Rapid communication

Imaging electrostatic fingerprints with implications for a forensic timeline

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ARTICLE INFO

Article history:
Received 16 September 2010
Received in revised form 3 February 2011
Accepted 28 February 2011
Available online 20 April 2011

Keywords:
Latent fingerprint
Imaging
Surface charge
Sensors
Scanning probe microscopy

1. Introduction

Classic fingerprint evidence remains a primary forensic method of identification in many criminal cases and has stimulated recent work aimed at quantifying the error rate in matching fingerprints [1] and also at a deeper understanding of the mechanism of pattern formation [2]. Whilst many techniques exist for enhancing fingerprints on a variety of materials [3], they all rely on either visible deposits or hidden (latent) fingerprints resulting from the transfer of residues from the finger to the surface [4]. Other microscopic imaging techniques suffer from severe limitations of scan area and scan speed. Atomic Force Microscopy can discern fingerprint residue on glass, but the scan area is restricted to 40 μm × 40 μm, insufficient to image a whole fingerprint [5]. Scanning electrochemical microscopy has a somewhat larger, but still restricted, scan area of 5 mm × 3 mm, however the scan time is 5 h and significant sample preparation is required [6]. Scanning Kelvin Probe microscopy [7] for latent fingerprint imaging is non-destructive and preserves DNA material, but is applicable to conducting surfaces only. It has found a particular application in recovering fingerprints from the curved surfaces of bullet casings. The scan area and scan speed achieved are sufficiently large to allow a whole fingerprint image to be built up, but the scan time is relatively long, between 6 and 30 h.

In addition, it is extremely difficult to establish even an approximate timeline of events from fingerprint evidence alone. It is important to distinguish here between aging, as in the determination of the age of the individual, and the length of time which has elapsed since the deposition of a fingerprint. Aging of the individual relies on the analysis of the chemical composition of the fingerprint using Fourier transform infrared techniques [5]. Other techniques for determining the time elapsed since deposition are based on either; physical appearance; the effects of environmental factors; chemical changes in the constituents of latent fingerprints. The first two methods suffer from the difficulty of reproducing the original conditions therefore the third is considered to be the only viable candidate [8,9]. Latent prints are affected by a wide variety of factors including subject factors and transfer and storage conditions. Subject factors such as stress, metabolism, diet, health, age, sex, occupation and quantity and quality of finger contamination all need to be taken into consideration. Transfer conditions include surface texture, physio-chemical structure, curvature, temperature, temperature difference, pressure and contact time. Storage environment parameters are also relevant such as temperature, humidity, UV radiation, dust precipitation, condensation, friction, air circulation and atmospheric contamination. By contrast the method proposed in this paper relies on contact electrification, which is widely accepted to be almost independent of both the subject and the transfer method [10]. The decay of the resulting surface charge is a function of the physical properties of the material and the environmental conditions prevailing [11]. Clearly the material may easily be characterised using a known test charge, leaving
only the environmental factors to be determined. Preliminary results are presented for the imaging of fingerprints using this technique and could form the basis for a method to estimate the time elapsed since deposition.

Results are presented here for a new laboratory based technique which images the electrical charge deposited when a finger contacts an electrically insulating surface. The method is distinct from conventional forensic electrostatic methods such as ESDA, where a large electric field is applied in order to reveal latent images, which may include fingerprints [12]. In the method described the extant electric field is measured, this arises from the deposited electrical charge and is not dependent on chemical deposits. The images have a spatial resolution appropriate for identification purposes, and are of comparable quality to conventional fingerprint images. Furthermore, the decay of the charge image with time can be observed and has two major implications. First, this method does not suffer from the background noise caused by a history of old fingerprints and second, it has the potential to determine the time sequence of recent charge fingerprint images. An additional benefit over conventional latent fingerprint development techniques is its non-destructive nature, allowing subsequent examination and processing of the fingerprint after charge imaging. The principle of static charge measurement at the microscopic length scale using the EPS sensor has not been discussed previously in the literature. However, charge measurement at a 1 cm spatial resolution [13] and high spatial resolution measurements of electric potential at the 1 μm scale [14], have been previously reported by the authors. Charge measurement was demonstrated on a range of insulating materials, including modern plastics such as PVC, PTFE, acetate and PVDF sheets [op cit. 13].

