SmartPen: An Application of Integrated Microsystem and Embedded Hardware/Software CoDesign.

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Abstract

This paper describes the integrated design of a new computer input device. The SmartPen is a stand-alone pen that can communicate the written gestures to a computer via an RF link. The operation of the pen is based on measuring the friction forces in three dimensions of the pen tip on the paper while writing and on measuring accelerations in three dimensions while moving in the air. Forces and accelerations are corrected by means of a two-axis tilt sensor. The whole system has been integrated in a pen, including sensors, mixed analog/digital electronics, embedded processing and an RF transmitter. Application specific IC's have been designed for the pen.

1. Introduction.

Human-computer interfaces are coming closer to the requirements of the end user. The current advent of pen computing is a well known example of this. Although interesting, the current developments are limited to the use of a plastic pen on an LCD screen or a stylus on a tablet.

To provide for better means of men-computer interaction, a novel computer input pen has been developed that can actually write on paper. This SmartPen has advantages for applications where a direct written record of the information is required. It is very natural and efficient in many every day activities to write with a pen on forms and papers. The feel of a pen that actually writes is better than a stylus that scratches on a tablet or glass cover of an LCD screen. In the next sections we describe the composition of the pen.

2. Operation principles of the pen.

The usage of a pen can be decomposed in two modes: 1) writing on paper and 2) movement of the pen in the air.

2.1. Pen model of the writing process.

For capturing the strokes written on paper, the friction force of the pen tip on the paper is being measured. Using a friction model, consisting of a static- and a dynamic model, the relationship between the friction forces measured in the pen and the velocity of the pen on paper can be calculated. From the integration of the velocity the movement on the paper can be determined.

The friction model of the pen on the paper is however related to forces as imposed by the pen on the paper. These forces in three dimensions according to a coordinate system related to the paper (the paper forces) can not directly be measured by the pen. The z-axis of the paper coordinate system is orthogonal to the writing plane. The pen embeds sensors that measure the forces in the three orthogonal dimensions in a coordinate system where the z-axis is according to the pen-axis. To be able to perform a coordinate transform, information on the position of the pen-coordinate system with respect to the paper coordinate system is required. This is measured by a two axis tilt sensor. The tilt sensor measures the angles of the pen axis with respect to the horizontal plane (of the paper) in two directions. In fact a third information of the rotation of the pen around the paper z-axis is not directly measured by this. It is assumed that the pen is on average held in the same position so that there is no rotation of the pen around the paper coordinate system z-axis. This is enforced by the construction of the pen, which has two pen-buttons which can be used in the same way as mouse buttons in conjunction with specific application software. The information of the rotation of the pen around the paper coordinate z-axis could be measured by means of an electronic compass.

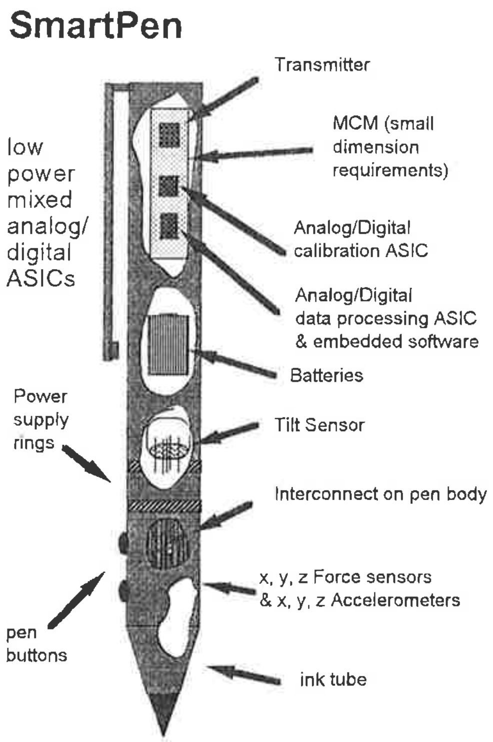

Fig. 1. Composition of the SmartPen Prototype.

