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An efficient method to detect series of fraudulent identity documents based on digitised forensic data

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ABSTRACT

Document fraud is a transnational form of crime, and its serial character has already been highlighted. To combat this phenomenon, the Interstate Database of Fraudulent Identity Documents (BIDIF) has been created and implemented in Switzerland. It supports the comparison of documents and the detection of series, i.e., documents that share a common source. To efficiently use such a system, forensic document examiners would benefit from a harmonised and proven profiling method. Thus, the aim of this study is to develop a method for comparing documents and establishing series. The method is meant to improve the detection capabilities of forensic document examiners operating BIDIF or engaged in the profiling of fraudulent documents. First, a method based on the visual characteristics of digitised images of fraudulent identity documents has been developed. Subsequently, the method was qualitatively and quantitatively evaluated using four tests. The first test verified the ability of the method to detect pre-existing series. The second test checked the capability of the method to detect links amongst isolated documents. Finally, two further tests were carried out to compare the method impact on the successful detection of series. These tests were carried out by professional forensic document examiners and Master students in forensic science, respectively. This allowed a comparison of the method influence on series detection. The method allowed a significant increase in the number of series and links detected, while also decreasing the occurrence of false negatives and false positives. Furthermore, links were more rapidly detected.

1. Introduction

Document fraud facilitates serious, organised and generally transnational forms of crime. Fraudulent identity documents (FID) – namely fraudulent passports, identity cards, driving licences, residence permits or any other type of identity or travel document – can be used to commit a multitude of different illegal activities. Furthermore, they are often produced in series by forgers. However, the ability to detect and recognise these series is a challenge in the daily practice of police services, border controls and forensic science. The profiling of FID represents a promising method to address such frauds in a more global and effective way, using a forensic intelligence approach [1–4]. Thus, an operational system was created to efficiently detect series of FID. In Switzerland, it is known as the Interstate Database of Fraudulent Identity Documents (hereafter called BIDIF[1]). Developed by the School of Criminal Justice of the University of Lausanne and implemented in 2017, this online system is used by eight state police services from Western Switzerland as well as the federal police. Technical characteristics of FID are described in the database (such as printing techniques or reaction under UV light), and documents are scanned (600 dpi, .png) using a standardised method to ensure high quality comparable digitised images [5,6]. The profiling (i.e., description and comparisons) is then carried out by users each time they insert a new document into the database, to check for potential similarities between their document and previous ones in the database. When similarities observed between two or more documents indicate a common origin or source, documents are considered to be part of a *series*. It is inferred that documents belonging to a given series were forged using the same methods and/or by the same (group of) forger(s) [2]. The detection of series highlights the activity of criminals and criminal networks that produce, disseminate and/or use

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[1] standing in French for Base Intercantonale des Documents d'Identité Frauduleux.

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FID. Forensic observations on documents can therefore be translated into investigative leads and operational or tactical intelligence [7].

While the database was created to facilitate the production and dissemination of forensic intelligence, it remains a challenge for BIDIF users to highlight series of FID in an efficient and harmonised way. In the absence of a systematic method to detect series, results remain subjective and depend on users' ability, experience and motivation (i.e., educational background in identity documents and forensic intelligence, previous FID casework experience and importance of the document and related case under scrutiny), and on the time available to the users. In view of the growing amount of data in BIDIF, implementing a working method becomes essential to detect series systematically, scientifically and efficiently. This study aims at developing a profiling method for comparing FID to improve profiling capacities, and better coordinate efforts to fight fraud.

2. Material and method

2.1. Interstate database of fraudulent identity documents (BIDIF)

The data contained in BIDIF was used to assist in developing and evaluating a method for the comparison of FID and the detection of series. The diversity of fraudulent documents contained in BIDIF allowed the creation of a general method for all types of FID. In February 2019, BIDIF contained 1355 FID including driving licences (36.5%), identity cards (25.1%), documents issued to non-nationals (27.1%) and passports (10.3%). Different types of fraudulent documents are reported in BIDIF, namely counterfeits (entirely produced by a forger to imitate an existing model of document), forgeries (alteration of a genuine document), pseudo-documents (counterfeit that does not imitate an existing model of document) and stolen blanks (alteration and personalisation of an unfinished genuine document). Counterfeits make up 85% of the documents contained in BIDIF.

Based on the examination and comparison of material features performed by forensic document examiners, approximately 50% of the documents were linked by the operators to at least one other FID in BIDIF. In total, forensic document examiners detected 62 series. For each series, characteristics specific to the series were described and illustrated. In addition, the system automatically suggests links based on document numbers as well as grouping based on the document type, the fraud type and the country of the documents. Automatic image comparison methods based on computer vision are also implemented in BIDIF to enhance and support series detection [5,6,8]. They are however beyond the scope of this paper.

2.2. Data selection

The 62 series were used to develop and evaluate the profiling method. Based on previous results [9], two thirds of these series were selected to make up the *development set*, which included 39 series and a total of 324 documents. The remaining third, namely 23 series containing 360 documents, made up the *test set* for evaluation purposes (Fig. 1). The distribution of the series within these sets was done homogeneously to equally represent the diversity of the database: the different series were divided between these two sets according to the document type, fraud type and the country of the document. The profiling method was then further applied on the 671 unrelated documents (representing the other half of the data contained in BIDIF) to check if additional links could be highlighted using the novel profiling method.