2. Materials and methods

The present technique utilizes the electric potential sensor (EPS) as has been previously described in detail in the literature by the authors [15,16]. This compact and robust solid state sensor may be configured to measure charges in either, spatial electric potential, electric field, or charge. Surface charge measurement is achieved in a method similar to the capacitive probe [17], in which surface charge is measured by the voltage induced on an electrode when it is brought in proximity with a charged surface. In contrast to conventional capacitive probes, the EPS has excellent DC stability with zero input bias current, and a much lower input resistance, high capacitance) probes. The measurement of static surface charge is performed by recording the transient output voltage of the probe when it is moved from one position to the next. The voltage output of the probe can be related to the surface charge density by considering the various capacitances involved, or calibrated by an independent measurement of surface charge [18]. The measure of surface charge density gradient is then numerically integrated to produce absolute surface charge density.

The scanning apparatus consists of a single electric potential sensor, a specially developed coaxial sense probe and a 3-axis positioning system, as shown in Fig. 1. Charge measurement was demonstrated on a range of insulating materials, including modern plastics such as PVC, PTFE, acetate and PVDF sheets [op cit. 13].

The scanning apparatus covering a large 300 mm × 300 mm area. The compact electric potential sensor and probe are mounted on the gantry. The scanning apparatus consists of a single electric potential sensor, a specially developed coaxial sense probe and a 3-axis positioning system, as shown in Fig. 1. Charge measurement was demonstrated on a range of insulating materials, including modern plastics such as PVC, PTFE, acetate and PVDF sheets [op cit. 13].
impression on the insulating plastic surface, which may be partially confined within the surface of the plastic itself, and also within the deposits left behind by the finger contact. No special preparations or development processes are required before imaging and the measurement is completely non-destructive meaning that it may be repeated, since the charge distribution is undisturbed.

The latent fingerprint charge images obtained by EPS charge scanning are presented in Fig. 3 and are intended to be indicative of the level of detail obtained by the charge imaging method, probably sufficient in resolution for forensic identification. Fig. 3 compares a latent fingerprint charge image with images of the fingerprint obtained directly from the finger by passive capacitance and optical methods respectively. Standard identification features in the ridge pattern such as bifurcations and ridge endings are present in all three images including the charge scan. Conventional fingerprint analysis techniques may therefore be applied to latent fingerprint charge images [23]. Whilst it is undoubtedly useful that a single apparatus could be used for both latent fingerprint imaging and surface charge measurement, it may be more convenient to utilize the surface charge measurement for timeline estimation only and utilize a conventional imaging technique for fingerprint imaging.

Fig. 4 shows the decay of such a charge image over a period of 14 days. The definition of the latent image remains intact throughout, although the overall level of charge is seen to diminish with time. Fig. 4d shows the image when the sample has been discharged using ionized air. A weak fingerprint image remains visible. This can be attributed to several effects, the inability of ionized air to completely remove any surface charge and differential discharging between the bare PTFE material and the areas where fingerprint residue is present. The decay of charge over time gives latent fingerprint charge images the useful property of strong time dependence. This property has two clear benefits; very old fingerprints are not visible using charge imaging and it may be possible to date or time-sequence recent prints. The amount of charge deposited by a finger contact on a given insulating material is largely dependent on the material and nature of the contact, and largely independent of the subject conditions including the charge being carried on the finger. It may therefore be possible to make an estimate of the initial charge.

