FEEDBACK-DRIVEN ACQUISITION OF ARTIST-GENERATED IMAGES WITH AN ULTRASONIC INTERFACE

Andrew Bradley, Martin Fleury, and Peter Noakes
University of Essex, UK

1 Introduction

Though there are a variety of graphics tablets, these do not necessarily allow an artist to interact with the computer as if handling traditional pens and brushes. A study of practising artists indicates that haptic and propriaptic feedback respectively of pen pressure and motion, together with a direct view of the image being created, is required. Flat-screen LCD (Liquid Crystal Display) technology now allows an artist to view an image while the stylus' spatial position is acquired. Through the use of ultrasonic sensors, position can be fixed without electronic interference from the display device, allowing an off-the-shelf LCD to be employed. Provision of other sensors in the stylus, such as pressure, acceleration, rotation, and tilt meters, replicate the experience of the artist when using a conventional drawing/painting method. The design of the interface has been accomplished, at a low cost, with a set of PIC microcontrollers [1] and standard ultrasonic sensors.

2 User study

A number of artists were filmed while they worked. In Figure 1, each artist holds a different tool and works either on paper or on canvas. An artist acquires hand-eye coordination through feedback from a line appearing at the tool's tip. Other physical feedback occurs such as pressure, Figure 2, orientation, Figure 3, and rotation, Figure 4. It is reported [4] that the response time of an electronic system should not introduce discernible delay (more than say 20 ms). A sequence of video frames, at 25 fps, were taken of an artist laying on a large area of colour, which is one of the most rapid movements made. It was found that samples taken at this rate (40 ms) adequately represented the line taken.

3 System design

The original design, though including multiple sensors, Figure 5, envisaged the same position-sensing tablet as employed in CAD applications. A set of conductive strips is laid out as a grid in the x and y planes, with each strip being electrically isolated from the others and terminated with a resistive load. When the x and y planes are systematically scanned with an AC signal, a field coil in the stylus tip detects an induced voltage when the strips nearest to it become active. The signal detected in the field coil is necessarily tiny, as any increase in the number of coils reduces the signal-to-noise ratio. An experiment determined that random fluctuations were detected as soon as the LCD was switched on, even though the stylus was stationary.

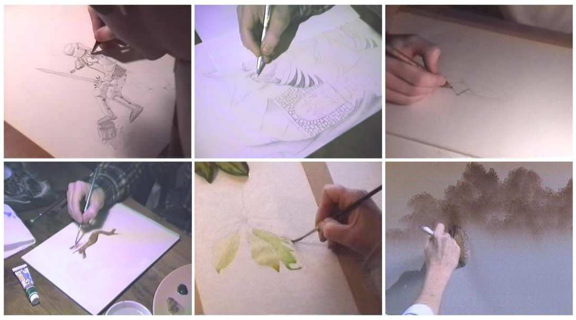

Figure 1: Video frames of artists at work

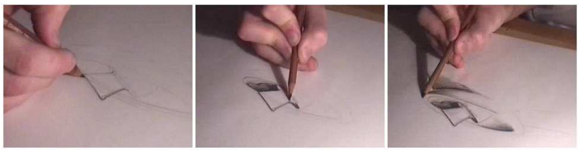

Figure 2: Pressure and tone with pencils

Figure 3: Effect of orientation

3.1 Position-sensing choices

One approach is to seek a position-finding overlay above the LCD. Touch-sensitive screens that are also transparent suffer from the difficulty of making a sufficient in-

Figure 4: Rotating flat brush

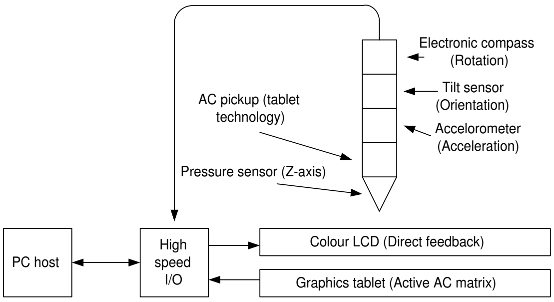

Figure 5: Block diagram of a direct-feedback interface

dentation in perspex (or glass) to allow accurate position detection by optical sensors (assuming a scanning light source in the horizontal plane) such as [9] with maximum distance 30 cm. Equally, constructing a transparent membrane with two thinly separated conductive layers (so that pressure causes a current to flow at the point of contact) suffers from the difficulty of finding a suitable transparent material. Another possibility, 5.8 GHz RF transducers, though omnidirectional, presumably require accurate timing to capture the time-of-flight [6].