2.3. Development of a profiling method

FID from the *development set* were analysed and compared to the documents in the series they belonged to. The analysis was performed by one operator and consisted in highlighting all the specificities that did not seem to match a genuine document, such as a lack of accuracy in the alignment of data, heterogeneity in the use of a typeface, the use of an incorrect typeface, spelling mistakes, etc. In this first step, the operator did not consider the observations made by forensic document examiners in BIDIF system. The comparison of documents within a series was then used to estimate the reproducibility of the different characteristics (i.e.,

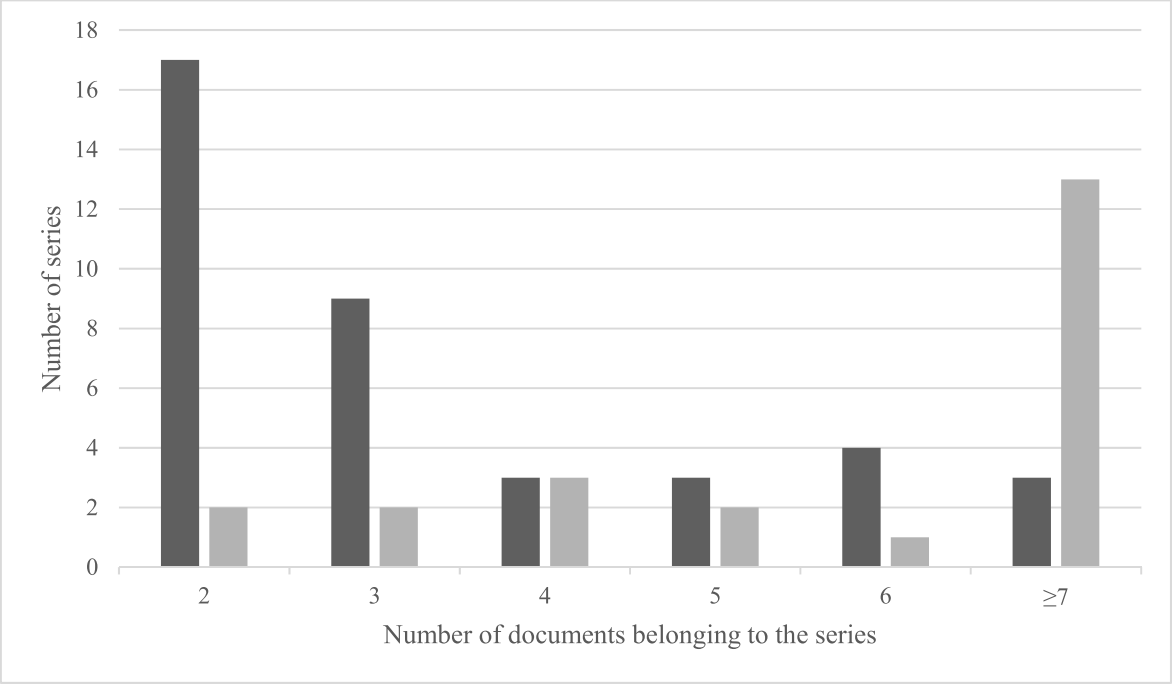

Fig. 1. Distribution of BIDIF series for the development (dark-grey) and test (light-grey) datasets. These were selected to represent two thirds and one third of the series, respectively. Three series contained more than 7 documents in the development set (8, 48 and 156), while 13 series contained 7 or more documents in the test set (2x7, 8, 2x9, 10, 11, 13, 2x15, 22, 36 and 160).

intra-variability of characteristics). In a further step, these observations were compared to the observations reported by BIDIF users to understand why documents were linked to a series. In addition, previous studies focused on the profiling of FID were used to define and select characteristics regularly examined on fraudulent documents [2,10,11]. These studies also allowed to estimate the discriminating power of selected characteristics, i.e., the capacity to differentiate fraudulent documents made by different forgers. The observations served as a basis for the creation of the proposed method.

2.4. Evaluation of the method

The profiling method was applied to the *test set* to evaluate to what extent existing BIDIF series could be found using the systematic profiling method. Then, it was applied to all unlinked documents to evaluate the potential of the method to detect additional series that were unseen by BIDIF users. Finally, the method was evaluated in real-life conditions on novice and professional experts, all of them having at least basic training in forensic science. Their ability to detect series before and after having been taught the novel systematic method was compared in order to evaluate the added value of the method. The first experimentation (hereafter called *test on professionals*) was conducted on about seventy professional forensic document examiners (level II, which can be considered as an advanced level) from all over Switzerland gathered at a workshop organised by the Swiss Police Institute. Some of them already had experience using BIDIF. The second experimentation (hereafter called *test on students*) was conducted on 17 forensic science master's students from the School of Criminal Justice of the University of Lausanne. Most of them held a bachelor in forensic science and were familiar with the Analysis, Comparison, Evaluation – Verification (ACE-V) process [12–14]. Feedback was obtained at the end of the second exercise during a free verbal discussion for the test on students, whereas collecting feedback for the test on professionals was not possible due to time constraints. Ethical considerations were respected as the collection of data was entirely anonymous, and no personal data was collected. The participants were informed and agreed through their participation that the anonymous data would be used for educational and research purposes.

