Non-destructive Identification Document Inspection with Swept-source Optical Coherence Tomography Imaging

Manuel J. Marques[1,*], **Robert Green**[2], **Roberto King**[3], **Simon Clement**[3], **Peter Hallett**[3], **and Adrian Podoleanu**[1]

[1] *Applied Optics Group, School of Physical Sciences, Division of Natural Sciences, University of Kent, Canterbury CT2 7NH, United Kingdom.*
[2] *Forensics Research Group, School of Physical Sciences, Division of Natural Sciences, University of Kent, Canterbury CT2 7NH, United Kingdom.*
[3] *Foster and Freeman Ltd, Vale Park, 2 Vale Link, Evesham WR11 1TD, United Kingdom.*
* M.J.Marques@kent.ac.uk

Abstract: We analyze identification documents using optical coherence tomography imaging. Owing to its sub-surface imaging capabilities, we established its usefulness for quantitative visualization of embedded security features in these documents, increasing the accuracy in forgery detection.

The identification of individuals, especially at international border crossings, has always been an issue that authorities must contend with. In particular, the ability to distinguish legitimate from counterfeit identification documents, and to do so quickly and with high sensitivity and selectivity are recurring challenges. Experts within law enforcement and border security cite passport fraud as the greatest threat to global security [1];

While significant advances have been made to ensure that these documents are not easily forged or altered, it is important that we stay one step ahead of the criminals and forgers. Hence, national governments are regularly refining production methods to add levels of security. The manufacturing of these documents has become ever more sophisticated, with a range of security features making counterfeiting ever more difficult. As the design of these documents becomes ever more complex, the greater the challenges in detecting forgeries becomes, and consequently an increased need for more complex forensic technologies to uncover such counterfeits.

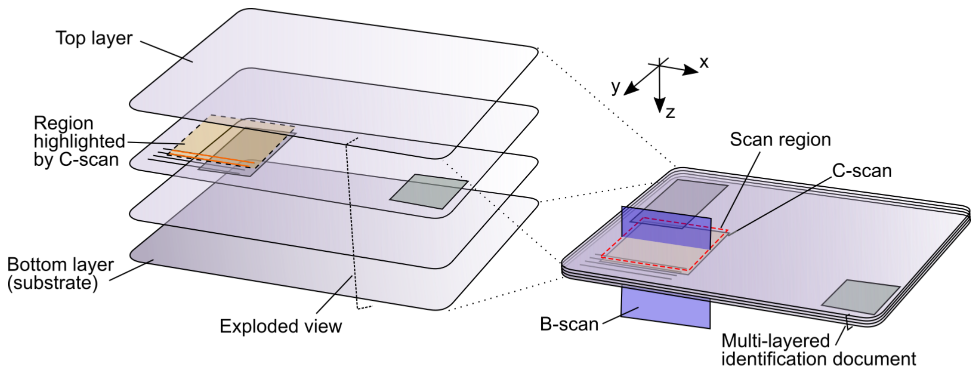

Fig. 1. Anatomy of a multi-layered identification document, with the exploded view (left) showcasing the various layers containing different security features. Adapted from Marques *et al.* [2].

Since the launch of the machine-readable passports, circa 1980s, the manufacture and design of identification documents have gone through several iterations. The latest generation of identification documents are manufactured by fusing together several semi-transparent layers of varying thicknesses, each of them containing different security features and/or information, producing a final, single-page, document, as schematically represented in Fig. 1. In this manner, the security features are distributed not just in different superficial areas of the document, but also located along several sub-superficial depths. Even so, the threats posed by fraudsters in 2020 are both widespread and serious [3]

Although, undoubtedly more secure than their predecessors, the latest generation of identity documents manufactured using polycarbonate layers remain susceptible to counterfeiting. Amongst the tactics used by fraudsters are the copying of paper or polycarbonate, reproducing the documents using sophisticated computer technology,

