Document aging effects and automated security document authentication

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***Abstract*—Image quality of scanned security documents is crucial to automated authentication systems such as an automated border control (ABC) gate. Due to natural aging effects as well as unavoidable processes such as wear&tear, abrasion, graffiti, or mechanical crumpling, security documents change their appearance within an inspection system. We study the influence of those effects w.r.t. the document age on the image quality delivered by a document reader incorporated in an ABC gate. Results are presented independent from a specific authentication device making use of a number of established image quality indicators.**

I. Introduction

Currently the status quo in the first line of document examination is a hybrid human-machine tandem that combines advantages of human skills with sensory capabilities and speed of document reading devices [1]. To ensure a seamless human-machine interaction it is essential to understand the limitations and shortcomings of the employed automated components. On the other hand, necessity of studying these aspects also originates from a general trend of favoring automated border control (ABC) systems all over the world. This trend is prompted by the ever increasing number of travelers crossing international borders and by the decreasing availability of personnel in public administration and police forces performing the task. The research presented in this paper has been conducted within a research project – FastPass, funded by the EU 7th framework programme. The aim of this project is to establish and demonstrate a harmonized, modular approach for ABC gates.

Automated document authentication based on optical properties includes reading and consistency checking of the machine readable zone (MRZ), checks of readability of the visible inspection zone (VIZ), verification of UV properties of the paper, optional comparison of data extracted from MRZ and VIZ, as well as pattern matching against templates stored in a document database [2], [3]. As there are no detailed guidelines how to perform these checks, especially the template matching part, document reader vendors develop their own proprietary algorithms for this purpose, which may deliver very different results compared with an expert's (human) opinion and have different sensitivity to external effects influencing the general appearance of a travel document [4].

One factor having strong impact on passport reading devices is the condition of the document itself. The physical condition of the document directly influences the quality of scanned images. During aging of a document there exist direct factors such as change of spectral properties of inks and paper, as well as indirect factors such as wear&tear, abrasion, graffiti, or mechanical crumpling. Despite these effects may have a severe impact on the general performance of ABC systems, authorities sometimes just recommend (but not demand) to carry out a regular system maintenance in order to mitigate the influence of such effects (see e.g. [3]). In this paper, we present a detailed study of mentioned effects w.r.t. the document age for various passport elements seen under different spectral channels based on real samples of genuine Austrian ePassports.

Another reason for having a detailed look at different aging effects, that influence the appearance of travel documents, is to map a natural variation in valid documents in circulation. This would yield a baseline for the acceptance ranges of ABC systems. This is particularly important for building models for the optical security document simulator for testing ABC systems we proposed in [5] as well as assessment of risks originating from the presentation attack on ABC systems described in [6].

This paper is organized as follows: In Section II, we introduce a document database used for analyzes conducted within this study. The statistical analysis of variation along with its results is provided in Section III. Section IV discusses aspects of document aging and provides statistical results in this direction. Conclusions are drawn and discussed in Section V.

II. Acquisition of document images

State-of-the-art document scanning devices perform a multi-spectral document verification in several ranges of electromagnetic radiation [7]–[9]. In accordance with the ICAO 9303 document [10], the inspection is typically performed in the following three spectral ranges: (i) visible (VIS, approx. 390 to 700 nm), (ii) near infrared (IR, approx. 870 to 950 nm) and (iii) ultraviolet (UV, approx. 365 nm). While in the visible and IR spectra the document is directly checked for specific responses in the same spectral range, in the UV channel the visible luminescence response to UV light is inspected instead.

We had at our disposal data-pages of 422 genuine Austrian ePassports with 10 year validity, with a maximum age of seven years. All these passports were acquired by the same state-of-the-art document reader at the resolution of 400 DPI. Currently this is a technology standard recommended by Frontex in their best practice technical guidelines for ABC systems [11].

The data was collected with the consent of passengers within a short operational period using an experimental ABC gate installed at the Vienna International Airport. For all these passports we applied a standard statistical analysis of variation in several regions of interest (ROIs). To allow for the ROI-based analyzes, all passports were first pre-registered to each other by means of a projective transform minimizing differences in non-personalized areas [12].