If a radiating ultrasonic source were to be placed in the stylus, then it is possible to detect the position of the stylus in 2D by triangulation, or with a minimum of four sensors, the position can be found in 3D. The geometry of this arrangement is shown in Figure 6, with RX1 the origin of Cartesian co-ordinates, and the fixed distance from the origin to RX2 and RX3 being the same D_s. Then by dropping perpendiculars to the co-ordinate axes from position S, it is easily found that

$$X_s = \frac{D_1^2 - D_2^2 + D_s^2}{2D_s}$$

$$Y_s = \frac{D_1^2 - D_3^2 + D_s^2}{2D_s}$$

$$Z_s = \sqrt{D_1^2 - X_s^2 - Y_s^2}.$$

By adding a fourth sensor, then the triangulation can be performed three times, with the result averaged. Z_s is not required by many applications. Further, X_s and Y_s value calculation does not require the same value of D_s. D_s is found by ultrasonic means, i.e. transmitting from (say) fixed-point (FP) in Figure 6 to RX1 at start-up time. Ultrasonic signals are less susceptible to ambient noise compared to optical signals, and the relatively slow transmission speed (the speed of sound) increases the time that the electronics has to respond.

Commonly available ceramic ultrasonic transceivers are directional, with a primary lobe of $\pm 30^o$ [10]. However, by modifying the case a radiating source becomes available. Latterly the authors became aware of the 400ET/R180 device, which is a sealed version of [10] for outdoor work, but as the resonator is attached to the casing, produces dual side lobes giving an effective 180^o beamwidth. There is also a cylindrical piezoelectric film omnidirectional transmitter [7], which is completely omnidirectional, but this is not a commodity device.

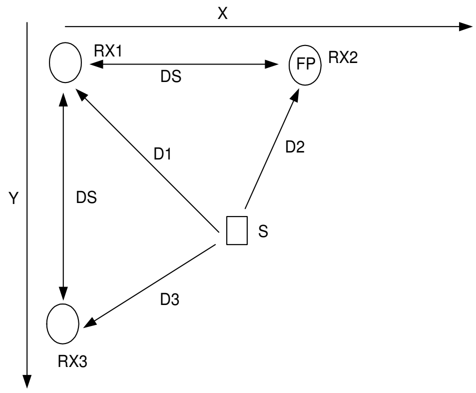

Figure 6: Triangulating the position of the stylus

Using the ultrasonic transceivers, which have a high 'Q' at 40 kHz, a PIC timer is clocked from an external source. Having reset the timer's counter, the counter starts incrementing upon receiving a start signal, Figure 7. Upon receipt of the start signal at the stylus, a pulse, modulated at 40 kHz, is transmitted. The receiver demodulates its input channel. When a pulse is detected, a transition to logic one occurs on the 'Stop Timer' line, causing the counter to be halted.

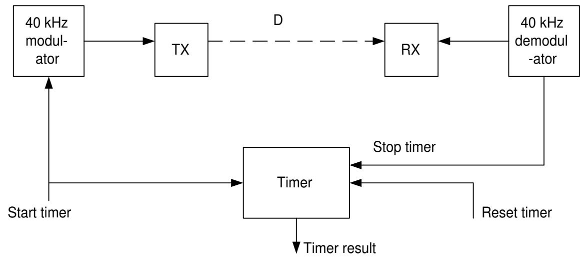

Figure 7: Ultrasonic distance measuring

3.2 Detailed prototype design

For reasons of flexibility, a software approach was taken for the prototype design. In Figure 8, all four timer units (each a PIC 16F84a) operate in parallel, as do the decoders (also a PIC 16F84a). The main PIC polls each timer unit for results, passing these to the PC host over an RS232 serial port (COM 1 or 2) for further processing (there are also PICs with a USB interface). iL_BASIC [5] proved convenient for programming the PICs, as it contains primitives for many of the necessary interfacing operations. The stylus channel is presently connected by a physical wire, but there are examples of wireless pen control through the BlueTooth interface, such as the Sony Ericsson Chatpen.

