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On Interoperability of Security Document Reading Devices

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***Abstract*—For travel document inspection systems in automated border control an inherent topic of interest is harmonization across devices ensuring vendor-independence at retained high security levels. This requires the development of (1) standards at hardware level; (2) unified approaches with regards to best-practice normalization methods in order to facilitate the comparison of passport images acquired using different readers; and (3) selection of robust optical security features to be investigated. This paper presents several normalization techniques for travel documents involving shading correction and colour calibration and evaluates its impact in cross-sensor setup using 9 different document readers. Results indicate a much better representation in terms of both well-known image metrics PSNR and SSIM facilitating harmonization of optical document inspection.**

I. Introduction

First-line border inspection relies on reliable document authentication. Passports are standardized [1] security documents with mandatory and optional specifications of design, security mechanisms, biometric/data storage and public key infrastructure to be considered by issuing authorities. However, for optical document authentication every country relies on specific implementations of security features and their appearance and representation in automated document inspection systems is neither entirely specified nor documented. In [2] we identified various effects influencing image quality of scanned security documents focusing on ageing effects due to wear and tear. An analysis of variance test indicated instability of ultraviolet (UV) security features over time, whereas features in visible (VIS) and near-infrared (NIR) retained their representation more robustly (with regards to intensity, but not for contrast).

Recent document challenges by Frontex [3], [4] have confirmed the need for more standardization with regards to unified vendor-independent document template databases. In a related document reader challenge comparing optical characteristics of inspection systems employed for automated border crossing [5] we identified high variability of optical resolution, contrast, and noise across the range of tested reading devices. Figure 1 illustrates this variability based on a cropout of a security document, motivating the assumption that appropriate calibration steps are crucial for the interoperability and modular use of inspection systems, especially with respect to a central vendor-independent database solution.

The contributions of this paper are as follows: (1) Focusing on the problem of harmonization of document inspection systems we present and investigate the positive impact of colour calibration and flat field correction on comparison of security features in travel documents facilitating cross-sensor compatibility; and (2) augmenting previous work [1], [2] we further present an exhaustive list of security features with a potential for automated document checks. Results are validated on a collected test database confirming the soundness of the proposed approach.

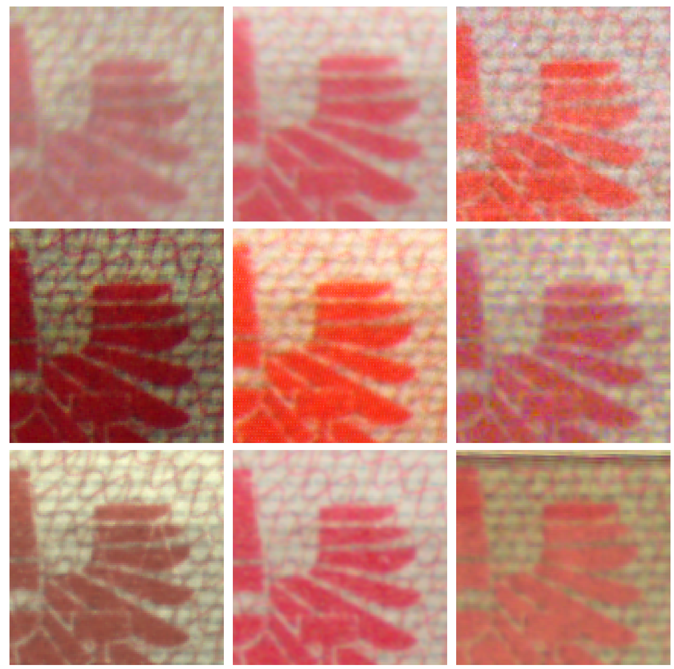


Fig. 1: Visible data page security print (eagle patch) samples for different passport readers.

The remainder of this paper is organized as follows: Section II presents related work in optical security features, visualizing challenges and identifying prospective security features for next-generation inspection systems. Section III presents proposed methods for increased interoperability of inspection systems, followed by an experimental validation of suggested methods using Peak Signal to Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM) [6] and ΔE analysis in Section IV. Results are summarised and an outlook into future developments in document inspections is drawn in Section V.

