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PIEZOELECTRIC SENSOR PEN FOR DYNAMIC SIGNATURE VERIFICATION *

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ABSTRACT

The concept of using handwriting dynamics for electronic identification is discussed. A piezoelectric sensor pen for obtaining the pen point dynamics during writing is described. Design equations are derived and details of an operating device are presented. Typical output waveforms are shown to demonstrate the operation of the pen and to show the dissimilarities between dynamics of a genuine signature and an attempted forgery.

INTRODUCTION

There has always been a need for positive identification of personnel in law enforcement, national and industrial security operations, and business transactions. Use of computers for electronic funds transfer (1) and security problems associated with the proliferation of charge card systems has stirred interest in electronic means of personnel identification. Nuclear proliferation and rises in terrorism create a need for personnel identification with higher reliability than conventional badge/guard systems. Three different electronic identification systems now exist for possible application in these areas (2). Automatic fingerprint identification relies completely on the unique anatomical characteristics of fingerprints. Speech recognition draws both on the anatomical information of vocal cavity resonances and on learned characteristics of speech. Dynamic signature verification is based primarily on learned characteristics of handwriting style with some dependence on hand structure and musculature.

The present work concentrates on the input device for dynamic signature verification systems (3). The basis for this identification concept is that ones signature is personalized early in life and repeated often enough that the action of signing ones signature is automatic. The hypothesis is that, although the written result of a signature can be forged, the dynamics of the act of signing the signature are unique to the individual and forgery of those dynamics is improbable (2,3).

Numerous systems for dynamic signature verification have been proposed, primarily in the patent literature (3,4). All of them use a dynamic variable, or variables, such as pen point pressure and/or the two components (x and y) of pen point velocity or acceleration in the plane of the paper as a function of time. Typically, the variables are sampled digitally and then characterized in some statistically significant way. Enrollment with several signatures provides a mean and standard deviation for each characteristic of the dynamic variables; these can be stored and called up for comparison with values obtained upon attempted verification.

Descriptions of input devices for such systems are found also mainly in the patent literature and include xy platens, magnetic sensors, strain gauges, and capacitive pickups (5). Some of the important requirements placed on input devices include being rugged, capable of repeatable calibrated outputs, easily replaced, and inexpensive because of the large numbers required. The present work describes such a device which uses piezoelectric sensors to measure pen point dynamics in the plane of the paper (x and y axis). Also, a piezoelectric platen for detecting the third dynamic variable, pen point pressure as a function of time, is briefly introduced.

SENSOR PEN CONCEPT

Consider the forces in the plane of the paper which are acting on the pen point during writing. These forces are a function of the coefficient of friction, pen point pressure, pen point velocity or acceleration, and ink viscosity. Alternatively, these forces are proportional to the learned muscle responses in the hand which we are trying to characterize. These forces are carried between the hand and the paper by the flexual rigidity of the pen shaft, while pen point pressure is primarily carried by longitudinal stresses in the pen shaft. Thus, if one measures the flexing of the pen shaft, signals are obtained which are functions of the forces in the plane of the paper.

Consider one component F, say left to right (x axis), of the pen point force. The curvature K(z,t) caused by F(t) acting on a cantilevered shaft (see Fig. 1) of flexual rigidity D is

$$K(z,t) = F(t)\ (\ell - z)/D, \qquad (1)$$

where z is measured along the axis of the pen shaft and ℓ is shaft length. K(z,t) is the quantity to be measured.

The curvature sensing element used in the present device concept is a commercially available piezoelectric bimorph element. This sensor is made of two thin bars (length ℓ, thickness τ, width w) of ferroelectric ceramic stacked and glued with their major surfaces together and with one polarization up, the other polarization down. Any stress pattern with even symmetry about the center plane of the bimorph causes no voltage across the stack because the induced voltages or currents in each of the two layers are opposite in sign and cancel. However, bending motions cause stress patterns with odd symmetry about the center plane. In this case the voltages in the two layers are the same sign and add. Thus, the voltage measured across the stack or current induced in the bimorph sensor is proportional to bending motions only. Two of these sensors bonded in quadrature along the length of the pen shaft can measure the desired flexing for two directions in the plane of the paper (x and y axis). The sensors will not pick up the longitudinal stresses caused in the shaft by pen point pressure.