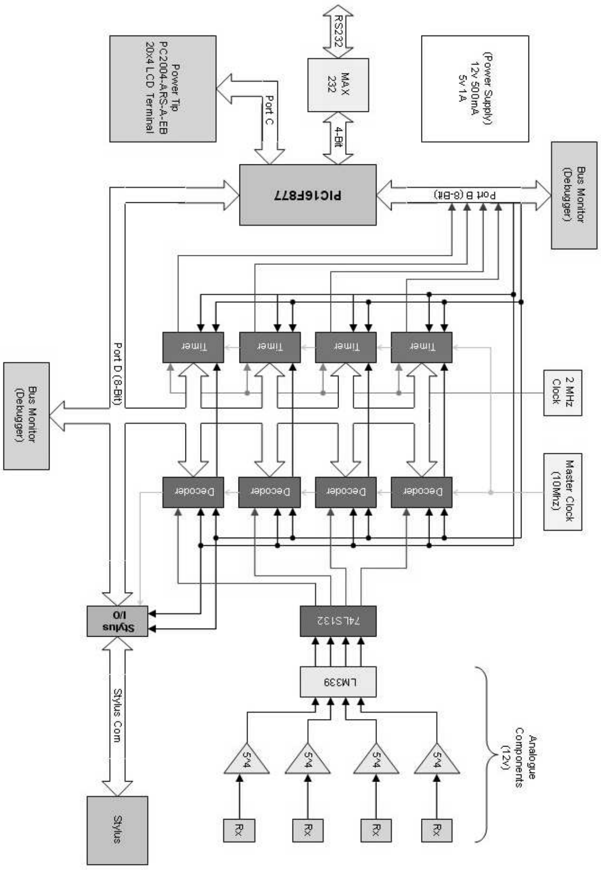

Figure 8: Complete design

In iL-BASIC, embedded assembly language is needed to access PIC internal timers, so as not to conflict with usage of timers by the compiler. An external clock to drive timers is required to make accurate range measurements. Though it is possible to divide down the system clock to drive the ultrasonic transmitters, and though Fig. 8 shows a 2 MHz system clock driving the timer units, in fact, more satisfactory results arise from using a standard 555 timer IC circuit as external clock source. As the range, R, of the tracking system is given by:

$$R = \left[\frac{v_{snd}}{f_c}\right] r_{cn},$$

where v_{snd} is the speed of sound (approx. 340 ms^{-1} in air), f_c is the counter clock frequency, and r_{cn} is the range of the counter, a 340 kHz clock source, with an 8-bit timer counter gives a resolution of 1 mm and a range of 25.6 cm (though, in practice, a small offset should be deducted due to decode time).

The maximum time of flight is given by $T_{of} = R/v_{snd}$, which herein is 0.75 ms, and represents the sampling rate, which is more than adequate[1] (Section 2), given than the bulk of the processing is on a PC, and the RS232 transfer bit-rate is 115.2 kbps.

A graphical tablet interface was created, Figure 9, to monitor the results obtained. One shot tests can be synchronised using the 'trigger' button. The stylus pulse frequency and width can be altered, and individual decoder and timer registers monitored. The data from the serial port interface software [8] is relayed to a simple drawing application, Figure 10, constructed to monitor the effect. The application can take advantage of the features of the hardware in real-time, such as brush rotation, pressure, and orientation. In Figure 10, RGB are the colour coordinates, updated by the user, whereas W is width, H is height, and T is θ, the rotation angle, to be updated by the hardware.

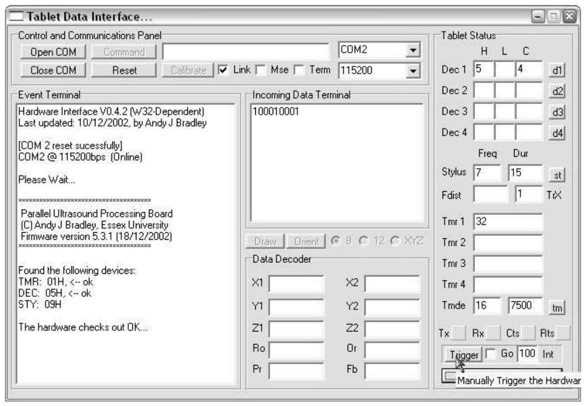

Figure 9: Graphical tablet monitoring interface

In the Figs. 11 and 12, the isolated line is the true distance to about an LCD width, whereas the other (superimposed) lines are ten repeats, with the PIC's clocked at 20 MHz, but without a reference clock. The horizontal response corresponds to the transmitter (400ET/R180 40 kHz device of Section 3.1, receiver unsealed ceramic oscillator) being held in the configuration of Fig. 7 top measure 'D', whereas the vertical response measures reflected sound with the stylus is held in the more realistic configuration of Fig. 5. Placing the receiver nearer the desk, as would be typical for drawing, results in an improved signal. There were 15 cycles in the ultrasonic burst, as reducing this to just 2 cycles also results in an erratic response. It is possible to tune further to avoid any echoes resulting from the stronger 15 cycle signal.

