Utilizing Characteristic Electrical Properties of the Epidermal Skin Layers to Detect Fake Fingers in Biometric Fingerprint Systems—A Pilot Study

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***Abstract*—Electronic fingerprint systems are now gaining acceptance in mainstream consumer applications worldwide. It has been shown, however, that about 80% of these systems are easily fooled with different kinds of fake fingers with imprinted patterns. Hence, a live finger detection mechanism will be a crucial part of any fingerprint system used in security applications. We present such a system based on measurement of electrical characteristics of different layers of the skin.**

***Index Terms*—Bioimpedance, biometrics, electrode system, fingerprint, live finger, skin impedance.**

I. Introduction

ELECTRONIC fingerprint systems will in the near future eliminate the need for keys, pin-codes and access cards in a number of everyday products. While fingerprint recognition traditionally has been used only in high security applications, it is now gaining acceptance in mainstream consumer applications worldwide. One such large-scale application will be the need for secure mobile transactions when paying for the groceries with your mobile phone at the local supermarket. Such a system will need to be able to detect a fake finger on the sensor, and will require specification of a maximum false acceptance rate. Matsumoto *et al.* [1] reported for example that moulded "gummy" fingers were able to fool about 80% of all tested fingerprint systems. While sophisticated fingerprint systems are able to produce a FAR well below an acceptable value, the development of suitable fake finger detection systems has not come equally far.

Some possible approaches are to measure impedance, temperature, blood oxygenation or pulse on the applied fingertip, but none of these methods will in general give acceptable security. A simple impedance (or any other electrical parameter) measurement will have to be given a rather wide range of acceptable values because of large seasonal and physiological variations, and will hence be easily fooled for example by applying a thin layer of moisture on a fake finger. A dead finger will also probably be accepted since in most cases the already dead stratum corneum will dominate the measurements. Temperature measurements are obviously easy to fool, and blood oxygenation or plethysmographic pulse measurements will fail in cold weather because of the lack of microcirculation in the fingertip [2]. Finally, measurement of ECG-pulse is easily fooled (with a small signal generator) and furthermore unrealistic with access to only one fingertip.

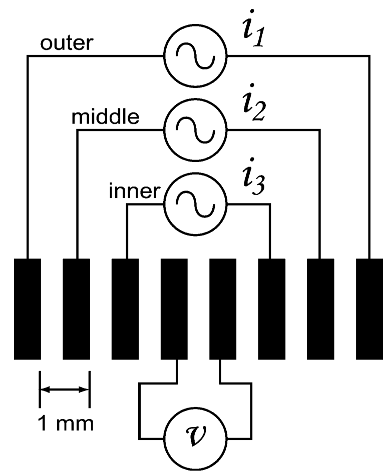

Fig. 1. Electrode array with three alternative current injecting electrode sets and one set of voltage pick-up electrodes. Electrode width and separation is 500 μm.

In this paper, we describe a new, patent-protected method for live finger detection, based on simultaneous measurements of the electrical bioimpedance of different skin layers [3]–[5]. The measurements are sensitive to characteristic properties like stratum corneum impedance, viable skin impedance, dispersive behaviour of these layers in the measured frequency range and anisotropy in the stratum corneum.

The results from this pilot study show that we are easily able to separate live from fake fingers when a multivariate classification algorithm is used.

II. Materials and Methods

Fig. 1 shows a diagram of the measuring set-up. A Solartron 1260 + 1294 frequency response analyser was used for the impedance measurements on an array of eight gold plated electrodes. Both the width of each electrode and the electrode separation was 500 μm, which is in the range of typical fingertip stratum corneum thickness. Different electrode lengths were tested, ranging from one to several millimetres. They all

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produced similar results, but longer electrodes (stripes) gave better reproducibility.

The two middle electrodes were connected to the differential voltage input of the analyser, and the three other electrode pairs were in turn connected to the internal oscillator. The analyser thus performed three successive four-electrode measurements, each time using the same voltage pick-up electrodes, but different current injecting electrode pairs, denoted "inner," "middle," and "outer" in Fig. 1.

In each measurement, a genuine or fake finger was placed on top of the electrode system with a light pressure and was held in place for about 2 min before the first measurements were conducted, in order to reduce drift between the three consecutive scans (due to water build-up in the skin because of the occlusive effect of the electrode array). Three frequency scans were then performed, using an applied voltage of 10 mV root mean square on the current injecting electrodes, at nine discrete frequencies from 10 kHz to 1 MHz.

