Digisketch: Taming Anoto Technology on LCDs

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ABSTRACT
The Anoto technology uses a non-repetitive pattern printed on paper to enable a camera-equipped pen to locate its absolute position on that pattern. This technology is also used on projection screens to create large-sized interactive areas, but suffers from the drawbacks such as shadow casting or space requirements. Up to now, no implementation exists that enables a tracking on LC-displays using the Anoto technology. Thus, we introduce Digisketch, which uses special films that can be applied to LC-displays, to back and front projections, or to glass, allowing pattern recognition for the pen's camera. After describing the technical development of a prototype, we compare this new possibility of using Anoto compatible surfaces with other traditional tracking systems for LC-screens.

Keywords
Optical tracking, pattern recognition, user study, pen tracking, LCD, Anoto

INTRODUCTION
Today, most CRT (cathode ray tube) displays were replaced by LCD or plasma screens because of several reasons. Less required space, less flickering, less electromagnetic radiation, flat surface and better image quality are some of the main reasons. Also the input technologies moved from indirect input (mouse, keyboard) to direct input (touch, pen, TUI (tangible user interface)) input, enabling more natural interaction techniques. Despite these digital trends, there is still a high demand for analog input with pen and paper, since it is still quite common in many business processes. The new technologies removed a very important channel of sense: the haptics. Writing or sketching does not mean touching a glass plate, but grasping a stylus, feeling the resistance of paper when dragging and adjusting inclination and pressure to optimally control a fluid motion. The Anoto technology [1] with its pattern detecting pen provides such a haptic paper sensation while nevertheless working with digital data.

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RELATED WORK
Several commercial systems exist that use styli as input devices, e.g. Wacom tablets [2] with the inductive working principle or the Mimio pen [3] based on ultrasound. Wacom cannot be combined with paper whereas Pegasus [4] can be applied to a paper booklet.

When Memo-Pen [6] was presented in 1995, pen tracking was an issue in research. This pen was equipped with a CCD camera and could record partial images of the writing process. An intelligent software then reconstructed the full image. PaperLink [7] also used a camera mounted on a pen to record the user's input, but it focused more on the linking of certain text areas in a document. Hideki Koike et al. showed a different way of working with real paper. They presented EnhancedDesk [9], a system that supported finger pointing input on tagged paper. The system was able to detect pointing gestures and orientation of tagged paper. In 2005, PapierCraft [8] used the Anoto technology for paper-based digital document editing. Images and text passages could be arranged and aligned directly in a new document by notes on the real paper. PaperWindows [10] used computer vision to track IR-reflective markers on sheets of paper. Every paper was an interactive document. Text or even browser windows were projected onto the sheets which could be manipulated (stacked, bent etc.) like plain paper. Interaction with hand gestures and marker enabled pens was also possible. The Media Interaction Lab used the Anoto technology on rear and front projections [11] and presented the feature-rich application Intoi [12] that enabled intuitive creative interaction. They also showed the fluid combination of analog and digital content in the shared design space [13].

The GlobIS research group at ETH Zurich has developed a range of Anoto-enabled applications based on their iPaper platform [13] for interactive paper solutions. These applications include PaperPoint [14], a paper-based PowerPoint presentation tool, EdFest, a multimodal interactive festival guide as well as iPaper-based solutions for tabletop computing (iTable).

Song et al. developed PenLight [17] that used pattern enabled paper, but extended the interaction space to the area above the paper. By lifting the pens from the paper, the pens switch to another state which serves as a menu selection and a layer navigation aid. This is realized by front-projecting the menus onto the interactive paper and is intended to be replaced by a mini projector mounted on the pen itself.

Many systems have been designed, which use pens as input devices. Some of the systems combine analog and digital input, but only few of them use display devices such as LCD or Plasma screens. One of the reasons is that the used Anoto pattern is not applicable without any special adaption of the surface. In this paper, the analysis of this adaptation will be described and a prototype will be introduced. Finally, the paper concludes with a preliminary user study.

SYSTEM BASICS

Anoto working principle

The Anoto pen is an active pen that includes a tiny camera with optics as well as a microprocessor for image analysis. A non-repetitive pattern printed on plain paper can be seen by the camera when being illuminated with the built-in infrared flash. By analyzing this pattern, the pen can detect its absolute position. A correct pattern is seen if the tiny dots on the paper absorb the infrared light while the background reflects the infrared light. Thus, the image seen by the camera is a white background with black dots.