2.2. Movement of the pen in the air.

When there is contact of the pen to the paper, friction forces can be used for the determination of the pen movements. When the pen is moving in the air, this can not be done anymore. To determine the movement in the air, accelerations need to be measured in three dimensions. From these accelerations, the positions and movements can again be calculated. Here again, as the pen coordinate system in which the accelerations are measured is different from the paper (or real world) coordinate system, the information needs to be transformed making use of the measurements of the tilt sensors.

2.3. Composition of the pen.

The composition of the pen is illustrated in figure 1.

In the front the SmartPen uses a standard ink-tube, that can be replaced when empty. This ink-tube is supported in a mechanical structure that is used to measure the friction forces as imposed on the pen-tip. This is accomplished by means of a mechanical flexor structure, as is illustrated in figure 2.

The flexor is a small Al-structure in the form of a cylinder, in which the ink-tube can be mounted. This structure is constructed in such a way that controlled deformations occur at specific places in the structures. By using finite element modeling techniques, the structure can be dimensioned in such a way that the Aluminum is not subject to plastic deformation during extreme writing conditions, so that the aluminum is used in the linear deformation zone. On top of the controlled deformation zones of the aluminum flexor, strain-gauges are mounted. The flexor has been designed in such a way that the ink-tube can be passed through the cylinder of the flexor. For obtaining a cost-effective production process it is required that the strain gauges can be mounted in one plane as mounting them on several different places complicates the production process. This is also required for the case where a complete integrated micromachined Si-structure is used, as it is impractical to realize non-planar Si-structures. The Al-flexor structure as shown in figure 2 has been designed in such a way that forces in 3 dimensions can be measured by strain gauges mounted in a single plane and taken up in 4 Wheatstone bridges. Figure 2 illustrates the mounting as well as the interconnection of the strain gauges on top of the flexor structure, together with the interconnection structure. For the interconnection a capton flex is used.

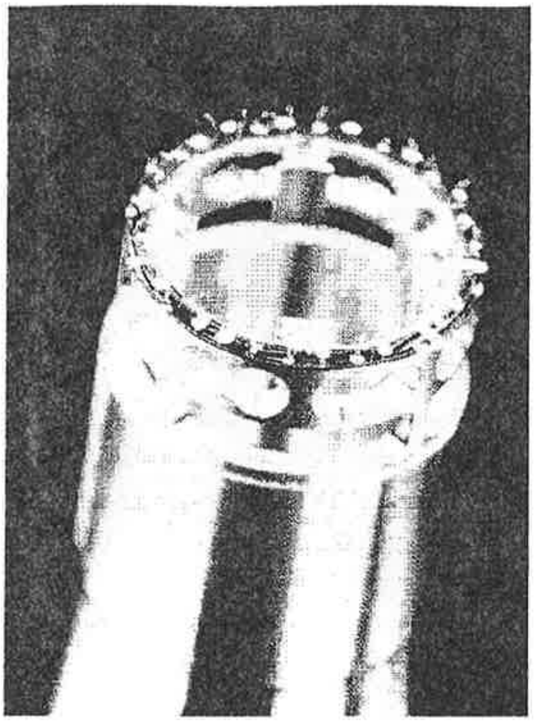

fig. 2. Photograph of force sensor structure and flex interconnect.

The tilt sensor consists of a small glass tube that has five electrodes of which four are positioned in the form of a cross, with one electrode in the center. The tube is filled with a resistive fluid. Such tilt sensors are also used for example in airplane navigation systems. In this case a dual axis tilt sensor is used. The angle of the tilt sensor (and consequently the pen axis) with respect to the z-axis of the paper coordinate system can be measured, as the fluid surface remains horizontal in the tube, thereby making that certain electrodes are more and others less covered by the fluid in the tube. By measuring the difference in resistance of the different electrodes the angle can be determined. In this measurement no DC currents can be used as the fluid tends to ionize near the electrodes and give rise to a polarization of the fluid and resulting in wrong measurements.

The signals resulting from the four strain-gauge Wheatstone bridges and the two-axis tilt sensor are digitized with an accuracy of 12 bits.