II. Optical Security Features

Security features in passports were traditionally designed to be inspected by humans. With long deployment cycles of travel documents it is not surprising, that support for automated optical inspection is still in its infancy. Optical security is just one of several independent characteristics to be considered for authentication of a genuine document, yet remains extremely important, because sole electronic security is not bulletproof.

There are not many publications on optical document inspection. Recently, optically variable devices (OVDs) - these are images based on diffractive structures exhibiting various effects, such as colour changes - have attracted attention in the literature: Hartl et al. [7] report on efficient hologram verification using mobile phones, Stolc et al. [8] inspect diffractive optically variable image devices (DOVIDs) via photometric methods as holographic security features detecting counterfeits more reliably and [2] reports on ageing issues of UV security features. DOVIDs vary when viewed at different angles and are common security features not only in travel documents but also, e.g., banknotes. While being a prospective future security feature for automated verification relatively hard to counterfeit, the sensing process comes with a series of challenges, and none of the tested readers currently provides a normalized image of sensed holographic features. In principle by subtracting glare-free with images without glare removal a representation of OVDs can be obtained, but their intrinsic ability to change appearance over different angles of incident illumination is currently neither supported nor standardized across different document readers. So far, there is no exhaustive list of security features identifying hardware requirements.

In the following section we provide an overview of most state-of-the-art optical security features recommended for use in modern MRTDs by ICAO in [1]. In Table I, security features are organized in groups by domain of integration and evaluated with respect to their applicability to the existing reader technology and suitability for the automated document check. We considered the following four applicability categories:

- Implemented / partly implemented (green / yellow): security features that are already implemented in most or at least some document readers. Note, that this category consists mostly of security features that do not rely on any special hardware technologies (i.e., technologies that are not yet fully incorporated in existing readers). Naturally quality of implementations may vary, but in principle all these features are handled in some way.
- Disabled (red): security features that cannot be implemented in existing document readers due to their basic principle. In most cases, the reason is that all state-of-the-art readers are limited to a single page operation and ultimately lack a transmission sensor, back-illumination, or double-sided camera system.
- Future (blue): security features that have potential of being implemented in the future document readers provided some additional hardware components. Most of these security features rely either on multiple dark-field illuminations or on a high-resolution camera. Note that none of the listed security features is tightly linked to the bright-field illumination.

TABLE I: List of optical security features with a potential for the automated document check.

Cat	Security feature	VIS	UV	IR	RF	Hardware	Applicability
Paper	Controlled UV response		✓				Implemented
	Two-tone watermark	✓		✓		Transmission	Disabled
	Registered watermark	✓		✓		Transmission	Disabled
	Cylinder mould watermark	✓		✓		Transmission	Disabled
	Invisible fluorescent fibres		✓	✓			Implemented
	Visible (fluorescent) fibres	✓	✓				Implemented
	Security thread	✓	✓			Transmission	Disabled
	Watermark	✓		✓		Transmission	Disabled
	Laser-perforated	✓		✓		Transmission	Disabled
	Die cut security pattern	✓		✓		Transmission	Disabled
Substrate	Optically dull material		✓				Implemented
	Optically variable features	✓		✓		Multi-dark-field	Partly impl.
	Window/transparent feat.	✓		✓		Transmission	Disabled
	Tactile feature	✓		✓		Multi-dark-field	Future
	Laser-perforated feature	✓		✓		Transmission	Disabled
	Surface characteristics	✓		✓		Coaxial illu.	Partly impl.
Background and text print	Two-colour guilloche BG	✓	✓	✓		High-res cam	Future
	Rainbow printing	✓	✓			High-res cam	Future
	Microprinted text	✓	✓	✓		High-res cam	Future
	Intaglio print	✓	✓	✓		Multi-dark-field	Future
	Latent image	✓				High-res cam	Future
	Anti-scan pattern	✓				High-res cam	Future
	Duplex security pattern	✓		✓		High-res cam	Future
	Relief design feature	✓		✓		Multi-dark-field	Future
	Front-to-back register f.	✓		✓		Transmission	Disabled
	Tactile feature	✓		✓		Multi-dark-field	Future
	Unique font(s)	✓	✓	✓			Implemented
	Laser-perforated doc.nr.	✓		✓		Transmission	Disabled
Ink	UV florescent ink		✓				Implemented
	Optically var. ink	✓		✓		Multi-dark-field	Partly impl.
	Metallic ink	✓		✓		Multi-dark-field	Future
	Penetrating numb. ink	✓		✓		Transmission	Disabled
	Metameric inks	✓	✓	✓		Optical filters	Partly impl.
	Infrared dropout ink	✓		✓			Implemented
	Infrared absorbent ink			✓			Implemented
	Phosphorescent ink		✓	✓			Future
	Invisible ink		✓	✓			Implemented
	Anti-stokes ink	✓				Special illum.	Future
Copy prot.	Optically variable feat.	✓		✓		Multi-dark-field	Party impl.
	OVD intaglio overprint	✓		✓		Multi-dark-field	Future
	Laser-perforation	✓		✓		Transmission	Disabled
	Anti-scan pattern	✓				High-res cam	Future
Alteration	dev. overlapping portrait	✓					Party impl.
	Heat-sealed laminate	✓					Future
	Steganographic feature	✓	✓	✓			Party impl.
	Additional portrait	✓	✓	✓	✓		Partly impl.
Misc	MRZ digit check	✓		✓			Implemented
	LED-in-plastic security	✓	✓	✓	✓	RF-pow. LED	Future
	Display readout	✓	✓	✓	✓	RF-pow. display	Future
	Retroreflective foil	✓				Coaxial illu.	Future
	Barcodes	✓	✓	✓			Implemented