To make sure that the pattern is detected correctly, carbon based ink is required, which is used in most of the standard printer cartridges. The pattern has to be printed with at least 600 dpi to make sure that all the needed 36 (6x6) dots can be seen in an area of 1.8 x 1.8 mm.

The Anoto Pen

The Hitachi Maxell G303 (sold by Magicomm) consists of optics for the camera, an infrared flash (850 nm) and some electronics for image processing and Bluetooth communication. A vibration motor will feed back pattern detection failure, shut down, or synchronization establishment (see Figure 1).

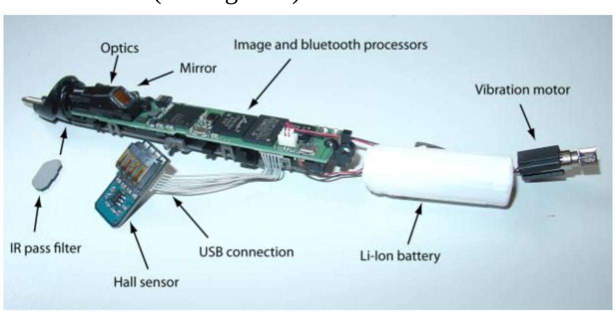

Figure 1: Components of the Anoto pen

The pen's overall tracking rate (including the image pre-processing within the integrated microprocessor, which will sample over several frames) is 76 Hz, while the actual illumination period only lasts about 155 µs. This guarantees that only as little light as possible is used for exposure in order to save battery energy. Such update rates are considered to be sufficient when looking at common writing speeds of 30 mm/s [18] and typical font sizes of 7 mm. However, if the pen is used on large-sized interaction areas, the update rate may be too slow for large and very fast drawing or sketching.

The Anoto pen does not feature a hovering state (tracking state according to Buxton et al. [19]). Altough this would be possible by the hardware, the current firmware does not support it.

LCD

Liquid Crystal Displays (LCD) are constructed in the following way: At the front side, there is the main displaying element, the LC-matrix, which comprises very small liquid crystal cells that can be switched on and off by an applied voltage. Several diffusion and enhancement films are mounted behind the LC-matrix in order to distribute the illuminating light homogenously. In most of the current LC-displays, CCF (cold cathode fluorescent) lamps are used to generate light for the background illumination, but there is a trend towards LED background illumination. A light guide is used to direct the light emitted by the light sources at the screen edges towards the center. In LED backlight panels two different layouts are possible: The LEDs may substitute the CCF lamps at the edges or they may be mounted directly behind the LC-matrix in a grid layout.

Software

To further process the pen's input via Bluetooth, the iTable framework that was originally developed for tabletops solutions is used. iTable has been realized as an application of the more general iPaper platform [14] for interactive paper solutions that was developed by the GlobIS research group at ETH Zurich. The application analyses the Bluetooth traffic of multiple Magiccomm G303 pens and generates either mouse commands or sends interaction data using the TUIO protocol [16].

The readability of the Anoto pattern can only be measured indirectly by analyzing the sent coordinate packages of the pens. With optimal pattern recognition, the pen transmits packets every 13 ms (76 Hz). If this value decreases, the pattern can be considered as not being optimally tracked.

Anoto on LCD

The very first obvious solution to make the pattern recognition work on LC-displays is to adjust the pen's internal parameters such as exposure time, filter, interpretation algorithms, and illumination length. However, if doing so, the pen might work only on displays, but not on regular paper anymore. Furthermore, adjusting the parameters is only possible by having access to the pen's source code and circuit design, which are property of Anoto and Magicomm.

Another way of solving this task is to adjust the external environmental parameters. One obvious way is to apply an additional IR-reflecting layer behind the LC-matrix, since the principle of Anoto relies on an IR (infrared) reflective background and IR absorbent dots. However, it was found that the LC-matrix absorbs up to 85% and reflects only around 4% of incident IR light. The transmission value weakly depends (4% influence) on the displayed color or grey levels. Thus, there is not enough reflected IR-light for the pen's camera; it only sees a black image or in other words: 96% IR light is missing for an optimal tracking. Figure 2 shows the Anoto on LCD principle.

