect strength, the Arduino board is assigned to drive the electromagnetic coil (Fig. 5). The conducted experiments demonstrated that the speed of the signal processing in this setup is marginal. An additional motion tracking system within the pen, and the direct transmission of these values to the Arduino board might improve the setup (Fig. 6).

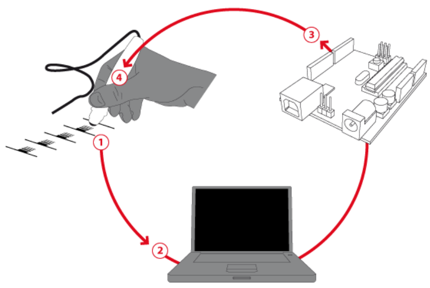

Fig. 5 Current signal processing.

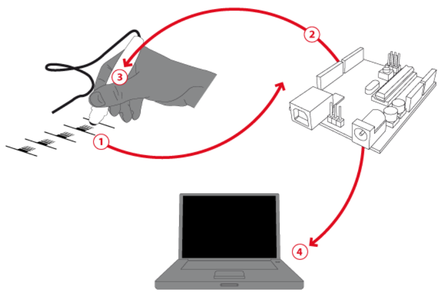

Fig. 6 Enhanced signal processing.

4 Interface Applications

There has been distinct research investigating crossing-based interfaces as an alternative to conventional point-and-click interfaces. According to Apitz and Guimbretière [9], crossing-based interfaces support the fluid interaction processes of pen-based computing. To test the reflective haptics prototype, we focused on interface samples that are based on stroke gestures. According to the findings of Poupyrev et al. [6], users especially appreciate haptic constraints, as the user receives a sensation similar to a pen hitting a groove or guide.

Snap: There are three different events for the composition and representation of a virtual "snap" behavior: *enter* (Fig. 7), *within* (Fig. 8) and *leave* (Fig. 9). Due to the varying magnetic strength and durability, the effect can be specified. Virtual edges can therefore be differentiated as well as virtual object mass.

Guide: The perception of guidelines – as they are used in common drawing programs – can be assisted, through the raise of resistance for a short period or time (Fig. 10).

Drag: The mass of a virtual object can be simulated via constant friction, which is a distinctive criterion of their individual characteristic (Fig. 11).

Draw: The process of free drawing can be enhanced by adding haptic information. Constant friction increases not only the accuracy of the gestures, but also provides some information about the simulated paint brush (Fig. 12).

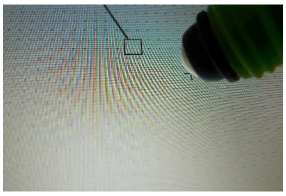

Fig. 7 Entering an object.

Fig. 8 Within an object.

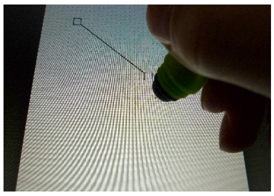

Fig. 9 Leaving the object.

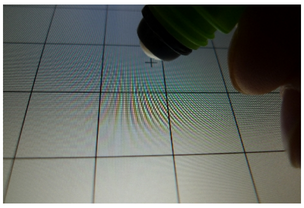

Fig. 10 Display of guidelines.

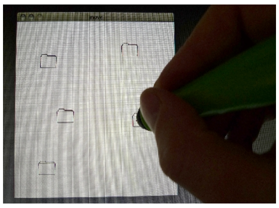

Fig. 11 Variable object mass.

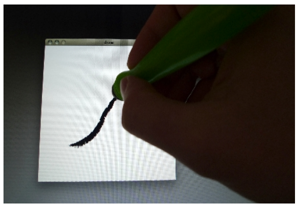

Fig. 12 Drawing task.

5 Conclusion and Future Work

First evaluations of the different reflective haptic pen prototypes showed promising results concerning the haptic support of stroke gestures. Most participants were convinced by the overall performance of the pen and its implementation with crossing-based interfaces. Prototype A received the best results regarding the effect strength but was perceived as beeing too big and too heavy. Prototype B showed a suitable relation between size and effect-strength. Prototype C received the best ratings concerning its size and weight, but the haptic effect was too weak to be differentiated from the basic friction of the steel ball. In most cases, the participants assigned the haptic sensation to the visually displayed surface and *not* to the stylus. An exception was the guideline interface sample (Fig. 10) where the effect of rendering delay became obvious. Therefore, the improvement of the signal rendering seems to be a goal worthwhile to follow-up on in the near future. By integrating motion tracking into the stylus – in combination with the location tracking of the touch screen – a faster signal processing could be achieved. In order to explore how reflective haptic feedback can improve the interaction process for different applications, further studies need to be conducted. For the generation of a pressure-dependent feedback, we also plan to integrate a pressure sensor in the setup. To meet the demands of mobile applications, we intent to minimize the existing setup and work towards a wireless version of the pen.

Acknowledgments. This work has been supported by Deutsche Telekom Laboratories, Ernst Reuter Platz 7, 10587 Berlin, Germany

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