Fig. 1 shows averaged images as well as corresponding variations in the visible, IR and UV channels. The ROIs are overlaid on the respective images. In detail, the ROIs have the following characteristics (see Fig. 1a):

ROIs in the visible spectrum:

- VIS-1 – Object in red ink
- VIS-2 – Plain paper without print overlaid by hologram
- VIS-3 – Personalized machine-readable zone (MRZ) in black B900 ink
- VIS-4 – Pattern in yellow/red ink with gray microtext (appearing as fine lines in the images)
- VIS-5 – Non-personalized text in blue ink
- VIS-6 – Fine pattern in orange/black ink
- VIS-7 – Fine pattern in orange/black ink

ROIs in the infrared spectrum:

- IR-1 – Object in IR-reflective ink, with microtext background (gray lines)
- IR-2 – Plain paper without print overlaid by hologram
- IR-3 – Personalized MRZ in IR-black B900 ink
- IR-4 – Microtext in IR-absorbing ink (appearing as gray lines)
- IR-5 – Fine pattern in IR-reflective ink

ROIs in the ultraviolet spectrum:

- UV-1 – Plain UV-dull paper without print containing few UV-fluorescent security fibers
- UV-2 – Fine pattern in UV-dull ink containing many UV-fluorescent security fibers
- UV-3 – Object in UV-green ink (greenish star)
- UV-4 – Object in UV-blue ink (bright stripe on flag)
- UV-5 – Object in UV-red ink (red stripe on flag)

All 422 passports were used to calculate the overall color variation in each spectral channel shown in Fig. 1b.

III. Analysis of variation

In this section, we present results of a standard statistical analysis of variation (i.e., mean $\pm$ standard deviation) applied to all considered ROIs. For the sake of shortness, we restrict ourselves to those image quality indicators, where the most significant results were obtained. Specifically, each ROI is analyzed w.r.t. the mean intensity (Int) and overall contrast ($Cont$), expressed by the coefficient of variation, defined as follows:

$$Int = \mathrm{mean}(I), \quad (1)$$
$$Cont = \mathrm{std}(I) \;/\; \mathrm{mean}(I), \quad (2)$$

where $\mathrm{mean}(I)$ and $\mathrm{std}(I)$ stand for mean and standard deviation of intensities over the entire analyzed ROI, respectively. Regarding the intensity values, in the case of IR spectrum, the camera delivers directly single-channel data comprising IR intensities. It the case of visible and UV spectra, the intensity is derived from acquired RGB values according to the following formula:

$$I = 5/16\ R + 9/16\ G + 2/16\ B. \quad (3)$$

TABLE I summarizes quantitative results of the analysis of variation for all considered ROIs. Visual examples of several extreme cases detected in the entire database of 422 passports are shown in Fig. 3, 4, and 5. In the following, we comment on the most important observations one could make from the obtained results:

A. Effects in the visible spectrum

Visually the most prominent variation in intensity and contrast can be observed for the elements printed using the B900 ink, typically used for personalized elements such as the MRZ (e.g., see Fig. 3c). Additionally, the font thickness in the MRZ may also vary due to production differences, which can however be seen best in the IR spectrum (see see Fig. 4c). Nevertheless, these variations are not apparent in our quantitative results.

Looking at the standard deviations expressed in percents (i.e., $\pm$% columns), it is obvious that documents are in general most stable in the visible spectrum. There is just one ROI – VIS-2 – where the variability in contrast exceeds 10 %. However, this can partly be attributed to naturally variable rendering of overlaid hologram as well as dirt, which is mostly visible in unstructured areas such as VIS-2 (see Fig. 3b).