The charge decay versus time for a single pixel of a fingerprint image on a PTFE substrate is shown in Fig. 5. Such a decay curve is easily obtained for any given material using the present charge imaging method. A clear exponential decay is observed, with additional variations synchronized with the diurnal cycle. At certain points the graph indicates an apparent increase in surface charge. This is caused by environmental conditions affecting the relation between actual surface charge and sensor output voltage, and is therefore erroneous. The data of Fig. 5 is compared with a standard exponential decay curve [24], shown as a dotted line, fitted for a charge \( Q \) at time \( t \) as, \( Q(t) = Q_0 \exp \left[-t/\tau\right] \) where \( \tau \) is chosen for the best fit to the graph, and \( Q_0 \) taken to be the charge at time \( t = 0 \), corresponding to the time of the first measurement. The charge decay rate, \( \tau \), is dependent on both material and environmental factors. The intrinsic decay rate, due to the material, may be easily determined experimentally using the present technique and a known test charge. It has been previously shown that repeated measurements made using this method have no effect on the charge decay rate [18], demonstrating the non-destructive nature of the measurement. Not only is the surface charge distribution undisturbed, but any surface deposits from the fingerprint also remains intact. Whilst attempts have been made to quantify the triboelectric charge for a given material, variations in composition and surface treatment make producing a universal data set difficult [10]. Instead, it is more useful to have the ability to make triboelectric charging and decay-time measurements in the lab for a given sample, easily achieved for any material using the EPS scanning system.

The data of Fig. 4 indicates that the probe responds only to surface charge, and not to surface topography variations in the absence of any such surface charge. It is however not clear from the present results whether the majority of the surface charge is confined to the plastic sheet itself or is predominantly present in
the fingerprint deposits on the surface. Evidently, if a surface charge is on a ridge on the plastic surface, it will produce a larger probe output voltage than if it were further away, for example, on the surface of the plastic itself.

4. Conclusions

Preliminary results have been presented for an electrical charge scanning system based on the electric potential sensor. Both the spatial distribution of the surface charge and the time dependent decay of that charge have been imaged. It has been demonstrated that the images obtained resolve common fingerprint features, as used for identification purposes, and that the quantity of charge in the latent fingerprint is strongly time dependent. Although the system described in this paper is a relatively slow laboratory based instrument we have already demonstrated the use of EPS in both one and two dimensional array formats [25]. It is envisaged that a practical version of this instrument based on a high density two dimensional imaging array of EPS is feasible and would overcome the two major problems with the current laboratory based system. Namely, the scan time would be significantly reduced with real-time imaging possible over an area limited only by the size of the sensor array. Such a device would also be appropriate for field deployment, since the requirement for precise positional stability and control in the current system is due to the necessity to build up the image by raster scanning. The development of such large scale EPS imaging ICs is the focus of a current collaborative research project. The scanning EPS as a surface charge imaging system has further applications in materials testing and fundamental research into charge migration processes, with current research effort being directed toward improvement of the spatial resolution. At present, images with $5 \, \mu m$ spatial resolution have been acquired with the scanning EPS system. The present measurements have all been conducted on thin sheets of insulating materials ($\sim 50 \, \mu m$ thick). High resolution measurement of significantly thicker samples presents additional difficulty, since the measurement probe is influenced by space charge within the bulk material. This problem has received significant attention in published research and has

Fig. 4. Measurements of surface charge density on a 50 $\mu m$ thick PTFE sheet; (a) immediately after application, (b) 5 days after application, (c) 14 days after application and (d) after exposure to ionized air.

Fig. 5. (a) Plot of the peak surface charge density of a single latent charge fingerprint ridge deposited by a momentary finger contact on a 50 $\mu m$ thick PTFE sheet. Measurements are repeated at 30 min intervals for 110 h. An exponential decay curve is fitted (shown dotted) with $\tau = 25$ h. (b) Profile of the latent fingerprint ridge used in (a) as a function of time.
been partially addressed by inverse matrix techniques [26,27]. Further experiments are required with a much wider variety of donors and with different fingers preparations such as, solvent cleaning, or unclean fingers with significant sebaceous material. This would help to resolve the independent contributions of the triboelectric charging effect of the plastic surface and the relative contribution of the charge retained in the fingerprint deposits. The unique ability to obtain this charge information over large scan areas, with the potential to do so in real-time in the near future, opens up the possibility of a new forensic method for aging or time sequencing fingerprints.

Acknowledgement

The authors would like to thank the Engineering and Physical Sciences Research Council for funding this work under Grant Number EP/E042864/1.

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