As an example of potential security features, [2] gives an overview of regions for optical verification in visible light. Fig. 1 illustrates an area with high-resolution security print obtained by different readers, highlighting the subtle changes in colour, noise and intensity, clearly pointing out the challenges of security pattern authentication (the Austrian e-passport is

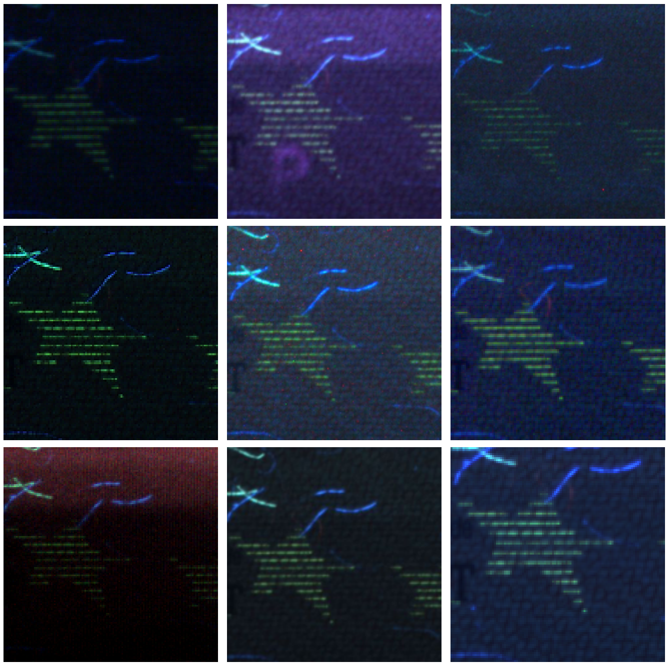
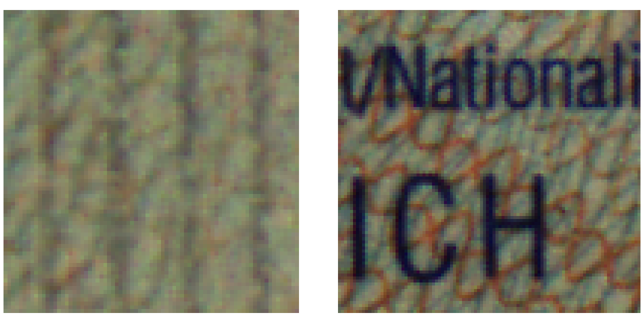


Fig. 2: Sample patches with UV security fibres for different passport readers.



Microprinted text   Standard security print

Fig. 3: Further examples of security features in VIS.

used) for different passport readers. An even more pronounced variability (and weaker robustness [2]) can be observed for UV features, see Fig. 2. Systems have to be able to cope with this high variability for genuine documents and at the same time be sensitive for any counterfeits. These examples are ideal motivators for the calibration methods introduced in this paper. Fig. 3 shows that microprinted text as a security feature is hardly sensible with provided optical resolution.