B. Effects in the IR spectrum

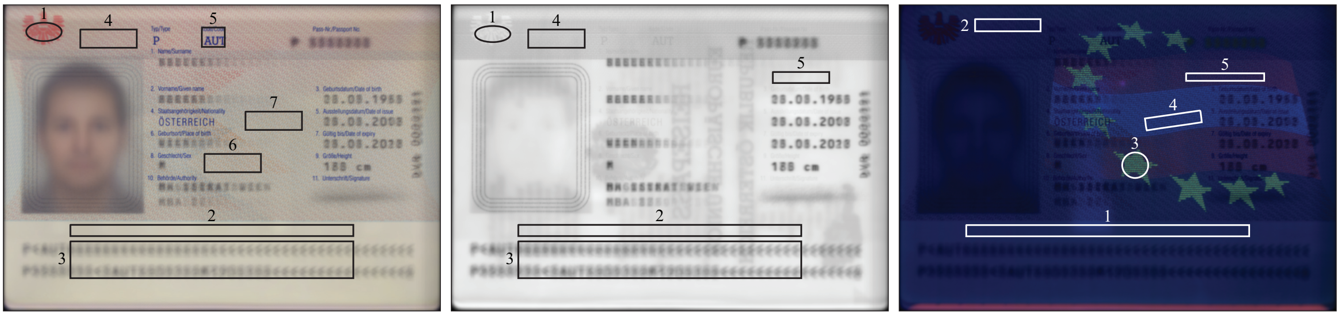
In the IR spectrum, all ROIs except for IR-3 show the contrast variability $\geq$10 %. As the Austrian ePassport mostly does not contain any high-contrast structures in the IR spectrum (except for the MRZ, i.e., IR-3), the observed high variability in contrast can likely be explained by dirt and/or mechanical crumpling, which is easiest to detect in unstructured areas (see Fig. 4a through 4e).

Inspecting mean intensities in the visible and IR spectra, the observed variability never exceeds 3 %. This observation most likely testifies in favor of good stability and durability of the analyzed documents in those spectral ranges (see Fig. 3a through 4e). However, it may also mean that the employed document reader quietly applies some sort of image brightness normalization, leading to a seeming stability in the absolute intensity.

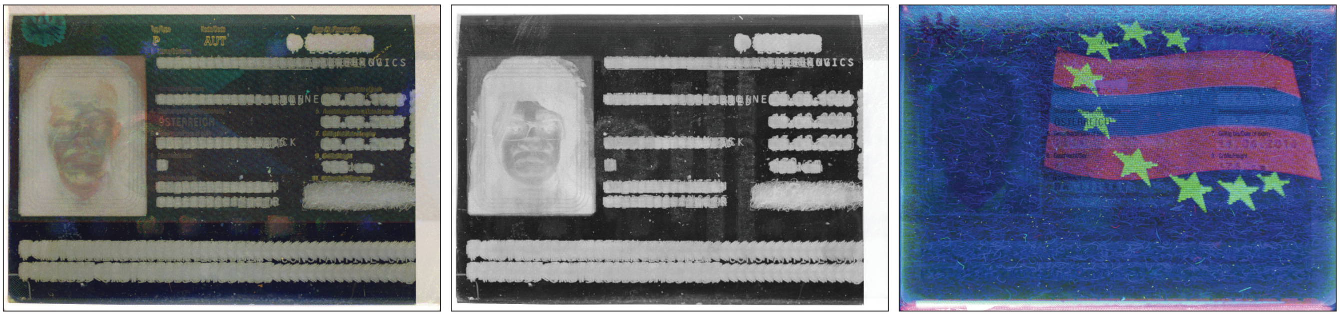
C. Effects in the UV spectrum

The most significant visual variability can be observed in all ROIs of the UV spectrum in both mean intensity and contrast measures. This observation clearly testifies in favor of very diverse appearances of UV security features either due to a rather steep aging curve of UV-fluorescent inks, differences in document handling, or perhaps even differences in production processes over time (see Fig. 5a through 5e).

The overall largest perceptual variability of 51.64 % was observed in UV-2 for the contrast measure. As this region should be characterized by high presence of UV-fluorescent



(a) ROIs considered in the visible (left), IR (middle), and UV (right) spectra.