The equations governing the piezoelectric bimorph when sensing the bending of a cantilevered pen shaft are as follows. The magnitude of the stress T along the length direction on the major surfaces of the bimorph, which is caused by a bending of $K(z,t)$, is given by

$$T = \tau K(z,t)/s_{11} \qquad (2)$$

where τ is the thickness of the individual layer (2t is the total bimorph thickness) and s_{11} is the elastic compliance along the length direction. This stress induces a sinusoudal time dependence of radial frequency ω

$$J/j\omega = d_{31}\tau K/s_{11} + \epsilon_{33} V/2\tau \qquad (3)$$

where d_{31} is the piezoelectric coefficient in conventional notation for poled ceramics (6), ϵ_{33} is the dielectric constant, and V is the sinusoudal voltage induced across the stack. From Eqs. 1 and 3,

$$J/j\omega = d_{31}\ \tau\ F(\ell - z)/Ds_{11} + \epsilon_{33}\ V/2\tau\ . \qquad (4)$$

Integrating over the electrode surface area (ℓw) to obtain current I,

$$I/j\omega = d_{31}\ \tau\ Fw\ell^2/2Ds_{11} + \epsilon_{33}\ w\ell\ V/2\tau\ . \qquad (5)$$

Equation 5 tells us that the sensor acts as a transducer, converting a fraction of the work being done by the hand during writing to an electrical signal. For a voltmeter impedance of R_L,

$$V = IR_L \qquad (6)$$

and

$$V = \frac{j\omega R_L d_{31}\ \tau\ w\ell^2\ F}{(1 - j\omega R_L C)2Ds_{11}} \qquad (7)$$

where

$$C = \epsilon_{33}\ w\ell/2\tau\ . \qquad (8)$$

Equation 7 is the device design equation for the sensor pen concept. It tells us the electrical frequency response and allowable load impedances. For a low impedance sensing circuit,

$$V \propto \frac{dF}{dt} \qquad (9)$$

For a high impedance sensing circuit,

$$V \propto F\ . \qquad (10)$$

We have found that F is essentially proportional to pen point velocity for ball point pen tips where rolling resistance and ink viscosity are involved. Thus, for the more practical low impedance sensing circuit, the measured voltage is proportional to pen point acceleration. The impedances of conventional bimorphs are usually too high to use the open circuit, or high impedance, sensing circuitry of Eq. 10, so it becomes necessary to integrate the low impedance output if a signal proportional to velocity is desired.

Equation 7 also tells us that the output signal is inversely proportional to pen shaft flexual rigidity. Proper design must be a compromise between easy flexing for a large signal and the necessity of a stiff shaft for familiar writing "feel".

IMPLEMENTATION

Figure 2 shows the cantilevered shaft design chosen for our sensor pen. The central shaft is fixed at the top of the pen to cantilever it from the outer shell. The outer shell has flexual rigidity large compared to the cantilevered shaft. The central shaft contains a replaceable ball point refill. Two piezoelectric bimorphs are fixed with bands in quadrature along the central shaft to sense flexing in directions at right angles from one another. Banding is used instead of direct glueing to allow relative motion at the bimorph-shaft interface. This approach reduces the tensile forces acting on the bimorph when the shaft flexes but still senses the curvature. In practice, the pen is held so that one sensor detects flexing in the general direction of left to right on the paper (x axis). The other sensor detects flexing for top to bottom on the paper (y axis). A small component of the flexing arises from pen point pressure and shows on either or both axes depending on the angle of tilt of the pen body from the vertical during writing. This has not been a problem in practice, and in fact, enhances the uniqueness of the individual doing the writing because of roll in the hand position during writing.

Electrical leads are fixed at the top using flexible, light weight wires so that minimum interference occurs with customary writing habits.

Figure 3 shows a cut-away view of the pen. Also included in Fig. 3 are sample output waveforms for the x axis when one individual signed "Sandia" twice to demonstrate repeatability (top row). An attempted forgery by a second individual is shown on the bottom row. Although the written forgery compares well with the genuine "Sandia", the forgery dynamic signals (bottom row) are clearly different than the genuine dynamic signal (top row). These waveforms provide a visual picture of the philosophy behind dynamic signature verification.

In practice, digital comparisons must be done to implement a system concept. The output signals, typically as large as 1 V peak, can be amplified with a simple op-amp circuit to the 5 V peak amplitudes necessary for conventional analog to digital conversion. Also, high frequency noise (above 30 Hz) which is not repeatable and is attributed to paper roughness effects, can be eliminated with an RC low pass filter. We find that only the low frequency components of the output waveforms are highly repeatable (below 30 Hz).

The bottom of Fig. 3 lists some typical parameters that can be extracted from the digitized data to characterize the dynamic signature.