3. Results and discussion

3.1. Development of a profiling method

A structured method was developed to detect links between FID in an operational framework (see Fig. 2). The approach aimed at being general enough to be applied to different types of FID. At the same time, the method must be sufficiently specific to allow discrimination between different series (amongst the same type of document, type of fraud, and country, such as counterfeit French identity cards or forged American passports for instance). Four steps are proposed to examine the FID and detect potential links, forming a general usage script:

(1) A FID is considered for profiling and entered in BIDIF.
(2) The new questioned document is analysed to observe, highlight and describe profiling characteristics.
(3) The characteristics of the questioned document are systematically compared to those of other documents in BIDIF:
    (3.1) The document number is first automatically compared to all other documents. If any match is found, a series is created to group the concerned documents if the document number is long or complex enough to indicate that the match cannot result from chance alone. While a document number of four figures might not be complex enough, document numbers are generally composed of a higher number of digits supporting the hypothesis that matching document numbers result from documents having been produced by the same forger.
    (3.2) Then, the questioned FID is compared to pre-existing series.
    (3.3) Finally, the document is compared to isolated or unrelated FID (i.e., documents for which no link has yet been detected).
(4) After each comparison step, a decision can be taken. This includes evaluating whether the document should be added to a pre-existing series, whether a new series should be created, or whether the document has been profiled but no link has been detected (yet). This approach is inspired by the ACE process introduced in 1972 by Huber for questioned document examination [13,14], that has since then been widely used across forensic disciplines, such as fingermarks and shoemarks comparison, with the addition of a verification stage (V) [12,15].

3.1.1. Introduction of a fraudulent document and analysis stage

The process begins with the introduction of a fraudulent identity document into BIDIF database. Users are expected to make comparisons between the new document and pre-existing documents in BIDIF to detect series and inform the system about their findings. The aim is not authentication but profiling of fraudulent documents in order to reveal series and highlight the activity of criminal networks. Thus, it is important to thoroughly analyse the new document in order to detect and describe its general and specific characteristics. In this study, only visual characteristics and technical information (i.e., printing techniques) of the document will be processed for profiling purposes. Indeed, previous research [2] has shown that visual characteristics are sufficient and efficient to detect links. The use of resource-intensive advanced analytical methods is not considered in this study as operational efficiency needs to be prioritised.

3.1.1.1. General characteristics. All documents can be described using the following categories: the document number, the document type, the fraud type (counterfeit, forgery, stolen blank, pseudo-document), the country of the document and the substrate material (paper, cardboard, plastic, polycarbonate, etc.). In addition, the printing techniques of the background, the document number, the personal data and the picture contained in the document, as well as the fluorescence or non-fluorescence of the background can be determined on all documents. As all these documents share these characteristics, they are called general characteristics.

3.1.1.2. Specific characteristics. Specific characteristics are only shared by documents belonging to a series. Particular characteristics might be multiple and very different from one type of document to another (e.g., a paper-based birth certificate filled with a biro vs. a polycarbonate-based laser-engraved ID card with latest generation security features). Therefore, it is not possible to provide a comprehensive list of characteristics that will be present on all documents submitted to BIDIF. However, based on our study of the series contained in BIDIF, it is possible to guide the analysis of the document by observing different categories of characteristics, namely the layout and content of the identity document; the logos and security features; and the defects introduced during the reproduction process. The following examples illustrate each category and are provided as a guide to help users in their analysis of the documents.

3.1.1.2.1. Layout and content. In a *general to particular* observation approach, the layout and content are examined first. The layout is essentially based on the arrangement of the elements relative to each other, while the content refers more specifically to the text itself. For example, alignment errors are particularly discriminating because they are specific to the layout or template used by the forger. They appear as a