(b) Variation in the visible (left), IR (middle), and UV (right) spectra.

Fig. 1. Regions of interest (ROIs) considered in different spectral channels and variation of image content in the database of 422 passports.

TABLE I

OVERVIEW OF THE RESULTS OF THE ANALYSIS OF VARIATION (I.E., MEAN $\pm$ STANDARD DEVIATION). ALL CASES SHOWING SIGNIFICANT VARIATION ($\geq \pm 10$ %) ARE MARKED IN BOLD FONT. GRAY BACKGROUND INDICATES CASES WITH SIGNIFICANT AGING TREND ($p \leq 0.005$), WHILE ARROWS SHOW THE TREND DIRECTION.

Region	Mean intensity (Int)	$\pm$%	Overall contrast ($Cont$)	$\pm$%
VIS-1	0.5053 $\pm$ 0.0107	2.12	0.0922 $\pm$ 0.0063	6.85
VIS-2	0.7643 $\pm$ 0.0081	1.06	**0.0227 $\pm$ 0.0028**	**12.21**
VIS-3	0.7022 $\pm$ 0.0092	1.31	0.1929 $\pm$ 0.0085	4.39
VIS-4	0.6351 $\pm$ 0.0103	1.63	0.0563 $\pm$ 0.0046 $\downarrow$	8.10
VIS-5	0.5276 $\pm$ 0.0150 $\uparrow$	2.84	0.2639 $\pm$ 0.0132	4.98
VIS-6	0.6598 $\pm$ 0.0075	1.14	0.0550 $\pm$ 0.0046	8.42
VIS-7	0.6577 $\pm$ 0.0082	1.25	0.0471 $\pm$ 0.0045	9.46
IR-1	0.8303 $\pm$ 0.0189	2.28	**0.0411 $\pm$ 0.0062** $\downarrow$	**15.12**
IR-2	0.8649 $\pm$ 0.0118	1.37	**0.0450 $\pm$ 0.0046**	**10.33**
IR-3	0.7690 $\pm$ 0.0138	1.80	0.2594 $\pm$ 0.0124	4.79
IR-4	0.7804 $\pm$ 0.0224	2.88	**0.0448 $\pm$ 0.0064** $\downarrow$	**14.27**
IR-5	0.8707 $\pm$ 0.0133	1.52	**0.0309 $\pm$ 0.0067**	**21.66**
UV-1	**0.1436 $\pm$ 0.0317** $\uparrow$	**22.06**	**0.1127 $\pm$ 0.0220**	**19.48**
UV-2	**0.1136 $\pm$ 0.0272** $\uparrow$	**23.93**	**0.2114 $\pm$ 0.1092**	**51.64**
UV-3	**0.2797 $\pm$ 0.0404**	**14.45**	**0.3619 $\pm$ 0.0510** $\downarrow$	**14.09**
UV-4	**0.1887 $\pm$ 0.0278**	**14.71**	**0.1548 $\pm$ 0.0464** $\downarrow$	**29.98**
UV-5	**0.1677 $\pm$ 0.0350**	**20.84**	**0.1575 $\pm$ 0.0398** $\downarrow$	**25.30**

security fibers, it is interesting to observe that in some collected passports, fibers were not present at all, which manifests itself in highly unstable contrast (see Fig. 5b).

IV. ANALYSIS OF AGING EFFECTS

Aging effects leading to diverse visual appearance include fading of ink, dimming of transmissible film, folding or crumpling of paper, scratches, abrasion, dirt, etc. Image based authentication of security documents must reflect all these unavoidable disturbances by increased tolerances, while still preserving acceptable sensitivity to forged and counterfeited documents.