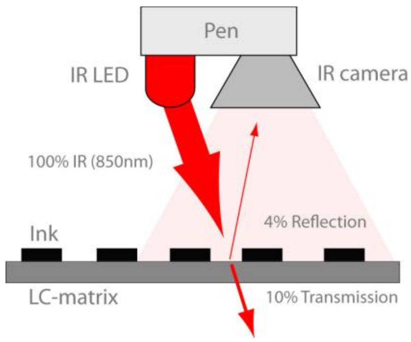

Figure 2: Anoto technology on LC-Matrix with printed dot pattern.

In a second approach, additional IR-illumination was provided. First, an additional IR-LED (850 nm) was mounted on the pen. This did not allow any reliable tracking because of the high absorbing LC-matrix. Also an IR-illumination from behind the LC-matrix did not work, since the required IR radiation was still too low (90% of the LED radiation were lost in the matrix). To overcome this, an enormous amount of IR radiation is required. However, power consumption would increase drastically and providing a homogenous IR background illumination would be very difficult.

To encounter the above problems, another approach is chosen. In order to increase the level of reflected IR-light, IR reflective films were tested that are normally used in automotive or architectural applications. However, since these films are placed in the light path of the visible light, they will also influence the quality of the displayed image.

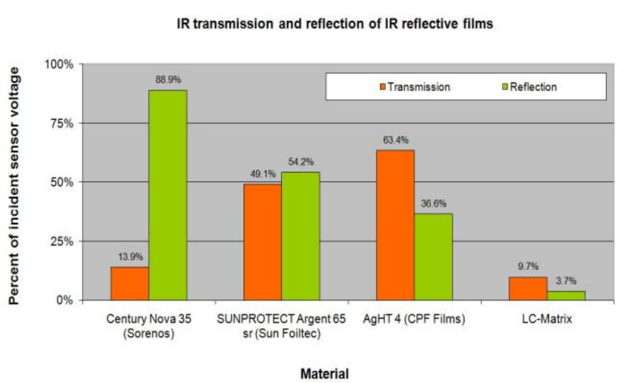

Figure 3: Reflection and transmission of IR light (850 nm, Sensor SFH235FA) for different films and perpendicular light incidence.

On the one hand, the film should be highly transparent to not influence the quality of the displayed image; on the other hand it should perfectly reflect IR light. Thus, the transmission and reflection of different films were evaluated (see Figure 3).

Although the analyzed films had high specular IR reflection values, the tracking did not perform well, since the pen was able to detect the pattern only in a perpendicular position. Thus, the diffusive component of reflection is very important, too. In order to generate a homogeneous IR-reflection for the pattern background, additional diffusive materials were tested. By using diffusive materials in front of the LC-matrix, the image quality is reduced in contrast and brightness. Hence, there is a need to find a balance between reliable pattern detection while still maintaining a good image quality.

Technical Solution

Several combinations of IR-reflective and IR-diffusive films were analyzed. In Figure 4, some films are shown that enable a reliable tracking. It is obvious that image quality strongly depends on these films. From this study, we found that the Kimoto 100 SXE [5] film performs best in maintaining image quality as well as in tracking capabilities. This film is normally used as a diffusive film between the light guide and the LC-matrix in an LC-display. It is important to note that only one side of the film is able to provide a suitable IR-reflection – the shiny side, since it reflects enough IR with the right amount of diffusive components.

Also inclination-dependant brightness loss of the display with attached films was analyzed, where the Kimoto 100 SXE film also achieved the best tradeoff between tracking ability of the pen and visibility of the LC-image at large viewing angles.

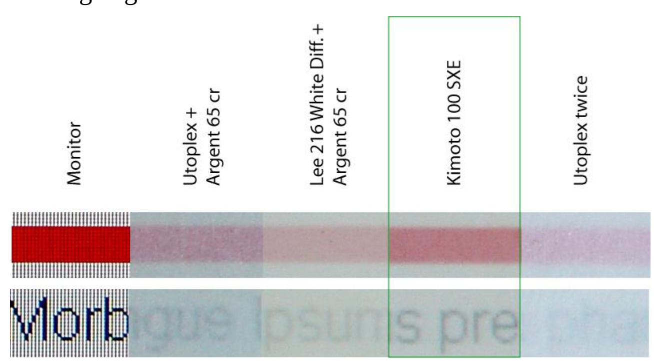

Figure 4: Combination of materials that enable good pattern recognition and their influence on image quality

Three films were used in the prototype (Figure 5): The Kimoto 100 SXE diffusive film was placed directly on the LC-matrix, followed by a transparent film with the printed Anoto pattern, and finally a scratch protecting sheet of acetyl film. Figure 6 shows the complete setup on a regular 15'' monitor.