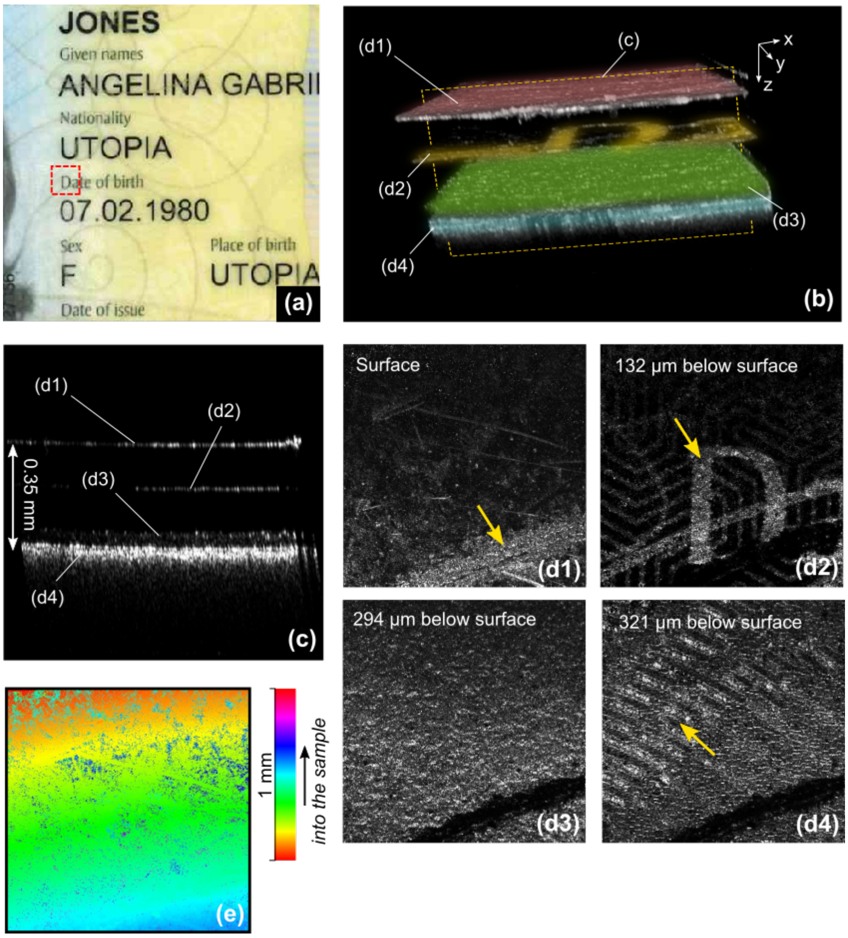

Fig. 2. An example volume ($2 \times 2 \times 0.35\,\mathrm{mm}^3$) from the specimen passport (adapted from [2]). (a) is a close-up of the color photograph of the document, with the square showing the approximate location where the OCT volume was acquired; (b) shows a 3-D render of the OCT volume; (c) the B-scan cut indicated by the dashed yellow region in (b); (d1)-(d4) show several C-scans at different depths into the document; (e) shows the color-coded surface map used to compute the flattened (x, y) mask distribution.

reproducing hologram images and re-laminating. Any of these tactics will affect the inner structure of the document, showing the importance of its sub-surface characterization.

Sub-surface imaging would address several points: (i) by assessing the depths at which each layer is placed, and comparing their depth values against a 'ground truth' (supplied by the manufacturer), we would be able to assess whether tampering or forgery has occurred; (ii) if there is evidence of the latter, one might be able to retrieve evidence from the document itself (for instance, fingermarks embedded into the laminates); (iii) aid in quality control processes employed by the manufacturers of identification documents themselves.

One technique which shows significant potential for sub-surface characterization of documents is optical coherence tomography (OCT). Since its debut in 1991 [4] , OCT imaging has been widely used in the medical and biomedical fields, recognized as transforming the field of clinical ophthalmology [5]. This technique [6] relies on the principle of low-coherence interferometry to depth profile scattering samples, with a resolution of tens of microns and over a range of a few millimeters (sample-dependent).

In this presentation, we will present the results stemming from applying OCT imaging specifically to a structural assessment of the latest-generation of identification documents, such as passports and national ID cards. These documents possess sub-surface security features. OCT will be able to accurately reveal the separate polycarbonate layers for both passports and identity cards in real-time and non-destructively. Our research would point towards the benefits of OCT in the detection of sophisticated counterfeits and also by the introduction of OCT-readable features during the manufacture of identity documents.

An example of a virtual "dissection" of a specimen passport (supplied by Trüb AG (Switzerland)) is shown in Fig. 2. The imaging system employed in this study, which has been described elsewhere [7], employs a 1060 nm swept-source (Axsun) with a tuning range of 100 nm and a sweep rate of 100 kHz, allowing an axial resolution of $\sim 10\,\mu m$. This, coupled with a 2-D galvo-scanner-based imaging system ensuring a lateral resolution of $15\,\mu m$, allows a dense volume ($500 \times 500 \times 500$ pixels, covering up to $12 \times 12 \times 6\,mm^3$) in approximately 5 seconds.

Interferometric data generated by the system is processed using Complex Master-Slave OCT (CMS-OCT) [8], which due to its operating principle, allows direct C-scan image rendering, which is particularly useful when imaging planar samples containing different features placed at each constant depth plane, effectively the structure of most modern identity documents. Unlike conventional OCT processing methods which demodulate the acquired spectra using a Fourier transform, CMS-OCT relies on a comparison operation between the spectra arriving from the sample and a set of pre-generated/captured spectra (denoted "masks" in our previous publications) representing all possible distinct axial positions that the system is capable of imaging [9]. This allows CMS-OCT to virtually "flatten" curved documents by synthesizing a x, y distribution of masks which follow the top surface of the document (as shown in Fig. 2 (e)), which not only compensates for the inherent curvature of the imaged region, but also has the potential to reduce strong specular back-reflections from normal incidence, as the document can be slightly tilted in relation to the objective and still have all of its layers correctly resolved.

The results presented demonstrate that OCT can perform quantitative, non-destructive, high- resolution subsurface analysis of multi-layered identification documents. The imaging throughput is also quite high, with a high-density volume (500x500 lateral points) typically taking less than 10 seconds to acquire, and with the CMS-OCT procedure allowing for direct visualisation of C-scan images, it is possible to obtain immediate virtual slices of the document under study. Inherently a non-destructive imaging method, OCT can preserve evidence which may be useful for a criminal investigation, or, on the other hand, prevent destruction of legitimate documents which may have been previously flagged as suspected forgeries.

In conclusion, manufacturers and issuing authorities are constantly playing catch-up from criminals involved in forgery of documents. We believe that the technology presented in this study can be used by multiple stakeholders in the field, namely the forensic scientists working to validate suspected forged documents in back-of-the-house laboratories, and the document manufacturers, having access to a non-destructive manner of quality control.

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