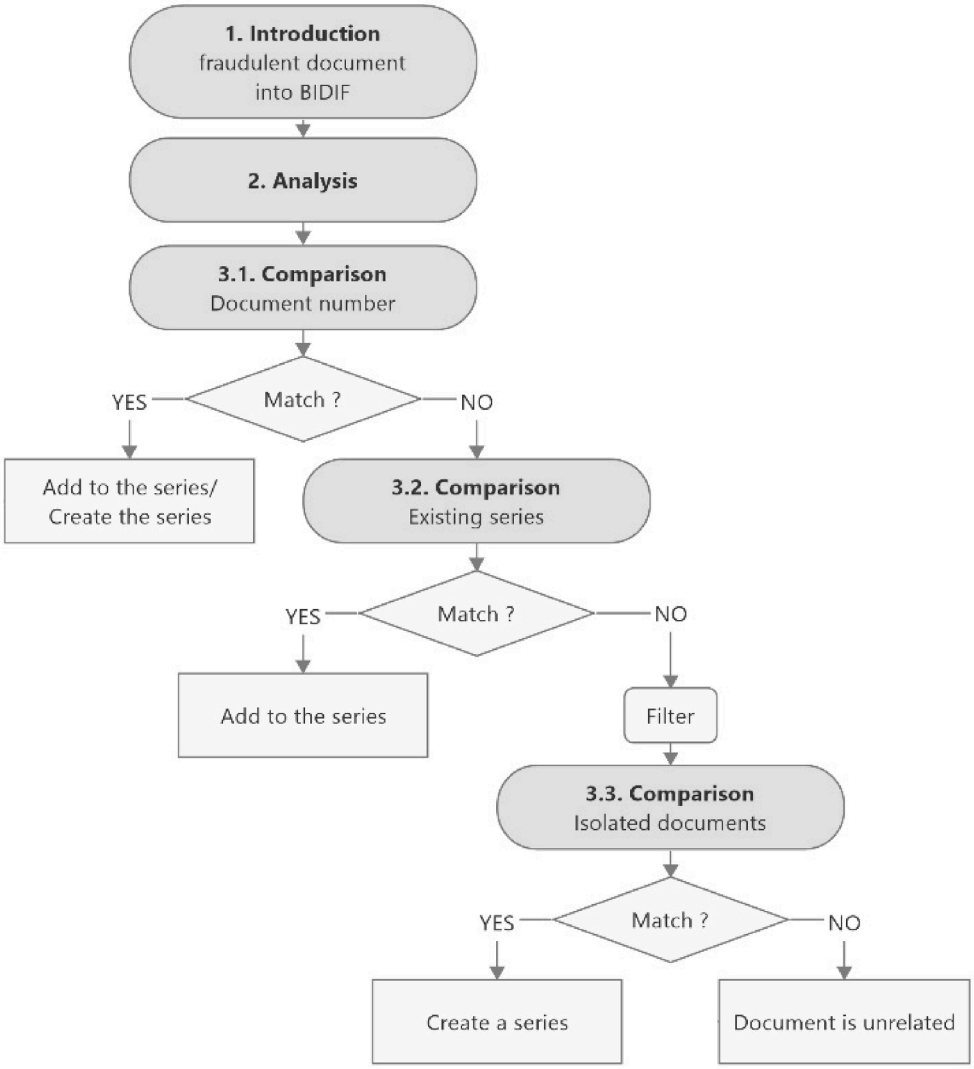

Fig. 2. Systematic method for the profiling of fraudulent identity documents (FID).

shift that can occur vertically and/or horizontally. Concerning vertical alignment, special attention should be paid to ensure that words and letters are on a same baseline (see misalignment example in Fig. 3).

Concerning horizontal alignment, any lateral shift of the text in the pre-written data, personal data or the areas between these sections must be examined closely. An example of horizontal misalignment is shown in Fig. 4.

In a similar way to the layout of the texts, the alignment of the boxes must be checked. The content of these boxes must in principle be centred (Fig. 5).

Concerning the content, spelling mistakes and syntax errors can be investigated. As the forger is not necessarily a polyglot and does not always have a genuine model or specimen to copy[2], it is relatively common to observe spelling mistakes and omissions of diacritical signs (see examples in Fig. 6). Syntax errors are less frequent but can occasionally occur, for example, when the forger writes the same word twice or when an omission of a word or sign has an impact on the meaning (see Figs. 7, 8 and 9).

Fig. 3. Shift upwards of the central letter 'S' from 'HOLDER'S' on a counterfeit Portuguese identity card.

These two types of errors are easily detectable in a language known to the forensic document examiner. However, it becomes more complicated in a foreign language or alphabet, especially when no contemporaneous genuine reference specimen is available. Nevertheless, the typeface, characters, punctuation and spaces can be investigated independently of the language. To do this, it is necessary to check the uniformity of the typeface within the document and its conformity in the Machine Readable Zone (MRZ), with the official typeface Optical Character Recognition type B (OCR-B) [16]. Attention should be paid to the use of capital letters in inappropriate places as well as characters with flourishes that are difficult to reproduce for counterfeiters. Concerning punctuation, a full point is present at the end of the sentence or

[2] Even when a model is available, errors are often introduced during the reproduction of the documents as it is very difficult and time consuming to be attentive to all details.

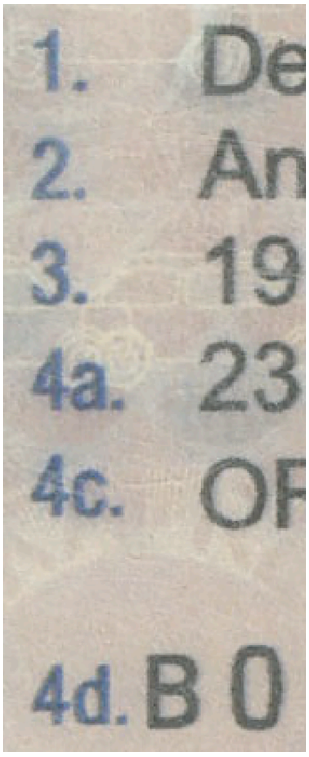

Fig. 4. Shift to the left of the content of the section '4d.' (B0…) on a counterfeit Slovak driving licence.

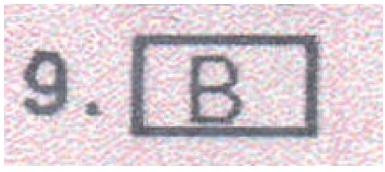

Fig. 5. Off-centring of letter 'B' on a counterfeit Slovenian driving licence.

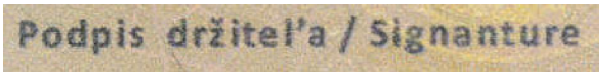

Fig. 6. Spelling mistake in 'Signature' on a counterfeit Slovak identity card.

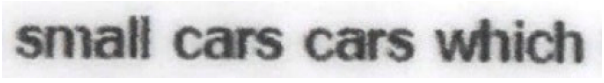

Fig. 7. Syntax error with the repetition of the word 'cars' on a counterfeit Syrian Arab Republic driving licence.

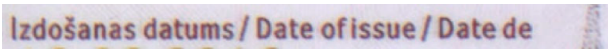

Fig. 8. Syntax error in 'Date de' on a counterfeit Latvian identity card. The French word 'délivrance' is missing.

usually after a number indicating a heading. Finally, irregularities can also be highlighted in spacing.

3.1.1.2.2. Logos and security features. The term logo refers to the various illustrations present on the identity document, such as vehicle category representations or the coat of arms of the country. The security features are elements implemented in identity documents to protect them from counterfeiting or forgery, such as stamps, optically variable devices (OVD), embossing or fluorescent logos. Forgers use several techniques to reproduce these, such as the imitation or the removal of a security element from a genuine document that is then affixed to the counterfeit. The main criteria for analysis are defects in quality, alignment, symmetry, interactions and continuity. Comparably to layout errors, misalignment of the different parts constituting a logo or security element can be detected as shown in Fig. 10.