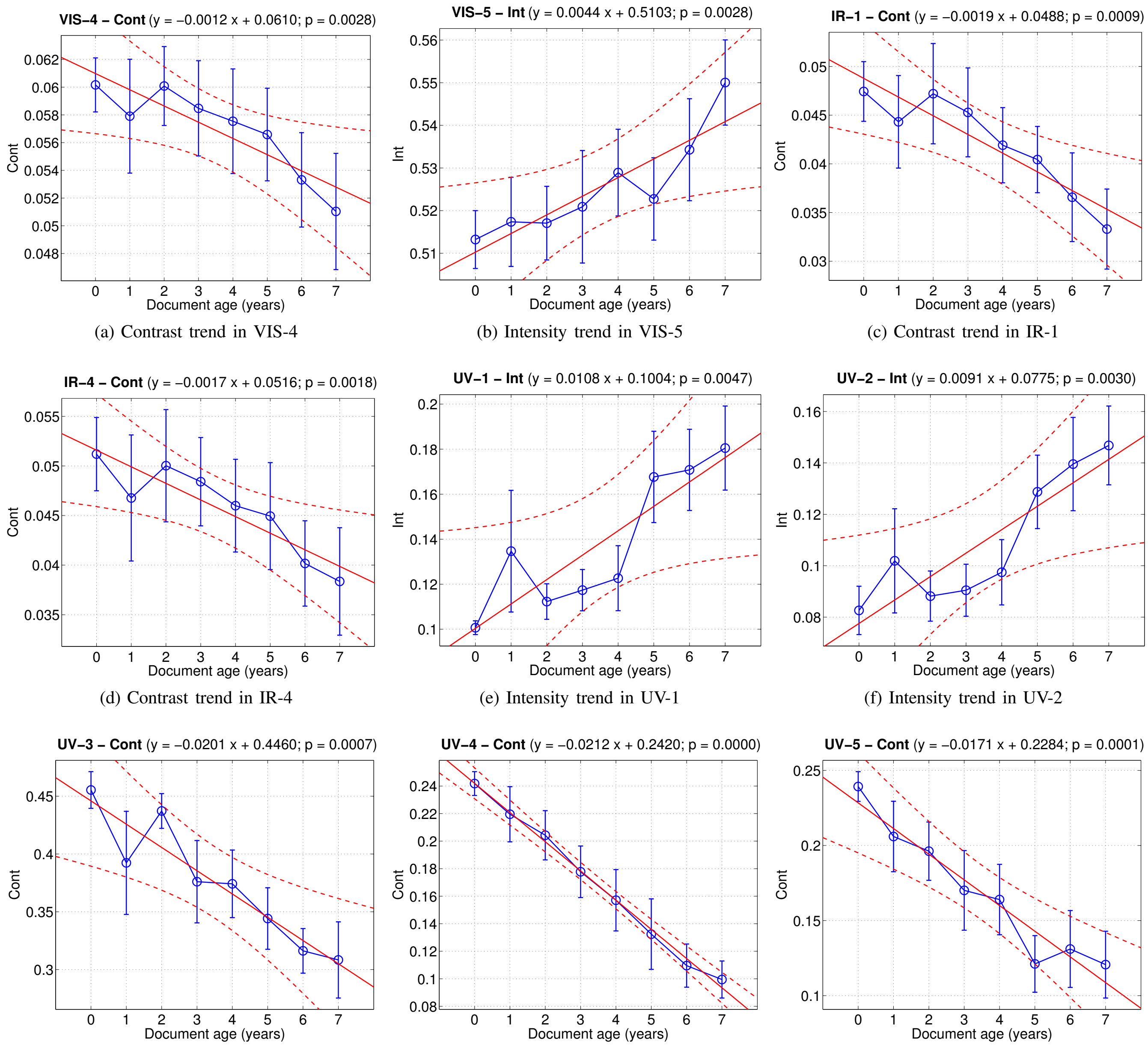
In TABLE I, all cases showing significant aging trend, expressed by a low p-value ($p \leq 0.005$), are denoted by gray background. The associated trend directions are indicated by arrows. Altogether we detected nine significant aging effects: two in the visible spectrum, two in the IR spectrum, and five in the UV spectrum (see Fig. 2). In the following we comment on those effects in detail:

A. *Aging in the visible spectrum*

In the visible spectrum, there were two significant aging effects, an increase of the mean intensity in the VIS-5 region, and a decrease in contrast in the VIS-4 region. Both regions feature a background consisting of grey microtext and a fine yellow/red pattern. The VIS-5 region also contains a non-personalized text printed using a dark blue ink, whereas the VIS-4 region consists only of the background (see Fig. 3d and Fig. 3e). Having a closer look at the examples, the observed trend in the intensity can be attributed most likely to fading of the microtext (fine gray horizontal lines), while the red pattern and the blue ink remain stable. The microtext is printed in a separate printing process, as the ink used is also visible in the IR spectrum, while the other print in those two regions is not.

B. *Aging in the IR spectrum*

Regarding aging in the IR spectrum, we also observed two significant effects, a decrease of contrast in the regions IR-1 and IR-4. Both regions feature a background of the before-mentioned microtext, which is visible in visible light



(a) Contrast trend in VIS-4 (b) Intensity trend in VIS-5 (c) Contrast trend in IR-1

(d) Contrast trend in IR-4 (e) Intensity trend in UV-1 (f) Intensity trend in UV-2

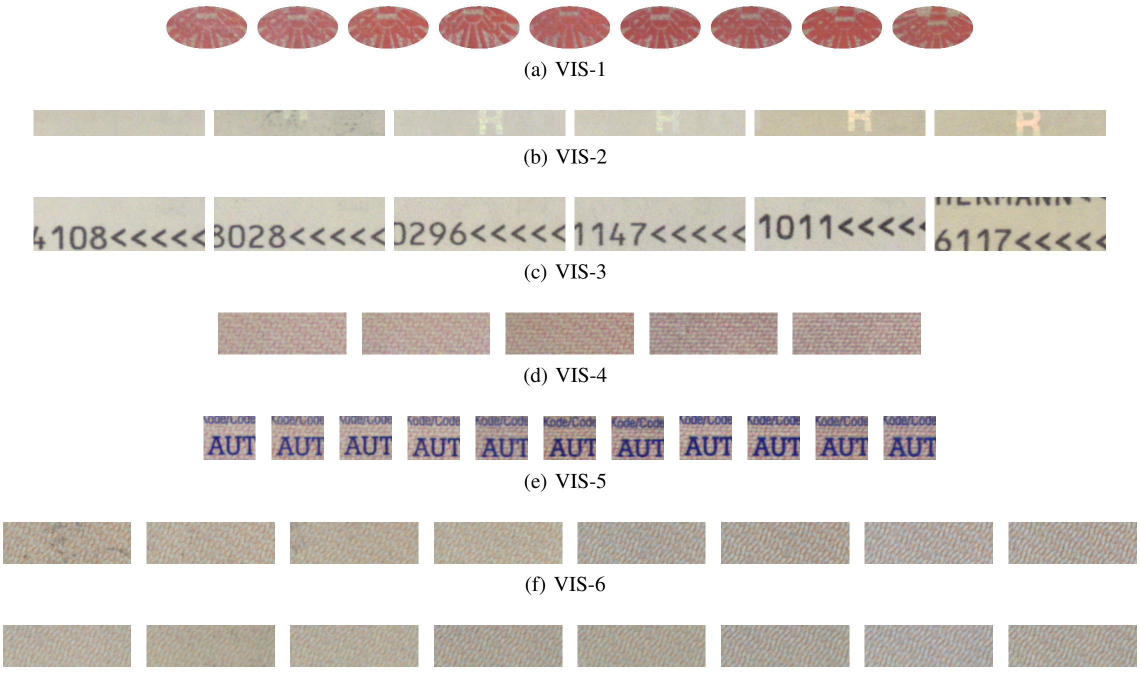
(g) Contrast trend in UV-3 (h) Contrast trend in UV-4 (i) Contrast trend in UV-5