[1]To avoid reflections the sampling interval can be made (say) ten times larger.

Further improvement in resolution may arise from tackling quantisation effects. In general, with this simple arrangement, a direct linear response can be seen, even before the application of a smoothing filter.

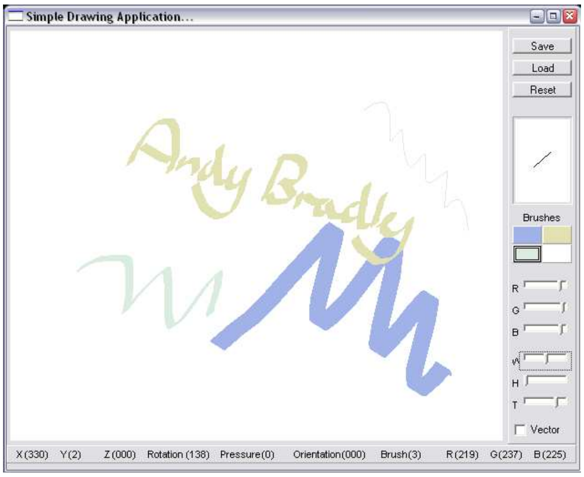

Figure 10: Test drawing application

4 Other designs

In [2], a mechanical linkage input/output device senses movements from the artists holding one end of the linkage, and provides Haptic feedback at the other. The software environment represents a deformable 3D brush, giving the artist a lifelike experience of using brushes. However, the linkage apparently restricts the range of the artist's hand movements and requires the brush to be held in mid-air, which is not realistic.

The Cintiq tablet from Wacom Tech. Corp., which is based on a specialised true-colour active-matrix LCD screen to which the pen is directly applied. Accuracy is ± 0.25 mm. Wacom devices of which the Intuos and Graphire2 are others [3] are being applied to tablet PCs, which are being developed by a range of well-known computer companies.

5 Conclusion

There is considerable commercial interest in direct input via an LCD screen. A number of image capture sensors have been considered, but as yet ultrasonics is relatively untried in comparison to modifications of active matrices, microradar, and touch screens. The attraction of ultrasonics is that it avoids proprietary interfaces to avoid interference from the LCD, though allowing an accuracy of 1 mm with PIC microcontrollers. Response time is below 10 ms. Completion of the prototype positioning interface is at an advanced state. Future work is, again at low cost, to substitute an FPGA for the main PIC as this will bring parallel processing to the responses, possibly with hardware triangulation unit, and PC interface.

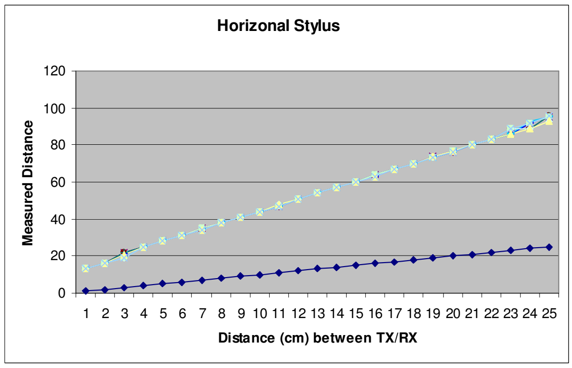

Figure 11: Wide-beam transmitter horizontal response

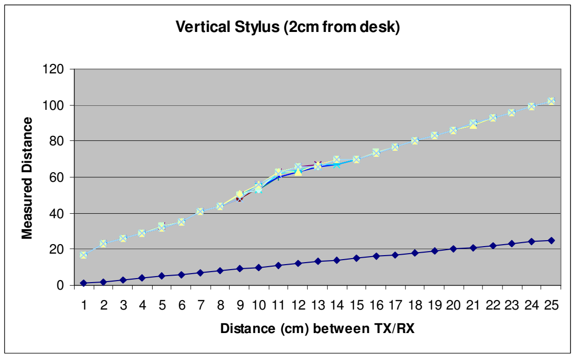

Figure 12: Wide-beam transmitter vertical response

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