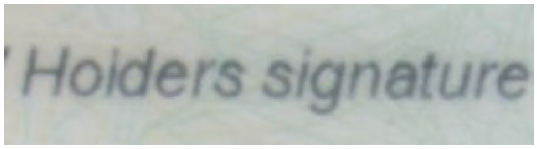

Fig. 9. Syntax error in 'Holder's signature' (missing apostrophe) on a forged Belgian identity card.

The symmetry concerns not only the general appearance of logos and security features but also the elements composing them as in Fig. 11.

Interactions between several security features or other parts of the document can yield visible characteristics such as overlapping ink lines showing stronger contrasts (Fig. 12).

Defects can also appear in the form of a discontinuity. As illustrated in Figs. 13 and 14, interruptions of lines can be observed in the repetitive drawings, the guilloche and even in the logo.

Finally, these visual characteristics can also be observed on the MRZ and the bar codes that increasingly appear on document models. In addition, a check of the bar code with a document reader application can link some documents with similar embedded data.

3.1.1.2.3. Reproduction process. Unlike the other categories, which concern defects related to the template, this one concern defects related to the scanning or printing process performed by the forger. Characteristics of the reproduction process manifest themselves mainly in the form of variations in colour or contrast within the text as well as accidental characteristics or defects present on the document, such as small spots or marks (Fig. 15).

3.1.1.2.4. Characteristics selection. In order to develop an efficient profiling method in an operational perspective, the selection of characteristics has been guided by criteria proposed by Baechler et al. [17]. It is important that observed characteristics be related to the criminal activity of the forger, and more specifically to the production methods used to create the fraudulent document (i.e., modus operandi). Characteristics, visible on the digitised images (i.e., 600 dpi scans of the documents), can be easily compared, without necessitating different illumination conditions (e.g., fluorescence) or magnification (e.g., microscope). The latter would only be observable on the physical documents and would thus be incompatible with a centralised and shared database such as BIDIF, without adding undue complexity in the data collection, acquisition and management process. For example, characteristics related to the MRZ or the bar code are not directly observable as they require an extra reading step, increasing the processing time. Visual characteristics also have the advantage of being easy to illustrate, yielding quicker and more reliable comparisons than text descriptions,

Fig. 10. Shift to the right of the letters 'EU' and missing stars on a counterfeit Slovenian driving licence.

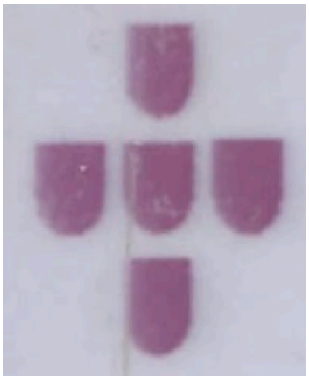

Fig. 11. Asymmetry of the shield centred on the right (bigger than the others) on a counterfeit Portuguese identity card.

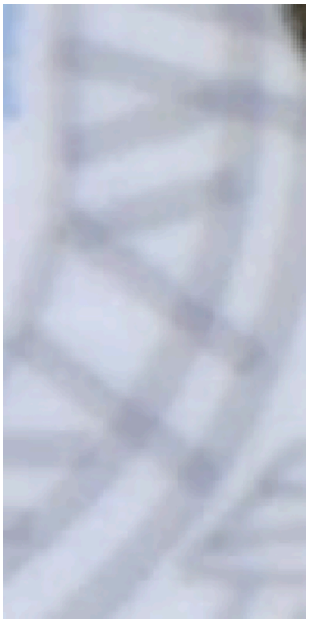

Fig. 12. Defect of interaction within a logo on a counterfeit Portuguese identity card.

that can be dependent on the author. The characteristics must also be available and fully observable on all FID. This criterion can be more complex to fulfil, as certain characteristics might disappear or appear within documents from the same series, due to series evolution. Therefore, more stable characteristics persisting for long time periods should be targeted. These can be found in stable zones such as pre-written data, the template and complex visual elements (i.e., areas that are difficult to reproduce due to many details or specific shapes). On the contrary, characteristics detected in personal data are subject to disappearance because they are constantly modified by the forger. They depend on the document holder, or in other words the forger's customer (see Fig. 16).

The template created by a forger is generally used to produce several documents. For example, a misalignment or a small accidental spot or defect on the template will be reproduced on further documents until a correction is undertaken. Thus, the characteristic lifetime will be influenced by the facility to detect and correct the error by the forger. While a flagrant and easily modifiable characteristic will have a shorter lifetime, a fainter or more complex characteristic might generally be more relevant for profiling [17]. Finally, the reproduction of complex elements such as wet stamps or logos not only require design expertise from the forger, but they also represent a significant workload. Therefore, these elements are usually reused in the creation of several FID and should

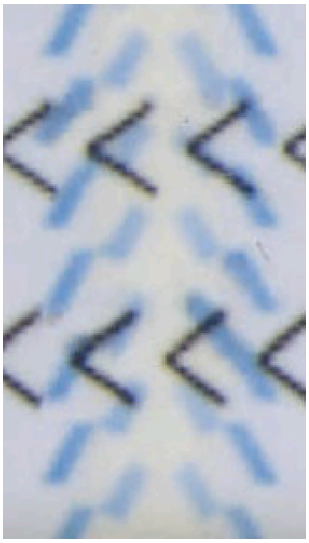

Fig. 13. Discontinuity in the repetitive drawing on a counterfeit Spanish identity card (see the black arrow).

Fig. 14. Discontinuity in guilloche (background printing) on a counterfeit Latvian driving licence.