III. Document Inspection Interoperability

Nowadays various automated border control (ABC) systems utilize different technologies of travel document authentication. In the effort to create a harmonized, modular approach for ABC gates, the research project FastPass hosting this work aims to study and suggest methods for passport reader-independent processing of all travel documents. One part of that is creating guidelines for the interoperability of different document readers by developing a calibration procedure that maps the output into a common operating space (colour, geometry, etc.).

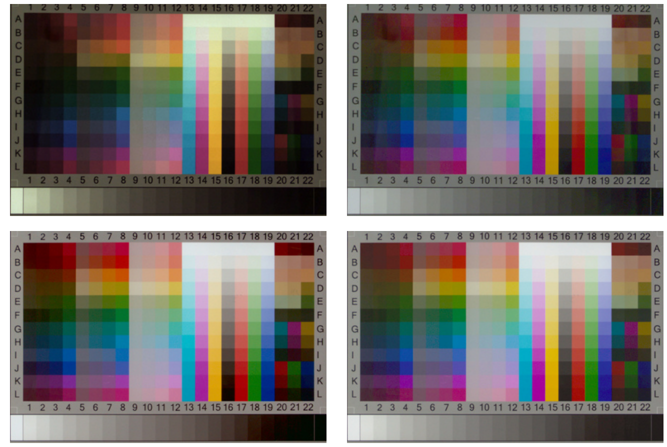
Eventually, a key observation of the study in [5] was the largely neglected employment of colour calibration across devices. This paper investigates the questions: "How good is the colour calibration of the devices?", "How can all the readers be mapped into one colour space (with reasonable error tolerance)?" and "How significant is the impact of colour calibration on inspection of security features?". As a solution to the normalisation problem we employ and propose colour correction, after flat field correction, using the IT8 colour target to get ICC profiles and be able to measure colour deviation [9]. When inspecting optical security patterns across devices, device-independent calibration is a useful step in avoiding the introduction of bias at the comparison stage. The CIE has standardized colourimetric systems recommending 3D colour spaces supporting measures of perceptual difference (ΔE). Reliable colour measurement is supported through projections into such joint colour spaces via characterization of input devices through colour profiles suggested by the ICC. Note, readers were considered as black boxes in the test and results might be affected by device-specific preprocessing steps. It was decided to treat all readers the same way and use the default settings of each reader, since only a single reader featured access to raw sensor data, explicit tuning of camera parameters and activating/deactivating processing stages.

A. Colour Calibration (CC)

We suggest an off-line calibration procedure calibrating all document inspection readers with regards to a common device-independent colour space, for which we propose CIE XYZ (modelling tristimulus values) to be applied. The calibration phase is based on the IT8.7/8-1993 colour target printed on a Kodak photo semi-glossy paper. This colour target was acquired with all the readers at their default settings, considering them as black box processing systems. In order to enable accurate colour calibration, flat field correction (FFC) was applied to the acquired images (and also as preprocessing step on all subsequent passport acquisitions). The calibration phase consists of the following steps:

1) **Acquisition of the colour chart** for estimation of device-specific RGB responses. Note, that the IT8 colour target is for use with VIS range only and indeed we employed it for this spectrum. However, for UV-A and NIR calibration similar methods could be applied.
2) **Applying FFC** to account for basic radiometric calibration and for internal glare. A matte target was used to measure the white frame. Due to inability to switch off the illumination on the readers, the dark frame (offset) was not measured.
3) **Post-processing**: In the post-processing phase, the images were cleaned-up from few-pixel-sized defects caused by for example dead pixels, dirt, or reflections from semi-glossy target. Then, in case of one reader (for which the sensor linearity was confirmed) pixel

Fig. 4: Before (left) vs. after (right) colour correction of specimen passport for different readers (A to I).



Before CC After CC

Fig. 5: Before vs. after colour correction of IT8 colour target for two different readers (top row: A and bottom row: D).

Before FFC After FFC

Fig. 6: Unprocessed vs. FFC-corrected IR sample of specimen passport illustrating the positive effect of FFC (for reader I).

intensities were linearly scaled to reach up to 90% of the dynamic rage.