Fig. 2. Overview of observed significant aging effects. The blue line refers to the mean $\pm$ standard deviation in individual document age categories. The solid red line stands for the linear trend fitted into the mean values per document age category. The area marked by dashed red lines represents confidence interval ($\alpha = 0.005$) for the regression line. Actual regression models as well as associated p-values for a non-zero gradient are provided in title of each individual plot.

as well as IR. In both regions, the microtext seems to fade over time, as we observed already in the VIS-4 and VIS-5 regions. This is supported by the fact that both regions also show a modest increase in intensity over time, although the significance levels ($p = 0.06$ and $p = 0.057$) barely miss our significance threshold, and thus plots were not included in the paper. The only other region containing IR - absorbing ink, IR-3, does not show any aging effects. Since the text in IR-3 is personalized for each passport, the printing process and ink is probably different than in non-personalized parts, and thus might be more stable. On the other hand, the aging trend might be present, but statistically hidden in the very high general variability in that region.

C. *Aging in the UV spectrum*

Paper with the UV-dullness property is commonly used for security documents. Studying the UV-1 region (see Fig. 5a) we observed a significant increase of the mean intensity over the range of seven years. Interpolated to the full validity time of 10 years that would amount to an increase of intensity (or loss of dullness) of 107%, which of course needs to be seen



(a) VIS-1

(b) VIS-2

(c) VIS-3

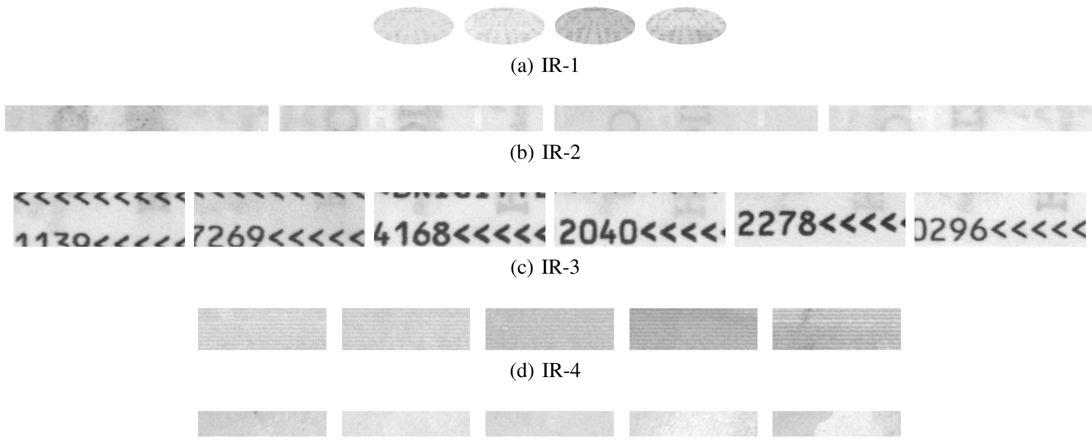
(d) VIS-4

(e) VIS-5

(f) VIS-6

(g) VIS-7

Fig. 3. Examples of extreme cases from the database of 422 passports in the visible spectrum.



(a) IR-1

(b) IR-2

(c) IR-3

(d) IR-4

(e) IR-5

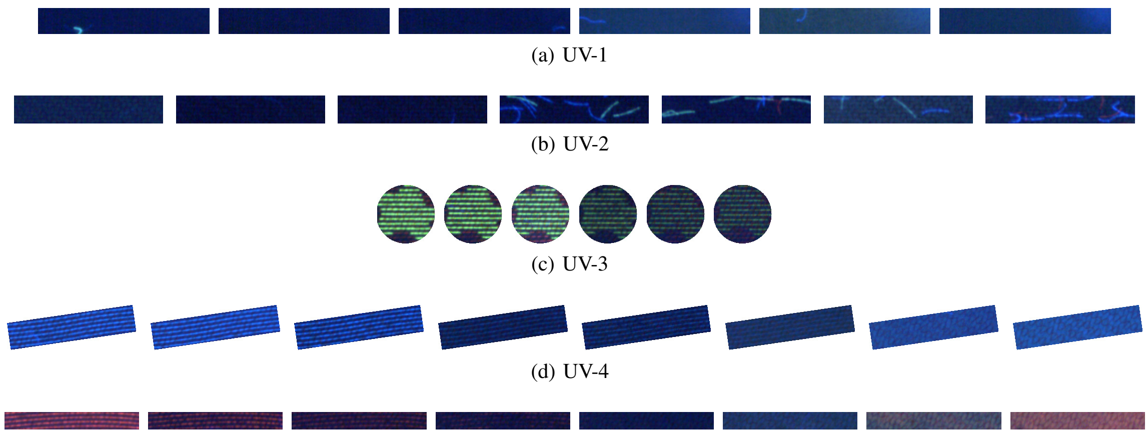
Fig. 4. Examples of extreme cases from the database of 422 passports in the IR spectrum.