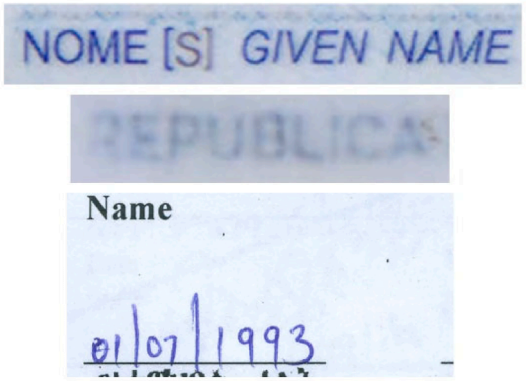

Fig. 15. Defect in the reproduction process: the colour of the 'S]' (left) and contrast of the 'R' (right) are not reproduced correctly on a counterfeit Portuguese identity card. Small black spots can be observed on the white background of a counterfeit Eritrean driving licence (bottom).

Fig. 16. Variability of characteristics in personal data on two counterfeit Latvian identity cards.

thus be more persistent throughout the series. The next criterion concerns the complementarity of characteristics. Ideally, characteristics should be independent to avoid redundant information. The selection of characteristics on the front, back and in each of the three categories described in the analysis section (layout and content, logos and security features, and reproduction process) will decrease the correlation of the selected characteristics. In addition, the characteristics should also have a low intra-variability, i.e., characteristics on FID coming from the same source should be reproducible in all documents with minimal variations. Characteristics should also have a high inter-variability, i.e., documents from different sources should have characteristics that significantly differ. While it is difficult to precisely determine the intra- and inter-variability without knowing the actual source of the documents (i.e., without FID from known sources), they can be estimated using established series. Thus, the characteristics that vary the least within series and differ the most between series should be selected. Finally, it is important to note that a single characteristic usually cannot fulfil all these criteria alone. Therefore, in order to satisfy a maximum of criteria, it is necessary to use a multidimensional approach considering several characteristics [2,11]. To be efficient, three specific characteristics must be selected in the analysis phase to serve as anchor points for the comparisons (much like in fingerprint comparisons [18]). Thus, if one of them disappears over time in the series, the others will still allow series detection.

*3.1.2. Comparison **and decision**.* Once the analysis is completed, the highlighted characteristics of the document can now be compared to the other documents stored in BIDIF following the proposed method. At this stage, it is recommended to use two screens or to divide the screen to place the document of interest on the left side and the documents already present in BIDIF on the right. This allows carrying out efficient comparisons in a back and forth process between the document of interest and other BIDIF documents.

3.1.2.1. Comparison of the document numbers. The first step is to check if other BIDIF documents share the same document number. Three scenarios are possible. First, a match is found with documents belonging to a series and the document of interest is added to that series. To confirm the link, the anchor points described in the series must be looked for the document of interest. Secondly, the document number is shared by another document in BIDIF which was isolated until now (i.e., not belonging to a previously detected series). In this case, the user must create and describe a new series containing those two documents. In the description, general and specific characteristics are described and illustrated. Finally, if no other document shares the same document number, the user carries on with the next comparison step.

3.1.2.2. Comparison with pre-existing series. As stated above, approximately half of the documents contained in BIDIF have previously been linked to series. Thus, the document of interest will be compared with potentially similar series, namely those from the same document type, fraud type and country. At this stage, series descriptions are useful for a quick comparison, and need to be sufficiently detailed and relevant. Conversely and as a confirmation, the three anchor points observed in the document of interest will be sought for in the documents belonging to the series. In case of doubt, it is necessary to deepen the comparison between the document of interest and the documents belonging to the series. If a link is confirmed with a pre-existing series, the document is added to the series and its profile is updated if required. If no link with existing series is highlighted, the comparison process continues to the next stage.

3.1.2.3. Comparison with isolated documents. At this last stage, the document of interest is compared to the documents stored in BIDIF that do not belong to an existing series (i.e., isolated documents). Those are targeted using a dedicated filter in BIDIF, and then relevant documents are selected on the basis of their general characteristics (document type, fraud, country, substrate material). Finally, the document of interest is compared with this reduced set of documents, one by one, using the anchor points to quickly triage the documents. If a link is detected between two documents, a new series is created. Then, the new series must be named, its profile (i.e., general and specific characteristics) described and illustrated.

3.1.3. Links detected

During the development of the method, the observation of new characteristics within the series of the *development set* permitted the detection of 16 new links, which contributed to 5 pre-existing series.

3.2. Evaluation of the method

The performance of the method was evaluated using the following four parameters: credibility, integrity, timeliness and flexibility [17]. Credibility is the ability of the method to limit erroneous positive information (false positives), i.e., to limit the detection of non-existent links. Integrity represents the ability of the method to limit erroneous negative information (false negatives), i.e., to increase the detection of actual links. The timeliness of the method is its ability to provide information which can be used quickly in various operational settings. The flexibility of the method is characterised by its adaptability to the rapid evolution of the criminal phenomenon, of modus operandi in general as well as of the general environment. It must be as universal as possible and easily used in a decentralised way by different users. In order to evaluate the method, it was first applied to a test dataset to check its capacity to detect pre-existing series. Then, it was implemented on isolated documents to evaluate if new series could be detected (i.e., series that had been missed by BIDIF users). Finally, it was qualitatively tested on active forensic document examiners during a workshop, as well as quantitatively tested on Master students in forensic science during another workshop.

3.2.1. Capacity of the method to detect series from the test set

To perform a blind test (i.e., without previous knowledge of the series), only digitised images of the front and back of the documents were used, without considering document numbers comparison and the comparison with pre-existing series. One document per series (23) was randomly selected and analysed (yielding a total of 23 questioned documents for the subsequent comparison stage). Based on the general characteristics (document type, fraud type, country of the document) of the selected questioned documents, the whole database (1355 documents) was filtered (i.e., the documented characteristics of the 23 documents were compared against all the other documents contained in the database). The application of the profiling method on the test data enabled the re-detection of all series (see Table 1).