The pen houses rechargeable batteries. They can be recharged via two power supply rings on the outer pen body. These rings touch a so-called "SmartInkWell" which includes a receive and a charger. Special attention for the charging of the batteries has to be taken care of to obtain a good battery lifetime. Overloading must be avoided and appropriate drip charging is foreseen depending on the battery status.

In the front of the pen are two pen buttons, that can be used in conjunction with the application software. They can be used in the same way as buttons on a normal computer mouse. An example of this would be that a button could be used to indicate that a signature is going to be started.

The mixed analog digital electronics, capturing of the analog signals from the sensors, the conditioning of the tilt sensor and the software calibration of the sensors and the capture of the pen button information is performed by an embedded controller. This processor converts the captured data into a serial protocol together with error detecting coding for wireless transmission.

The transmission of the information is done via an RF transmitter at a frequency of 418 MHz. This is a band available for domestic applications.

A receiver which is embedded in the SmartInkWell captures the information and includes the interface circuitry for the connection to a standard IBM compatible PC. On the PC the application software can determine the specific use of the pen.

3. ASIC design.

Application specific ASIC design, taking into account considerations of low power usage and compactness has been performed. Two mixed-mode analog/digital ASICs have been developed. A first ASIC (fig. 3) implements the front end-electronics to condition and capture the analog information from the sensors and the pen buttons. It emcompasses the formatting, error detecting coding and serial conversion of the information for the transmitter.

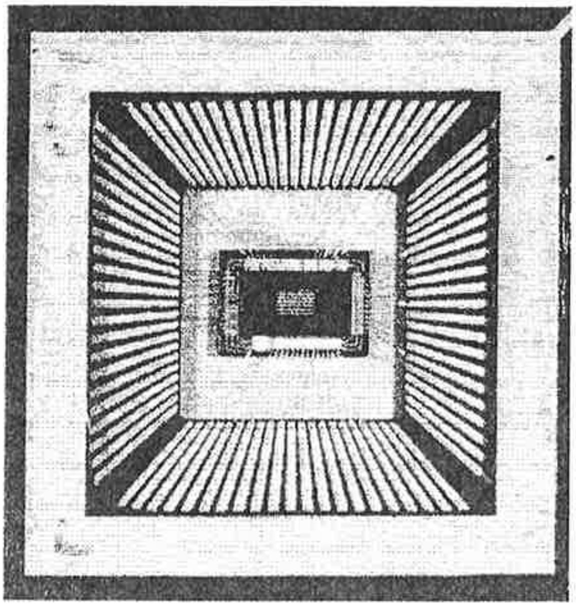

fig. 3. Controller ASIC.

A second ASIC (fig. 4) implements the control and software calibration of the offsets of the measurements from the Wheatstone bridges. A software solution can be controlled from a PC and does not require dedicated potentiometers, which even in an SMD (surface mount device) format take too much space in the pen. It avoids tuning by screwdrivers in the pen, with the risk of damaging the internals.

Both of the chips have been made scan testable.

The electronics is mounted on an MCM (multi chip module) carrier for obtaining compactness.

For the interconnection between electronics, sensors, buttons, batteries and charger rings, use is made of MID technology. MID stands for Molded Interconnect Device technology. This is a technology whereby a 3 D polymer molded structure (Ultem) can be used to also embed the interconnect. This is achieved by plating the 3D structure with Cu and implementing a structuring interconnect by removing the redundant Cu by means of a laser. This MID technology has the advantage that the pen body itself can embed the interconnect as well as the carrier for the electronics. As such it is also cheaper to produce.