4) **Creating ICC profile**: Finally, the ICC profile is created projecting device-dependent samples into the joint CIE XYZ profile connection colour space via look-up tables. The profile describes how the device perceives colour. The software Argyll (version 1.8.0) was employed for this task.

The difference between before and after colour calibration is illustrated in Fig. 4 on a specimen passport. Notice, that Devices H and F produce visible glare that may prevent proper calibration in affected areas. This illustrates the importance of the anti-glare feature provided by several devices for accurate colour processing. Figure 5 depicts the colour target before and after the colour calibration phase clearly visualizing the positive effect for two inputs from different devices.

B. Shading Correction (FFC)

Shading correction, also referred to as flat-field correction (FFC), is a basic radiometric calibration which aims to remove the intensity variation caused by different sensitivity of individual sensor detectors and/or by distortions in the optical path. For that, an acquisition of an uniform target needs to be performed both with and without illumination turned on. These are referred to as dark D and white F frames, respectively. In case of sensor with non-linear response, multiple white frames

TABLE II: Tested document readers.

	3M AT9000 MK2	**ARH** Combo Smart	**ARH** PRMc	**Bundes-druckerei** VE 600	**DESKO** ICON Gen I	**DESKO** PENTA Gen 4.0	**Regula** 7024m.111	**Regula** 7034.111	**Suprema** RealPass-V
									
Resolution (DPI)	400	500	500	400	500	500	380	400	420
Area (mm)	125x88	125x88	130x98	128x96	131x94	131x94	128x88	128x88	130x90
Anti-Gloss	yes	yes	yes	yes	no	no	yes	yes	no
Software	3M SDK	ARH SDK	ARH SDK	Visocore	ePassApi	ePassApi	RegulaSDK	RegulaSDK	RealPassSDK
Version	3.3.2.7	2.1.5-25	2.1.5-25	1.8.1	1.0.9	1.0.9	4.9.1	4.9.1	1.9.7
Visible, IR, UV	yes	yes	yes	yes	yes	yes	yes	yes	yes

with different exposure times needs to be acquired. Here we assume sensor linearity. The corrected image C is obtained from the raw image R in the following way: $C = (R - D) \cdot G$, where gain $G = \mu_{(F-D)}/(F - D)$. Note, that dark frames are not possible with the tested readers, therefore gain-only FFC is employed. The procedure therefore consists of acquisition of white frame, computing gain, and application of FFC. See Fig. 6 for an example of FFC applied to an IR acquisition.

IV. Experimental Analysis

At the heart of the contribution to existing work, this paper evaluates the impact of shading and colour calibration on document security features, in particular assessing statistical significance and impact on comparison metrics. In contrast to traditional intra-sensor inspection, cross-sensor setups are investigated, highlighting interoperability.

A. Setup

Experiments are validated on AIT's FastPass document reader challenge database [5] of passport's visible data pages, gathered with 9 readers (see Table II) and reported in anonymous form (readers A-I). In order to compare individual documents and patches thereof, registration (using image landmarks) is essential. We employed a registration algorithm using invariant key point detection and estimating a rigid transformation for this task, after re-scaling images to 500 DPI resolution and cropping images to avoid boundary artefacts.

B. Colour Accuracy

Colour accuracy in the visible range (VIS) was measured using the ΔE (deltaE) metric [10] which measures the perceptual difference / distance between two colours. The value ΔE is computed between the colour calibrated acquisitions of the colour chart and laboratory measurements provided by the vendor of the colour target. Results, according to CIE 1976 formula, are presented in Fig. 7. As Devices H and F are affected by substantial amount of glare as well as image noise, this translates into high maximal ΔE. Devices E and B, despite having the anti-glare feature, have relatively high maximum ΔE as well. This is caused by relatively high image noise. Overall, the obtained results show that presence

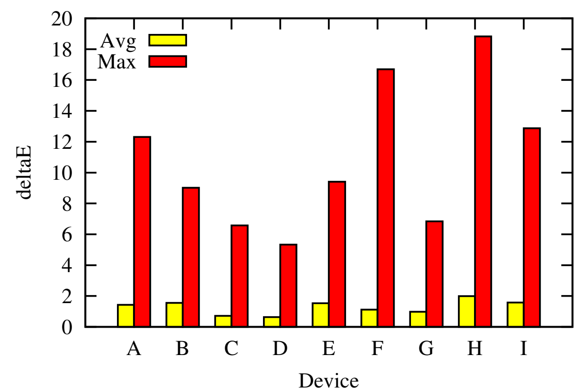


Fig. 7: Colour accuracy after colour calibration (CC).