in comparison to the very high variability of 22.06% in that region. The UV-2 region also shows a significant increase of mean intensity, however it also has the highest variability in both mean intensity (23.93%) and contrast (51.64%).

We observed three other significant aging effects in the regions UV-3, UV-4, and UV-5 that are highly consistent with each other (see Fig. 2g through 2i). These regions are associated with the greenish star as well as bright and red stripes on the Austrian flag, respectively (see Fig. 5c through 5e). Each of these three security features is printed by a different UV-fluorescent ink and it is designed to be very bright, high-contrast and dominant. From the provided examples it is apparent that this is not always the case, ranging from crispy high-contrast cases to completely dull and low-contrast cases. In the UV-3 region, we calculated a decrease by about 45 % in ten years time ($p = 0.0007$). In the UV-4 region, the observed effect was a steady decrease in contrast by about 88 % for the full validity of ten years ($p = 0.0000$). Last but not least, in the UV-5 region, we determined a drop in contrast by about 75 % in ten years time ($p = 0.0001$). All these mutually consistent observations clearly testify against temporal stability of UV-fluorescent inks and generally call usability of these features in security printing into question.

V. Conclusions and Discussion

In this paper, we presented a statistical analysis focused on various effects influencing image quality of scanned security documents obtained in ABC gates. We paid attention



(a) UV-1

(b) UV-2

(c) UV-3

(d) UV-4

(e) UV-5

Fig. 5. Examples of extreme cases from the database of 422 passports in the UV spectrum.

to the aging effects including wear&tear, abrasion, graffiti, or mechanical crumpling. Despite the fact that the results presented in this paper were derived just from a limited data set of Austrian ePassports, this security document comprises of state-of-the-art optical security features and therefore it is only natural to expect that other modern security documents should exhibit similar behavior.

We conducted two types of ROI-based analyzes with the aim to identify stable and unstable security features in all three spectral channels (i.e., visible, IR, and UV): (i) analysis of variation and (ii) analysis of aging effects. From the latter analysis it was apparent that security features in the visible and IR spectra preserve their appearance quite well w.r.t. the absolute intensity. However, this was not always the case regarding the contrast in these spectra. Speaking of the UV spectrum, all analyzed security features there showed extremely large variability in both the absolute intensity as well as contrast measures. That suggests that UV security features are generally difficult to handle in order to keep inspection tolerances for genuine documents narrow.

Regarding the aging effects that partially explain the observed variability of the data, we detected altogether nine significant cases: (i) intensity increase and contrast loss in the visible spectrum due to fading of IR visible ink, (ii) contrast decrease in the IR spectrum for the same reason, and finally (iii) decrease in intensity and contrast in the UV spectrum due to fading of UV-fluorescent inks over time. The effects in the first two spectra might be attributed to one specific ink or printing process, as other inks in these spectra did not exhibit similar behaviour. On the other hand, the effects observed in the UV spectrum are quite alarming as they call the entire UV security into question. In fact it seams that it is almost impossible to rely on the appearance of UV security features even if they are genuine, not speaking about the fact that various UV-fluorescent inks are nowadays freely available to the general public. These findings are crucial for the choice of appropriate optical inspection methods and spectral channels.

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