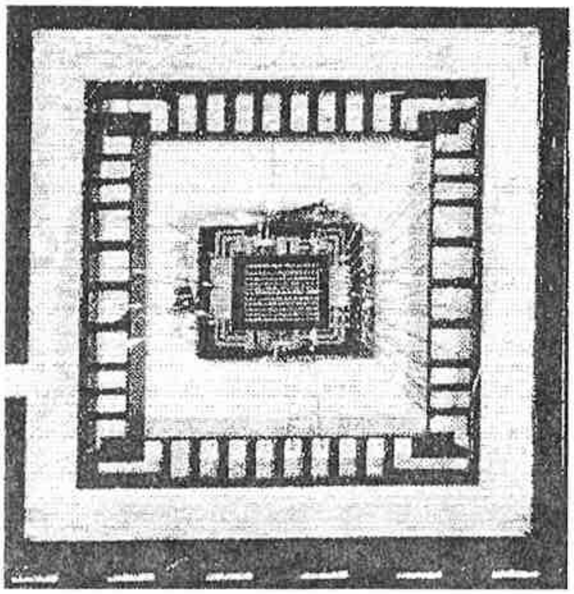

fig. 4. Analog calibration ASIC.

4. Applications of the SmartPen.

The SmartPen can be used to capture information as written by the pen. This can be done for capturing the written image as "electronic ink".

By using character recognition software, the pen can also be used to provide user input to electronics controlled devices. In fact the SmartPen measures more information than normal tablet based pens, this additional information (3D forces, 3D accelerations and 2 axis tilts) can help in getting a higher quality character recognition capability. This is especially the case for person specific character recognition. In such applications the pen can be used to give commands to an application by simply writing gestures or characters.

The special combination of sensors: measurements of forces at pen-tip, accelerations and tilts make it a unique instrument that can also be used for biometric person identification and verification by means of signatures. Current research addresses this problem to achieve better results than are possible with traditional methods such as for example the use of tablets.

5. Conclusions.

Figure 5 illustrates the current prototype of the SmartPen. It is shown besides a commercially available pen (Mont Blanc). Also shown are (a packaged) chip with the embedded processor for the treatment of the pen signals. Future work consists of producing a production version of the pen. This includes further optimizations of the various parts as well as application software for signature verification.

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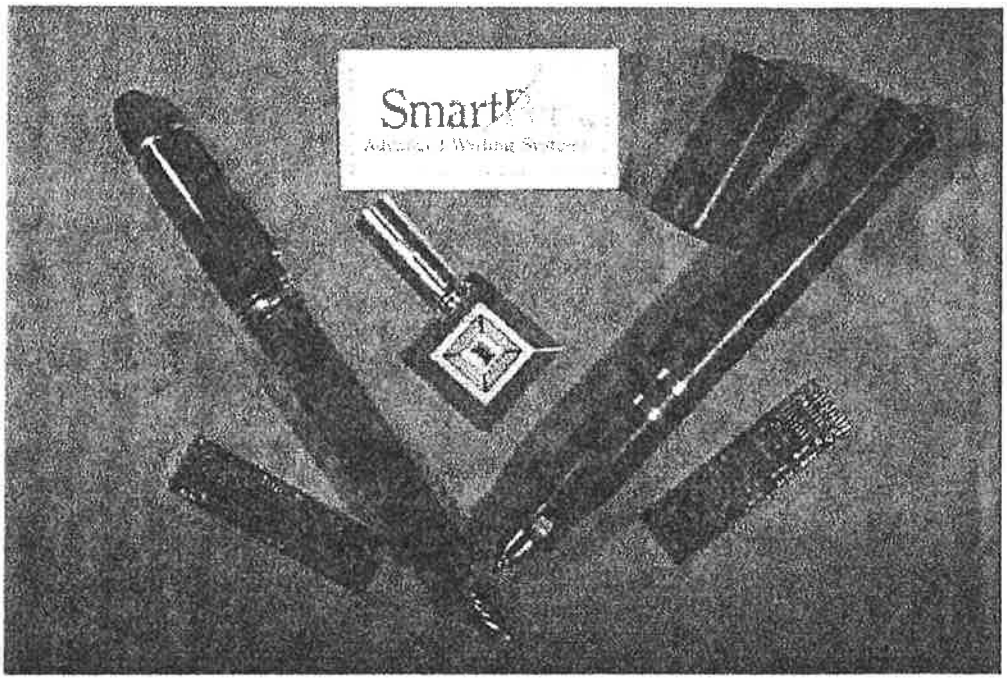

Fig. 5. An example of the current SmartPen prototype.