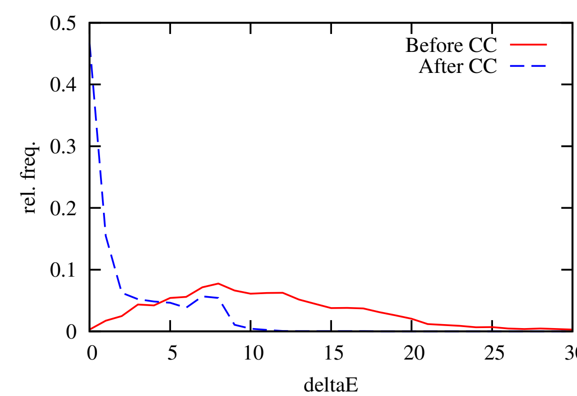


Fig. 8: Before vs. after colour calibration (CC).

of glare and image noise has a significant impact on colour accuracy. Nevertheless, for the tested readers the average ΔE is relatively small, confirming the usefulness of the suggested calibration step and enabling colour pattern matching for inspection of optical security features, which is assessed in the next section.

Further, we conducted a precision evaluation testing the hypothesis that before colour calibration, readers produce more different results for the same input than after colour calibration. For both "before" and "after" groups we selected the best mode of operation for a particular reader – enabling glare suppression if available. Then, for each unique pair of readers we measured ΔE (according to CIE 2000 formula) between the corresponding image patches of the IT8 target acquired by those two readers. Mean μ and standard deviations σ were clearly improved (before: $\mu = 11.629, \sigma = 6.228$, after: $\mu = 2.587, \sigma = 2.829$) for all the gathered ΔE measures. Results show that colour calibration helps a lot to get similar output for a similar input, see Fig. 8.

C. Impact on Document Inspection

In order to estimate the positive impact of calibration on optical document inspection in the absence of ground truth information, we assess pairwise image similarities using the PSNR / SSIM metrics for entire passport images and patches in a cross-sensor setup: The Peak Signal to Noise Ratio (PSNR) is a widely used and fast metric for comparing degradation of an $m \times n$ image O into I (e.g. in a compression-based context) based on the mean squared error $\mathrm{MSE} = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=i}^{n}(I(i,j) - O(i,j))^2$. It is computed for 8-bit images as:

$$\mathrm{PSNR} = 20\log_{10}\Big(\frac{2^8-1}{\sqrt{\mathrm{MSE}}}\Big). \quad (1)$$

The Structural Similarity Index Measure (SSIM) [6] is an image metric based on separate scores (luminance, contrast and structural) that are computed globally for the impaired I and original image O transforming the image first using a 11×11 Gaussian filter (convolution) and computing the scores as follows:

$$\mathrm{SSIM}(I,O) = \frac{(2\mu_I\mu_O + c_1)(2\sigma_{IO} + c_2)}{(\mu_I^2 + \mu_O^2 + c_1)(\sigma_I^2 + \sigma_O^2 + c_2)}, \quad (2)$$

with μ_I denoting the average pixel value of I, σ_I^2 being the variance of I and σ_{IO} being the covariance of I and O, and $c_1 = (k_1 M)^2$ and $c_2 = (k_2 M)^2$, with $k_1 = 0.01$ and $k_2 = 0.03$, variables used to stabilize the division.

We employed two different metrics to simulate the impact on different comparison tools. This way we simulate how devices would operate when applying device-specific calibration only and relying on vendor-specific document template databases. As typically individual patches are compared using non-disclosed comparison methods, we select two representative image metrics, which on one hand assess visual similarity of patches, on the other hand they have successfully been applied to binary classification tasks in the past: e.g., Hofbauer et al. [11] applied general purpose similarity metrics for biometric comparisons (comparing iris codes, which contain information to uniquely identify a person).