18 series were detected, identical to those from the test dataset (see Table 1). 3 series showed the added value of the new method: one false positive (ERI-DL-1) and two false negatives (SVN-DL-1 and FRA-ID-1) were additionally detected (meaning that one link was disproved and two additional links were found with the developed method, respectively). In addition, two series were merged with pre-existing series from

Table 1
Pre-existing series in BIDIF composing the test dataset. Results indicate if the series have also been detected by the developed method, how many documents were linked to the series (this number can be lower or higher than the original number of documents included in the series) and if modifications were brought to the series, such as merging or the creation of sub-series (modified lines are marked in grey).

Series anonymous name (23)	Country, type of document, type of fraud	# of documents linked to the series (total = 360)	Results
AFG-DL-1	Afghanistan, driving licence, counterfeits	7	Detection confirmed (7)
BEL-ID-1	Belgium, identity card, counterfeits	8	Detection confirmed (8)
BEL-ID-2	Belgium, identity card, falsifications	5	Detection confirmed (5)
BEL-ID-3	Belgium, identity card, falsifications	11	Detection confirmed (11)
CHE-RP-1	Switzerland, resident permit, counterfeits	10	Detection confirmed (10)
CHE-V-1	Switzerland, visa, counterfeits	3	Detection confirmed (3)
COD-DL-1	Democratic Republic of the Congo, driving licence, counterfeits	9	Detection confirmed (9)
ERI-DL-1	Eritrea, driving licence, counterfeits	6	Detection confirmed (5) Detection of one false positive (-1)
ESP-ID-1	Spain, identity card, counterfeits	2	Detection confirmed (2)
FRA-ID-1	France, identity card, counterfeits	13	Detection confirmed (13) Detection of one false negative (+1) Merged with a series from the development set (+6)
GIN-P-1	Guinea, pass. falsifications	22	Detection confirmed (22)
GRC-ID-1	Greece, identity card, counterfeits	3	Detection confirmed (3)
ITA-ID-1	Italy, identity card, counterfeits	7	Detection confirmed (7)
ITA-TD-1	Italy, travel document issued to non-nationals, counterfeits	160	Detection confirmed (160)
LVA-ID-1	Latvia, identity card, counterfeits	2	Detection confirmed (2)
SSD-DL-1	South Sudan, driving licence, counterfeits	4	Detection confirmed (4) Merged with a series from the development set (+8)
SVN-DL-1	Slovenia, driving licence, counterfeits	36	Detection confirmed (36) Detection of one false negative (+1)
SVN-DL-2	Slovenia, driving licence, counterfeits	5	Detection confirmed (5)
SVN-ID-1	Slovenia, identity card, counterfeits	9	Creation of sub-series SVN-ID-1a (7) and SVN-ID-1b (2)
SVN-ID-2	Slovenia, identity card, fantasies	15	Detection confirmed (15)
SVN-P-1	Slovenia, pass, counterfeits	15	Detection confirmed (15)
SYR-DL-1	Syrian Arab Republic, driving licence, counterfeits	4	Detection confirmed (4)
XKX-DL-1	Kosovo, driving licence, counterfeits	4	Detection confirmed (4)

the development set, thus increasing the number of linked documents in those (SSD-DL-1 and FRA-ID-1). Finally, one series was further divided into two sub-series (SVN-ID-1a and SVN-ID-1b). These results pointed to a problem[3] that might gain importance in BIDIF along with the increasing number of documents in the database.

Finally, the method has also shown its ability to distinguish series amongst the same types of documents. For example, BEL-ID-1/2/3 were all identity cards issued from the same country and could be easily classified into different series (see also SVN-ID-1a/b, explanations below). Therefore, results indicated that the method was capable of successfully detecting the series that were previously highlighted in BIDIF without a harmonised method. It was successful across a broad range of document types (i.e., driving licences, identity documents, passports, visas, residence permits and travel authorisations) as well as for different fraud types (i.e., counterfeits, forgeries and pseudo-documents). Thus, the criteria of credibility, integrity and flexibility were demonstrated. The time needed to form the series was not evaluated at this stage.

3.2.2. *Capacity of the method to link further BIDIF documents*

The method was then applied to isolated documents (671 documents) within BIDIF to evaluate its ability to detect new series. 11 series of 2 documents, 2 series of 3 documents and 2 series of 5 documents, for a total of 15 new series were detected (i.e., new links were detected for 38 documents in BIDIF previously seen as isolated). Series contained driving licences, identity documents and residence permits from five different issuing countries. All documents were counterfeits. These results confirmed the added value of the method to detect previously undetected series amongst various types of FID in BIDIF. The detection

[3] Indeed, the notion of series becomes more complex when documents have common characteristics, but also present some differences. While the notion of series aims at indicating that linked documents come from the same source (i.e., were produced by the same forger or group of forgers), differences can be observed between documents coming from the same source (intravariability) as well as similarities between documents coming from different sources (inter-variability). This can be explained by the counterfeiter's production evolving over time or, on the other hand, by the existence of trafficking between counterfeiters in terms of logos, stamps, templates and other material [4]. Thus, differences between two documents sharing a range of common characteristics should not lead to a separation, and similarities should be interpreted cautiously considering different possible significance of the detected links.

of the 15 series and all documents attached to them was relatively quick (on average less than 5 min per document).

3.2.3. Implementation tests

The same procedure was followed for both the professional and student tests to ensure the comparability of the tests. The session was divided into four stages, namely:

1. Presentation of BIDIF;
2. First exercise (without harmonised method);
3. Presentation of the method;
4. Second exercise (with harmonised method).