Also the pen tip had to be replaced by a touch tip so that it does not write on the films.

Since the backlight of the used monitor is not very bright compared to newer monitor models, the overlay influences image quality substantially. Black levels are brightened by

44% and white levels are darkened by 30%. However, for a normal writing or sketching application using black lines on a white background, this first prototype on an Acer 15" Monitor (Figure 6) already shows satisfying results.

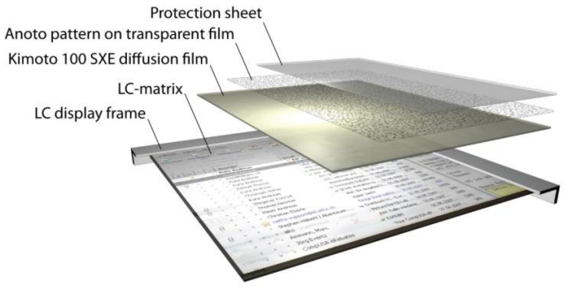

Figure 5: Layers in the prototype

The Kimoto diffusive film can additionally be used as a projection material, enabling Anoto pattern recognition on back projection systems as well by keeping the same layer design.

Figure 6: The Anoto pattern enabled 15" Digisketch prototype

Inclination dependency

In the current prototype, some inclination dependency exists concerning the readability of the pattern. Detection starts at angles larger than 40 degrees from screen surface (Figure 7).

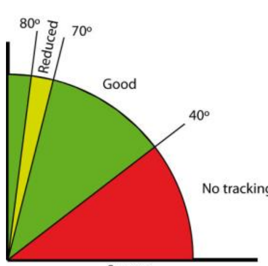

Figure 7: Inclination dependency of the Anoto pen with Digisketch prototype

It seems that the pen's algorithm will process particular positions better than other depending on the current inclination. Between 70 and 80 degrees, a reduced tracking update rate can be observed, which is probably caused by the inhomogeneous illumination on the used film.

PRELIMINARY USER STUDY

In order to evaluate the suitability of the adapted Anoto technology, a preliminary user study was performed. Digisketch was compared to a state-of-the-art interactive system, the Wacom [2] inductive pen tracking technology. It features accuracies of up to 0.5 mm, 130 Hz sample rate, and hovering of up to 10 mm above the screen.

The International Organization for Standardization [21] defined the ISO 9241-9:2000 standard. It defines measuring the input performance based on Fitts' Law [23]. A draft version of the ISO standard was assessed by Douglas et al. [22]. Their examination found the standard to be sound.

The test setup consisted of two 15" LC-displays - a Wacom Cintiq15X and the modified Digisketch enabled prototype. The test consisted of a simple point and click task according to Fitts' Law. The two Parameters D and W (see Figure 8) were used to determine the index of difficulty (in bits), from medium to high – 5.5, 6 and 6.5.

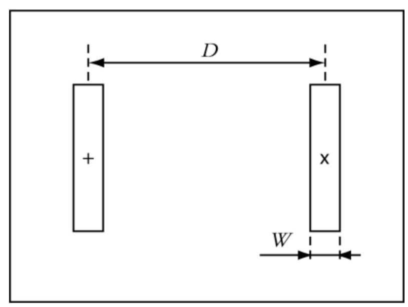

Figure 8: Layout and test parameters D and W of the one-directional tap test.

Three basic parameters were analyzed to compare the two different technologies:

Completion time: Required time for completing the task.
Error rate: Error rate is the percentage of targets selected when the pointer is outside the target.
Throughput (TP): The throughput in bits/s where

$$TP = \frac{\text{effective index of difficulty}}{\text{mean movement time}}$$

Results

The three parameters where assessed using 10 subjects who completed all three tests on each of the two setups. It can be seen in Figure 9 that the Digisketch prototype did perform weaker on most parameters compared to the Wacom system. Especially when looking at the error rate, it can be seen that the deviations are large and that the Wacom system performs twice as good as Digisketch at a high index of difficulty. This can be explained by the fact that users frequently complained about the Digisketch's low reactivity compared to the Wacom pen. The Anoto pen will sample several acquisitions before sending the data via Bluetooth to the driver application. This may result in a larger lag, which influences accuracy.

Although Digisketch could compete at lower difficulties with Wacom concerning error rate, it did perform lower in the completion time and in the throughput parameter.