In a first experiment we tested the impact of flat field correction. For this test we used the specimen passport (Utopia-"Musterpass") as printed by the Austrian State Printing House (OeSD) for showcasing state-of-the-art security features as a neutral reference document, see Fig. 4. While FFC is usually employed as a standard form of shading correction, we observed an overlap of confidence intervals for both PSNR (19.37 vs. 19.45 dB) and SSIM (0.876 vs. 0.886), higher values indicating better quality in both cases, when comparing the FFC-corrected with the uncalibrated passport versions and therefore could not observe a statistically significant improvement, see Table III.

The result changes drastically for our second experiment when employing the proposed colour calibration on the FFC-corrected samples. Now, image quality is clearly enhanced for PSNR (23.91 dB) and SSIM (0.956). An investigation of statistical significance inspecting the confidence intervals $[\mu - e, \mu + e]$ yielded that intervals do not overlap hence means are significantly different and proving that the employed calibration step is indeed very useful for harmonized document inspection.

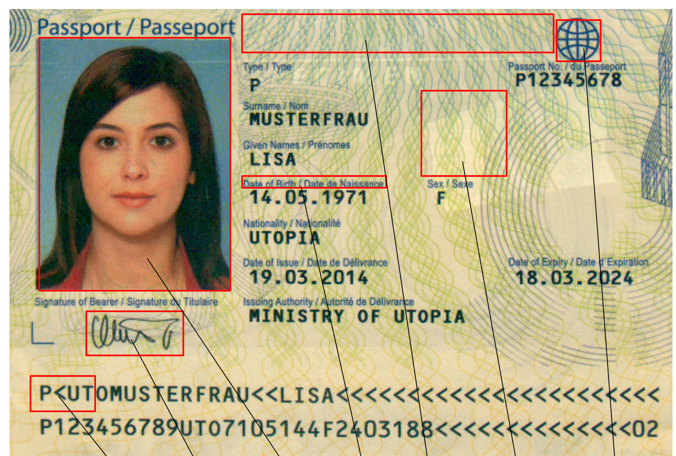
TABLE III: Musterpass VIS colour calibration vs. flat field correction significance (95% confidence interval $[\mu - e, \mu + e]$).

	PSNR (dB)			**SSIM**		
	Mean μ	StdDev σ	AbsErr e	Mean μ	StdDev σ	AbsErr e
CC and FFC	**23.91**	3.04	0.992	**0.956**	0.020	0.006
FFC only	19.37	2.44	0.798	0.876	0.056	0.018
No calib.	19.45	2.60	0.849	0.886	0.050	0.016

TABLE IV: Musterpass VIS colour calibration impact on document similarity (average for all cross-sensor combination).

PSNR (dB)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Before CC	18.28	19.66	19.12	20.96	19.89	18.25	20.73	18.71	18.71
After CC	22.07	25.51	20.84	25.98	23.70	23.43	25.86	21.86	25.91
Improvement	21%	30%	9%	24%	19%	28%	25%	17%	38%

SSIM	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Before CC	0.855	0.892	0.873	0.901	0.900	0.805	0.909	0.869	0.884
After CC	0.940	0.958	0.944	0.971	0.954	0.952	0.969	0.950	0.969
Improvement	10%	7%	8%	8%	6%	18%	7%	9%	10%



	MRZ	**Signature**	**Photo**	**Font**	**Top-BG**	**BG/OVD**	**Emblem**
ΔPSNR	6.92	5.76	0.76	5.59	5.73	6.49	3.82
ΔSSIM	0.145	0.102	0.003	0.085	0.141	0.181	0.067

Fig. 9: Colour calibration impact on Musterpass patches.

When further elaborating for which sensors the difference becomes important we notice, that indeed all sensors (see Table IV) report enhanced comparison, i.e., positive impact through colour calibration for both image metrics PSNR and SSIM (on average +4.54 dB PSNR, +0.08 SSIM) when tested on the specimen passport. Solely for devices C and H improvements were minor for PSNR (presumably as their calibration is closer to the mean setting across devices), yet SSIM differences are quite pronounced, also likely to taking visual differences better into account.