The sensitivity field of a four-electrode system is found by taking the dot product of the current density vectors resulting from driving a unity current through the current injecting electrodes and voltage pick-up electrodes, respectively [6]. Hence, bringing the current injecting electrodes farther apart will result in higher current density in the deeper, viable skin layers and consequently lower measured impedance due to the increased contribution from these layers. Using the inner electrodes (Fig. 1) will, on the other hand, constrain most of the current to the skin surface and hence produce higher impedance dominated by the electrical properties of the stratum corneum [7]. Anisotropy in the stratum corneum will in this case also greatly determine the measured frequency response. If the lateral (parallel to the surface) impedance is lower than the transversal, the current will, because of the small separation, partly be channelled via the voltage electrode metal, leading to a typical increase in low-frequency impedance. Thus, the total set of measured data will include information about a number of characteristic electrical properties of different skin layers, and should hence provide pertinent means for spoof detection when combined in a multivariate classification model.

We performed 21 measurements on live fingers from 15 different adult individuals and 41 measurements on different fake fingers. Fake finger were made according to the recipe based on water and gelatine given by Matsumoto *et al.* [1], and we also tested a range of different materials, including animal tissue, vegetables and fruit. These materials were chosen because of their assumed electrical similarity with layered skin.

III. Results

Figs. 2 and 3 show representative measurements on one live finger together with the results of the measurements on the fake "gummy" finger, which was made according to Matsumoto *et al.* [1]. All measured live fingers showed similar behaviour to the one in Fig. 1, and significantly different from any other material we have tested so far. Measurements on live fingers often produced slightly increasing impedance when the frequency increased from 100 kHz to 1 MHz. This is most probably due to self inductance in the tissue [8], [9].

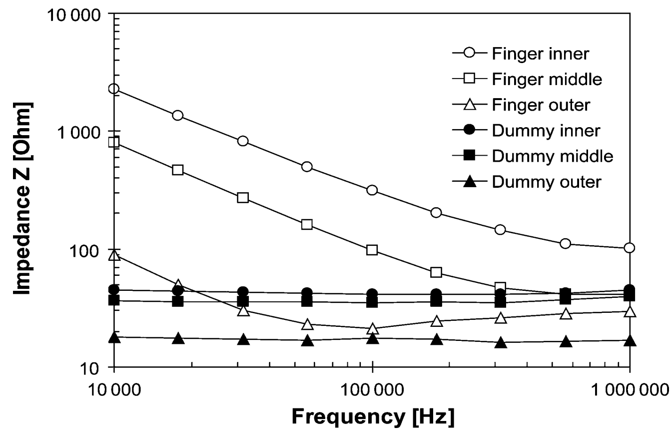

Fig. 2. Measured impedance modulus response for one live finger and "gummy" fake finger according to recipe by Matsumoto et al. [1]. Frequency range 10 kHz–1 MHz. Captions "inner, middle and outer" refer to the electrode set used for current injection (see Fig. 1).

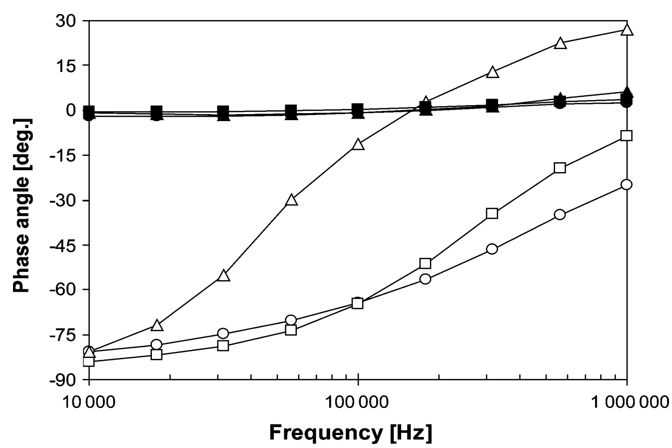

Fig. 3. Measured phase modulus as corresponding to Fig. 2.

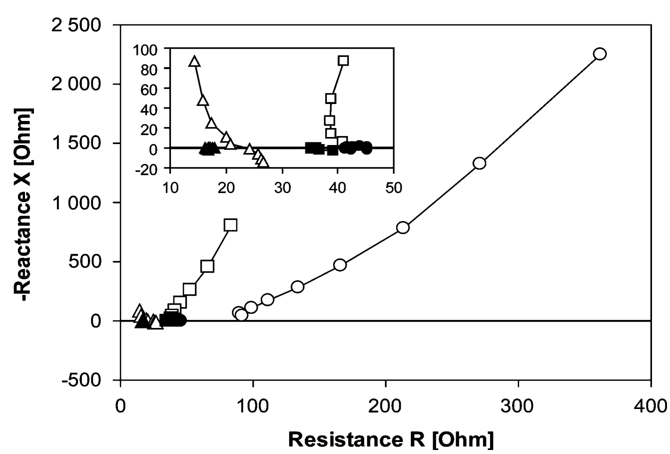

Fig. 4. Data from Figs. 2 and 3 presented as a Cole plot (Wessel plot), with inset showing details of low impedance values.