Figure 4 shows the pen in use. Also included in Fig. 4 is a platen which uses piezoelectric sensors to detect pen point pressure as a function of time. This platen is straight forward in design and will not be discussed in detail here. Suffice it to say that the observed pen point pressure signals are a third independent variable which can be used to raise the level of security.

REFERENCES

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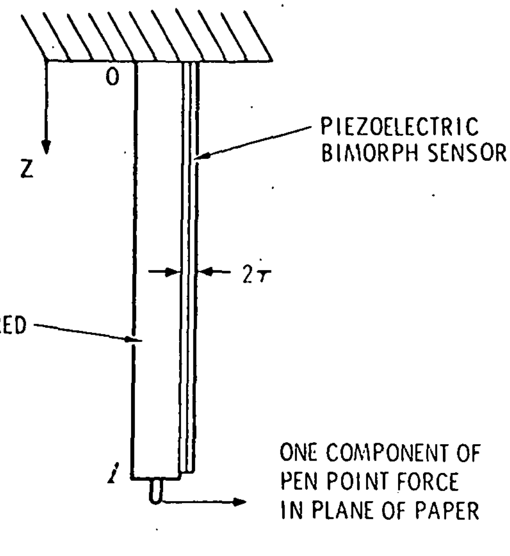

Figure 1 Mechanical model of a pen shaft flexing with the pen point force F.

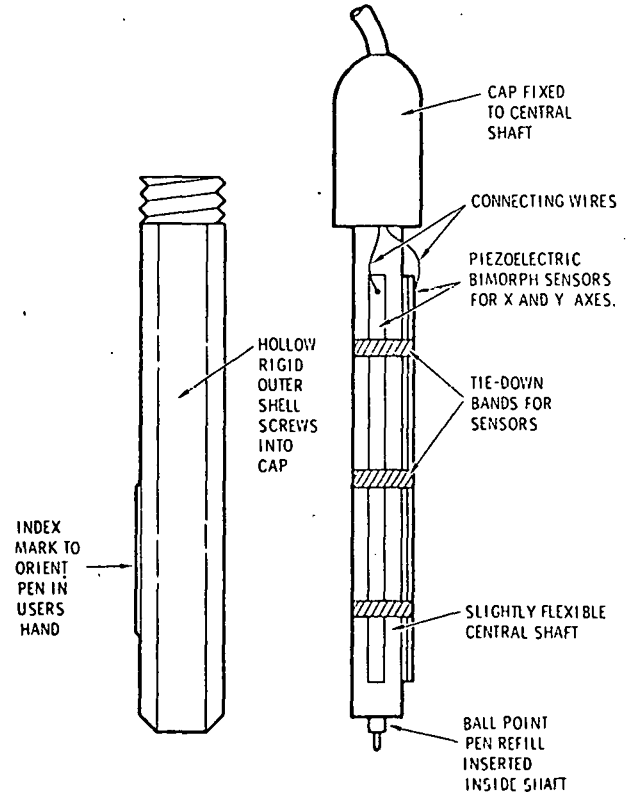

Figure 2 Detailed sketch of the piezoelectric sensor pen used to detect the in-plane (left-to-right and top-to-bottom on a page) dynamics of a pen point during dynamic signature verification.

