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Accessible biometrics: A frustrated total internal reflection approach to imaging fingerprints

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ABSTRACT

Fingerprints are widely used as a means of identifying persons of interest because of the highly individual nature of the spatial distribution and types of features (or minuta) found on the surface of a finger. This individuality has led to their wide application in the comparison of fingerprints found at crime scenes with those taken from known offenders and suspects in custody. However, despite recent advances in machine vision technology and image processing techniques, fingerprint evidence is still widely being collected using outdated practices involving ink and paper – a process that can be both time consuming and expensive. Reduction of forensic service budgets increasingly requires that evidence be gathered and processed more rapidly and efficiently. However, many of the existing digital fingerprint acquisition devices have proven too expensive to roll out on a large scale. As a result new, low-cost imaging technologies are required to increase the quality and throughput of the processing of fingerprint evidence. Here we describe an inexpensive approach to digital fingerprint acquisition that is based upon frustrated total internal reflection imaging. The quality and resolution of the images produced are shown to be as good as those currently acquired using ink and paper based methods. The same imaging technique is also shown to be capable of imaging powdered fingerprints that have been lifted from a crime scene using adhesive tape or gel lifters.

1. Introduction

Digital acquisition of fingerprints is becoming increasingly important for biometric identification and evidence gathering purposes. The proliferation of both capacitive [1–4] and optical based scanners [5–9] as fingerprint acquisition tools has meant that these types of device are being routinely used to provide access to smart phones and laptops as well as more security intensive applications that involve controlling human access to safes and restricted areas. Other important areas where digital fingerprint devices are useful include domestic and international policing applications, immigration and border control and in the identification of terror suspects.

Given the relative abundance of fingerprint acquisition technologies it may at first seem surprising that many domestic police forces in the UK choose to use paper based methods to acquire fingerprint evidence. However, recent and ongoing cuts in the forensic science budget have meant that even the cheapest of these technologies can prove to be prohibitively expensive when rolled out on a large scale to all scene of crime officers. Moreover, the software interface that comes with these devices is often not fit for purpose and has expensive software licences associated with it. Considerable expenditure and work therefore has to be done to integrate these new technologies with existing fingerprint database tools.

There are a number of disadvantages to using paper based techniques that make the move towards digital fingerprint acquisition increasingly more attractive. This is particularly true in the acquisition of fingerprints from suspects in custody and at potential crime scenes, as part of border control processes and in collection of so called 'elimination prints'. These elimination prints are usually collected at the scene of e.g. a burglary, and are designed to help police to eliminate the house holders prints from an investigation – as most of the prints found at this type of crime scene are likely to belong to the people that live there. In all of the cases mentioned above, the practical aspects of acquiring and transmitting the finger print data mean that ink and paper based methods can be unreliable and slow. Very often the person collecting the fingerprints will be an investigating police officer, an immigration official, or a member of the public (in the case of elimination prints). The fingerprints that are produced using ink and paper based techniques can sometimes become smudged, distorted or incomplete. If this occurs the fingerprints are likely to be less useful and in extreme cases unusable for identification purposes. In many cases, the resulting marks are then sent by conventional mail or courier to a fingerprint bureau where they are scanned at high resolution and imported into a

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fingerprint database - a process that can take many days. A more attractive approach would be to acquire these prints digitally and to transmit them to a fingerprint bureau electronically. This would increase the rate of transmission of the data (seconds vs days) while also reducing consumables costs (ink pads and paper) and ideally improving the quality of the transmitted fingerprints.

Digital images of fingerprints are routinely collected using capacitive [1–4] and optical based sensors [5–9]. In a capacitive sensor, an array of small elements is used to detect when a finger is brought into contact with the surface. The areas where the ridges of the finger touch the elements experience a change in capacitance and an image of the contact regions can be built up by electrically addressing each element in turn [1–4].

Optical sensors use light scattered by a finger which is in contact with a hard surface as a means of detecting the contact regions. A convenient and reliable approach involves the use of evanescent field techniques such as frustrated total internal reflection (FTIR) [5–9]. These devices are constructed such that light is incident on the interface between a glass (transparent plastic) plate and air at an angle of incidence that is greater than the critical angle [10]. As a result, the light is totally internally reflected inside the glass (plastic) plate and is confined within it, creating a so called waveguide. The boundary conditions are such that the electric fields associated with the incident light do not decay sharply to zero at the interface. In fact, the amplitude of the electric field decays exponentially over distances comparable to the wavelength of the light in a direction normal to the plate surface. This exponentially decaying field is referred to as an evanescent field and any objects that come to within a wavelength or so of the glass/air interface are capable of interacting with the light confined within the waveguide.