Fig. 4 shows the same data presented as a Cole plot (Wessel plot [3]), where the small inset shows a close-up zoom of the lower, left part of the large figure. The three curves resulting from the three pairs of current electrodes used were combined into one curve by a simple weighted average. We used these

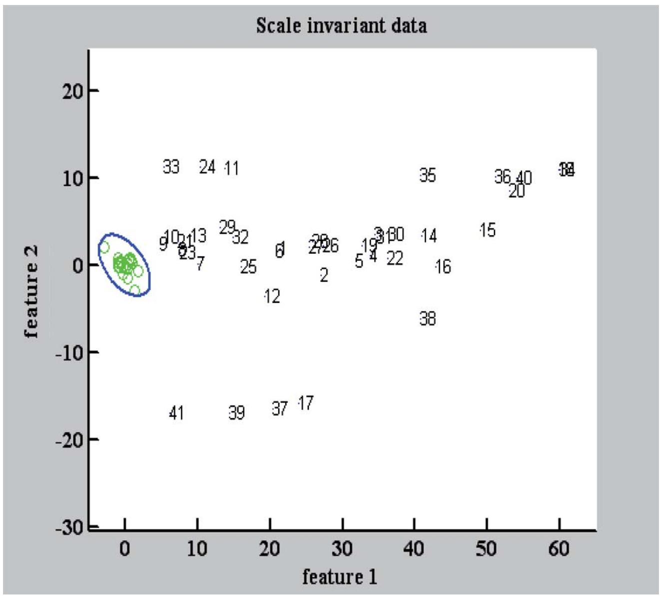

Fig. 5. Result of using a multivariate classification model where two of the four characteristic features of the measured impedance curves are utilizing. Some of the artificial materials used were "gummy fingers" (16,35,36), cucumber (1–6), paprika (7–10), alginate (11), tomato (12–14), banana (19), yeast (20), apple (21,22), sausage (24), grape (29), potato (32), and cheese (33,34).

combined curves to differentiate between the live finger measurements and the measurements of all the other materials. The combined curves resulting from the measurements of live fingers produced almost straight lines in the complex plane. This was the case for all the live fingers we measured. A straight line of fixed length is characterized by four different parameters, the x- and y-component of the two end points, or equivalently its slope, its length and the x- and y-component of one of the points falling on the line. We used the latter four and combined all the live finger measurements in a multivariate model in Matlab to create one live finger class with a centre and a covariance matrix.

Fig. 5 shows the results when only two of the features are used to create the live finger class, namely the slope (feature 1) and the imaginary part of the centre point of the estimated lines in the complex plane (feature 2). The entire set of live finger measurements (circles) fall well within the 3σ ellipse indicated in the figure ($1\sigma = 1$ standard deviation). All the fake materials (marked with different numbers) are easily discriminated from the live fingers. If we used all the four parameters, the discrimination improved so that the closest fake material fell more than 10σ away from the centre of the live finger class.

IV. Discussion

This paper shows that simultaneous measurements of the electrical bioimpedance of different skin layers provide a promising method for the detection of a fake finger in biometric fingerprint systems. The system has not yet been tested on post mortem finger tissue, but since the electrical properties of viable tissue change dramatically post mortem, it will most likely also be possible to define a multivariate class for dead fingers [10]–[13]. Furthermore, since all live finger measurements in this RMS were done on adults, we will also include children in the continued research.

In any practical fingerprint acquisition system, the live finger detection should be performed simultaneously with the capture of the fingerprint [14]. The measurements presented in this paper were performed with a commercial frequency response analyser, but we are currently testing a prototype version of an instrument where only a few periods of each frequency are used, and where the three current injecting electrode sets are measured simultaneously. Hence the total live finger measurement can be performed within a few milliseconds. Live finger detection can then for example be done when the finger is swept over a stripe based fingerprint sensor, without disturbing the capture of the fingerprint.[1]

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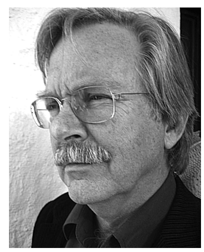

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