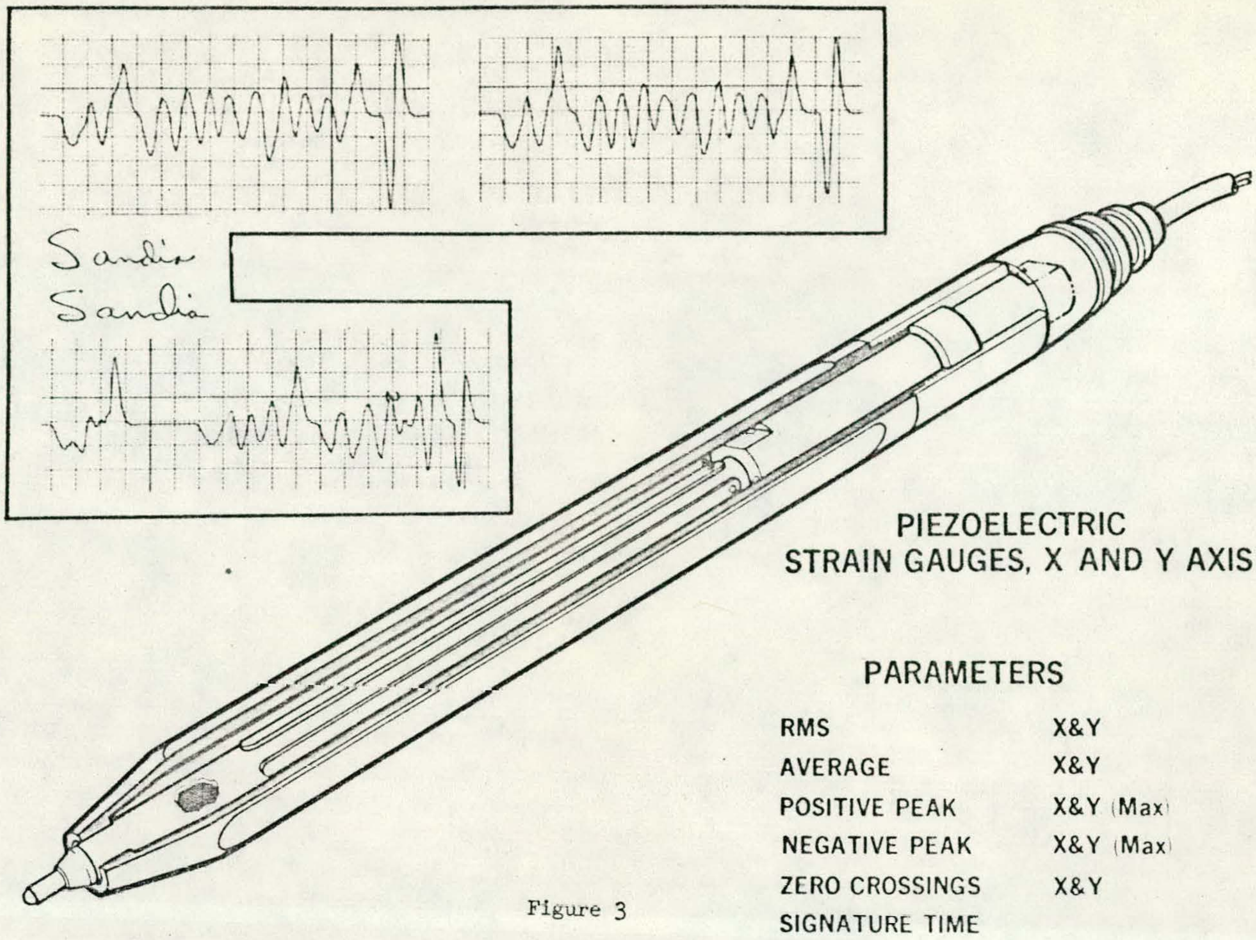

Figure 3

Figure 3 A cutaway of the piezoelectric sensor pen. The upper insert compares the horizontal output signal for an individual signing "Sandia" (repeated twice to demonstrate repeatability) with the horizontal output from an attempted forgery. The lower insert lists typical parameters that can be extracted from the pen output signals to characterize the dynamics for a verification system.

Figure 4 Demonstration of the pen along with a piezoelectric sensor platen that detects a third axis of information, the pen point pressure as a function of time.

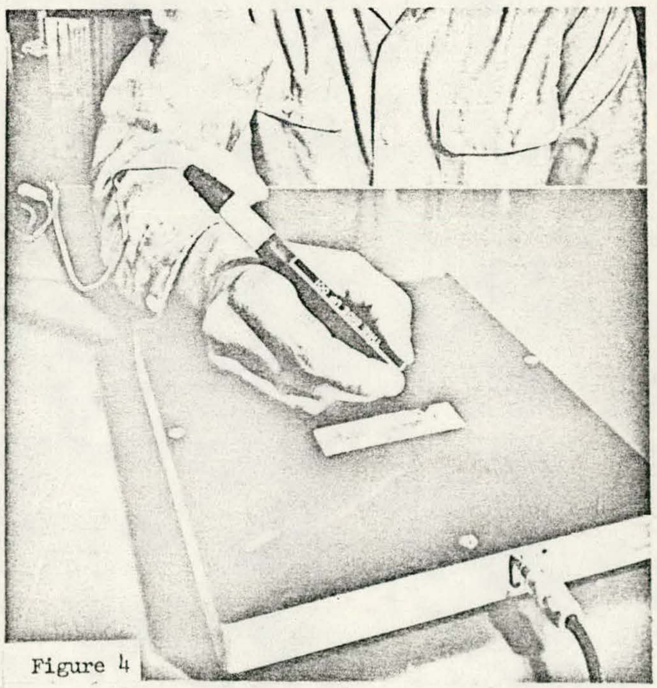

Figure 4