In a final experiment we evaluated the calibration impact on different types of patches in the specimen passport, defining an MRZ crop-out, personalized signature and photograph patches, and font, top-background, background with occluding OVD and emblem regions. Interestingly, for almost all patch regions the impact was very visible, except the face photograph, see Figure 9 for details.

V. Conclusion and Discussion

Colour calibration is an important preprocessing step in document inspection, which is essential for a successful interoperability between readers using different hardware components or implementing different acquisition principles. Through experimentation on 9 different document readers this paper verified that performing colour calibration enhanced PSNRs by on average 4.54 dB PSNR and 0.08 SSIM (for the specimen passport), which is shown to be statistically significant, while FFC based calibration surprisingly did not lead to an expected large improvement (possibly due to already existing flat field corrections in device-specific image processing). Patch-based analysis showed, that almost all patches could benefit of this calibration and overall ΔE values were below 2 after calibration, enabling the authentication of colour-specific security features.

Augmenting considerations in [5] we found, that even for devices with similar UV and IR illumination characteristics, device-specific image processing leads to pronounced quality differences in document images. Even more problematic, if specific calibration is only partly implemented, repeated calibration might introduce undesired artifacts, noise and reduced dynamic range, and therefore degraded results for a particular device. Ideally future standards specify calibrations enhancing overall interoperability and facilitating interoperability.

In the future, we intend to investigate document verification software from different vendors in order to find answers to the questions: “What optical security features are typically inspected by human border guards?” and “How accurate is document inspection for humans vs. machines?”. Besides reporting on technical specifications of individual readers, in the future it would be interesting to conduct further analysis of possible image defects (independent of readers) with the focus on potential implications with respect to document verification. Such effects may include: vignetting, photo-response non-uniformity, amp/sensor noise, hot/stuck pixels, demosaicing (Bayer/maze artefacts), and moiré.

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References

[1] ICAO, “Machine readable travel documents - machine readable passports,” Int’l Civil Aviation Organisation, Doc-9303, 7th Ed., 2015.

[2] S. Stolc, F. Daubner, and R. Huber-Mork, “Document aging effects and automated security document authentication,” in *Proc. IEEE Int’l Systems Conf. (SysCon)*, April 2015, pp. 347–352.

[3] M. Gariup and G. Soederlind, “Document fraud detection at the border: Preliminary observations on human and machine performance,” in *Proc. Europ. Intelligence and Security Informatics Conference (EISIC)*, Aug 2013, pp. 231–238.

[4] Frontex, “The document challenge II: Testing human and machine performance in detecting and classifying genuine and false travel documents,” Frontex R&D Unit, Report 2015-08-18, 2015.

[5] K. Valentin, P. Wild, S. Stolc, F. Daubner, and M. Clabian, “Benchmarking of security document readers for automated border control,” in *Proc. SPIE Security + Defence*, Edinburgh, UK, 2016, pp. 1–8, to appear.

[6] Z. Wang, A. Bovik, H. Sheikh, and E. Simoncelli, “Image quality assessment: from error visibility to structural similarity,” *IEEE Trans. on Image Proc.*, vol. 13, no. 4, pp. 600–612, Apr. 2004.

[7] A. Hartl, C. Arth, and D. Schmalstieg, “Ar-based hologram detection on security documents using a mobile phone,” in *Proc. International Symposium on Visual Computing (ISVC)*, Dec 2014, pp. 335–346.

[8] S. Stolc, D. Soukup, and R. Huber-Mork, “Invariant characterization of dovid security features using a photometric descriptor,” in *Proc. Int’l Conf. on Image Processing (ICIP)*, Sept 2015, pp. 3422–3426.

[9] R. Huber-Mörk, “Efficient local approximation of perceptual color differences for color inspection,” in *Image Processing: Machine Vision Applications V*, ser. Proc. SPIE, vol. 8300, Jan. 2012, p. 83000I.

[10] A. Valberg, *Light Vision Color*. Wiley, 2005, iSBN 9780470849026.

[11] H. Hofbauer, C. Rathgeb, A. Uhl, and P. Wild, “Iris recognition in image domain: Quality-metric based comparators,” in *Proc. Int’l Symposium on Visual Computing*, G. Bebis *et al.*, Eds. Springer, 2012, pp. 1–10.