When a finger or another object is brought into contact with the surface, the boundary conditions experienced by the light on this surface are changed and total internal reflection is frustrated. Specifically, the regions in contact have a different refractive index to that of air and one which is much closer to that of the refractive index of the glass/plastic plate. The result of this change in boundary conditions is that the condition for total internal reflection is changed and some light is transmitted in the contact regions. If the contacting object also scatters light, then the light scattered by the contact regions can be imaged using a camera or other imaging device. This technique produces images that quite clearly discriminate between regions of contact and non-contact and can therefore be used to image the ridge pattern of fingerprints. The technique has also been used successfully to image the contact regions between shoes and surfaces in forensic footwear imaging applications [11] and in other areas including multi-touch sensing applications [12], clinical imaging [13–15], measuring the gait of animals [16] and insects [17–19] as well as performing fluorescence [20] and scanning near field optical [21] microscopy measurements.

In the present study we demonstrate that the technique can also be used to image latent fingerprints that have been obtained from a crime scene. Fingerprints that have been developed using a powder and lifted using a transparent tape or gel lifter can be placed in contact with the surface of the waveguide and imaged. The regions of the fingerprint that are coated with powder scatter light at the interface in much the same way as a contacting finger would. This scattered light can then be imaged to obtain a digital image of the print.

Although the evanescent field and capacitive techniques described above are well described in the literature [1–9], the designs associated with practical devices can be quite expensive. In this manuscript we describe an inexpensive evanescent wave device for acquiring fingerprints that uses a webcam to image the contact regions between a finger and an acrylic polymer disk illuminated by a strip of LEDs. We also briefly describe open source software for acquiring images of the fingerprints that was written in the Python programming language – a copy of which is made available for use as part of the supplementary material along with a compiled executable file. Instructions describing how to build a simple device are also provided in supplementary information.

2. Materials and methods

Fig. 1(a) shows a schematic diagram of the fingerprint imaging device used in this work. It consisted of a waveguide optical element on which a person can place their finger. A low-cost, high definition (HD) USB webcam with 1290 × 1080 pixel resolution was placed beneath the waveguide at a distance of ~10 mm and used to acquire images of the fingerprint contact regions with a resolution of 610 dpi using software written in the Python programming language (see Supplementary information, Figs. S1 and S2). The resolution was checked by placing a square grid on top of the waveguide element and measuring the number of pixels per inch in the images acquired by the webcam. Higher resolution images could have easily been achieved by using a more expensive camera. However, this resolution is comparable to that used in UK police fingerprint bureaus when scanning fingerprint images from samples taken using ink and paper based methods.

The waveguide optical element used in FTIR illumination is made from a single disk of acrylic (Perspex) polymer that is 50 mm in diameter and 6 mm thick. Illumination of the waveguide element was achieved by placing USB powered ultrabright white LED strip lights around the roughened edge of the acrylic polymer disk as shown in Fig. 1(b). The LED strips were mounted on the inside of a removable lid (see Fig. 1(c) and (d)). This lid served to secure the LED strip in place and was designed to mask part of the flat surfaces of the disk to prevent ambient light from entering the waveguide at the edges. The masked regions of the two largest faces of the disk were assembled in such a way that light from the LEDs which subtended an angle of incidence less than the critical angle required for total internal reflection was prevented from escaping the waveguide (see Fig. 1(b)–(d)). As a result, only light with an angle of incidence greater than θ_c was incident on the surface and was confined within the waveguide as a

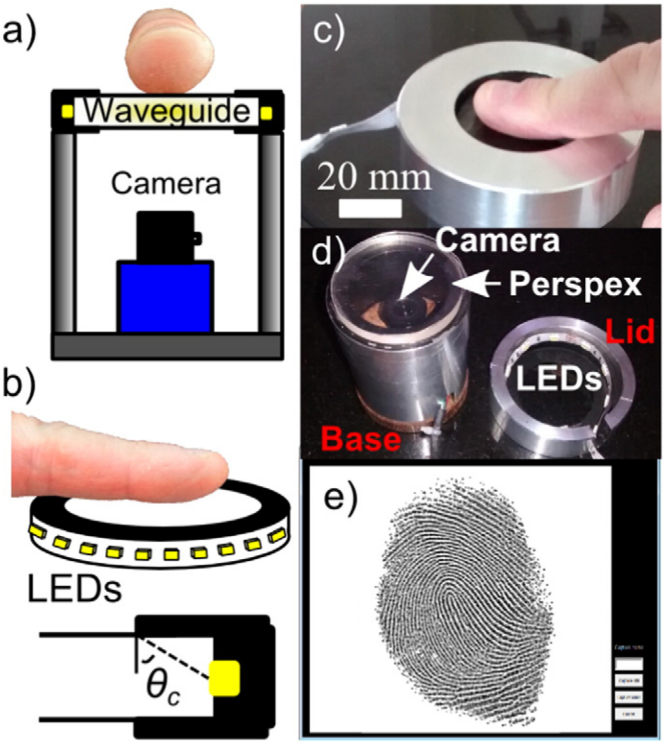

Fig. 1. Waveguide imaging device for the collection of elimination fingerprints. Panel a) shows a schematic diagram of the device. Panel b) illustrates how the LEDS are wound around the outside of the acrylic polymer disk and shows how the flat surfaces of the disk are masked to ensure that light which is incident on the surface at angles less than θ_c is prevented from escaping. Panels c) and d) show photographs of the device used in this study and panel e) shows a screenshot of a fingerprint that was obtained using the Python software.