Another issue is the mentioned inclination dependency, which will influence error rate at high levels of difficulty significantly. A click combined with missing tracking information will lead to an error. This is particular possible if the pen is placed at an inappropriate angle of below 40 degrees and between 80 and 70 degrees.

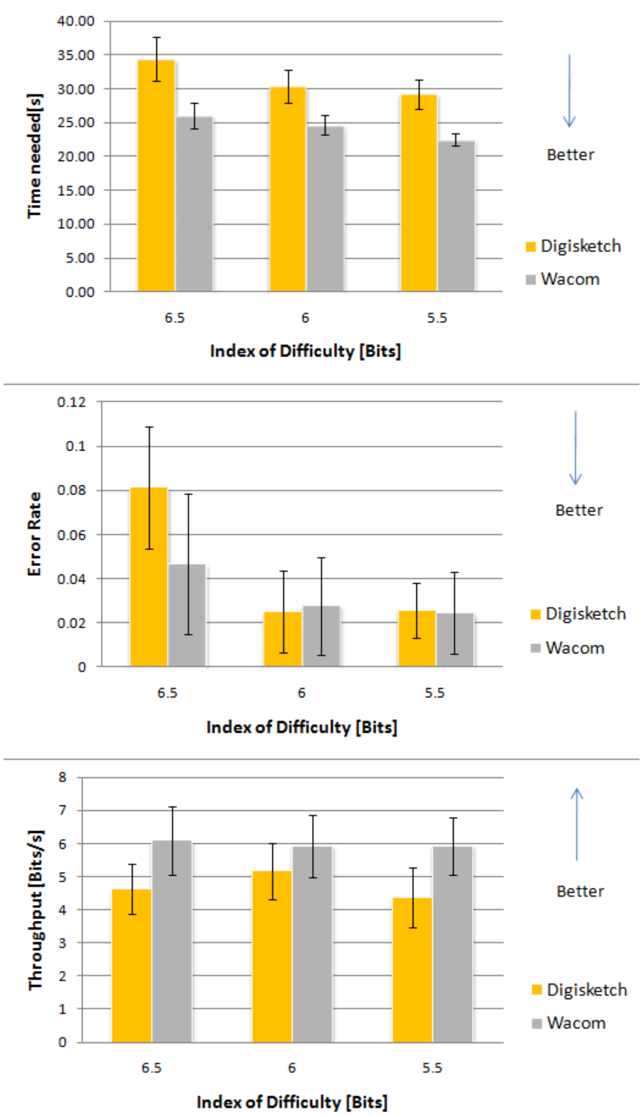

Figure 9: Test results: completion time, error rate and throughput for different indexes of difficulty for Digisketch and Wacom.

CONCLUSION

A special film was evaluated that enables the correct pattern detection of the Anoto pen on LC-displays. This opens a new field of applications to the pen, since it is not restricted anymore to normal paper or projective displays. Typically, every LC-display can be converted into an Anoto enabled tracking device. Although the display quality is influenced by the diffusive film overlay, newer displays with very bright backlight can still produce an acceptable image.

The conducted preliminary tests show that the performance of Digisketch is unfortunately inferior to the Wacom tablet pen. The performance difference can be explained by the inclination dependable tracking ability and the system inherent lag of the Digisketch pen.

The drawbacks of the presented prototype could be overcome by having access to the firmware running on the chip. Adjusting the filtering and processing parameters would most likely enable a better tracking capability on LC-displays when being provided with less attenuating films. An inverted pattern by using infrared reflective ink (used by security companies) and adjusting the filtering to inverted mode could probably lead to a more accurate system and to better image quality.

Despite the improvable performance, the Anoto pen offers the possibility to be used additionally on Anoto pattern enabled paper or any pattern equipped surface. The surface can basically be of any size since the pattern will provide absolute positioning for areas up to millions of km^2.

By incorporating two different tips that can be switched from LCD to paper mode or adding an ink-repellent overlay to the LCD, a smooth transition between digital and analog work can be created.

Additionally the absolute tracking technology allows tracking of multiple pens without any interference, since every device is autonomously scanning its position on the pattern. Only the capacity of the Bluetooth interface to the software defines the maximum amount of simultaneous pens on the same surface.

OUTLOOK

It is planned to equip larger screens with the same films. For this, a method has to be found to attach the large films properly to the matrix so that their optical characteristics are not influenced. Additionally, we will experiment with different laminations and printing methods. Also the image quality may further be improved by using new materials.

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