3.2.3.1. Test on about 70 professional forensic document examiners. After BIDIF and its functions were presented to the participants, they were asked to search for links between one preselected questioned document and BIDIF documents. This exercise provided an opportunity for participants to find similarities at multiple levels: document number, description of series, printing techniques, etc. This aimed at observing which aspects professionals focused on and if their choice was efficient to detect links. Then, the profiling method was presented and participants were asked to profile a second document independently, deemed more complex than the one from the first exercise. The description of the series to which the document belonged was incomplete and did not make it easy to find the link. This allowed raising the participants' awareness on the importance of series descriptions. This test aimed at determining how participants used BIDIF, how they compared documents and established series, and how the new method was understood and applied. Due to the workshop time restraints (1 h), the evaluation of the results was essentially qualitative. There was not enough time to collect structured feedback due to organisational reasons.

During the first exercise without knowledge of the method, most participants quickly found a correct match by checking the document number between the document of interest and those in the database. Then, they searched other links in the database using filtering options. Thus, the document number comparison and the use of the filtering options appear to be intuitive to forensic document examiners and anchored well in practice. On the other hand, the selection of characteristics by these specialists to search for matching documents were not clearly defined and based mostly on intuition alone (except for the document numbers comparison). Thus, while some examiners were able to give a correct answer (a link with one document), they could not specify the common characteristics between the documents. Other examiners noted the following points: an asymmetry, a difference in the printing techniques or in colour compared to the genuine document. However, they found no links with the series based on these characteristics. This highlighted that examiners did not systematically carry out a detailed analysis phase (i.e., they probably only recorded general characteristics for their database search to set relevant filters), but started directly with the comparison steps. This is a problem commonly known in forensic science circumvented by the introduction of the ACE-V approach [12–14].

After being trained on the method, the examiners actually followed the new procedure, especially with the pre-existing series. After pooling the relevant profiling characteristics (i.e., results from the analysis stage), all participants were able to give a quick and correct answer. This highlighted again the importance of the analysis stage, necessary to detect series based on subtler anchor points such as those found in this exercise: syntax errors, spelling mistakes in the pre-written data, the particular shape of a letter and irregularities in the frames. It was also noted that some experts only examined the front side of the documents. While this sped up the process, links can be missed if profiling characteristics are mainly present on the back side of the document.

This experimentation showed that the use of BIDIF and the profiling method were relatively easy to address even for new users. In addition, by correctly following the proposed method the participants were able to detect similarities more quickly, with greater confidence and transparency as they could explain the features they considered. Hence, more efforts should be put on teaching the importance of the analysis and comparison stages, in particular the comparison with pre-existing series.

3.2.3.2. Test on forensic science students. Two exercises stages aimed at comparing the performance of the students prior to and after being taught the profiling method. First, an introduction of BIDIF and its functions was given through an example. Then, students were divided in two groups of 9 and 8 students. Each group received 9 documents (respectively A1-9 and B1-9) from a pool of 18 case examples (see Table 2). The students had 30 min to compare each document in BIDIF and answer a questionnaire choosing one of the following three options for the 9 FID:

- stating whether the document was linked to a series (which one),
- whether the document was linked to another document (which one),
- whether the document remained unlinked.

In the third stage, the method was presented and illustrated through a practical case. Finally, students were given 9 additional documents to profile in 30 min (using the same questionnaire for reporting their results). The group having dealt with the documents A1-9 in the first exercise was given the B1-9 documents for the second exercise, and vice versa.

In this test, documents belonging to series as well as isolated documents were selected. Moreover, some documents (A6 and B2) were selected because their characteristics were very close to other series as well. Finally, several documents were of the same type and were issued from the same countries, but belonged to different series: Eritrea driving licence (A1, A8, B1, B7), Romanian identity card (A2, A7, B5), Syrian Arab Republic driving licence (A3, B3) and Afghanistan driving licence (A5, B4). This selection of documents was representative of BIDIF's

Table 2
Description of the documents from the exercises submitted to the forensic science students.

Series anonymous name (18)	Country, type of document, type of fraud	Existence of a link in BIDIF with
A1	Eritrea, driving licence, counterfeits	Series
A2	Romania, identity card, counterfeit	Series
A3	Syrian Arab Republic, driving licence, counterfeits	One document
A4	Democratic Republic of the Congo, driving licence, counterfeits	Series
A5	Afghanistan, driving licence, counterfeits	One document
A6	South Sudan, driving licence, counterfeits	Series
A7	Romania, identity card, counterfeit	One document
A8	Eritrea, driving licence, counterfeits	Series
A9	Guinea, pass, forgery	Series
B1	Eritrea, driving licence, counterfeits	Series
B2	Slovenia, identity card, counterfeit	Series
B3	Syrian Arab Republic, driving licence, counterfeits	One document
B4	Afghanistan, driving licence, counterfeits	Series
B5	Romania, identity card, counterfeit	One document
B6	France, identity card, counterfeits	Series
B7	Eritrea, driving licence, counterfeits	One document
B8	Belgium, identity card, forgery	Series
B9	Switzerland, resident permit, counterfeits	One document

diversity and thus enabled students to be tested under conditions as close to the reality as possible.

The students' feedback was unanimously positive. They all mentioned the ease-of-use of BIDIF and the clarity of the profiling method. They reported that the first exercise was relatively easy, while they had the impression to be less effective during the second exercise. However, as can be seen in Table 3, students globally profiled fewer documents during the first exercise compared to the second one: in total 85 (56%) compared to 102 (67%), respectively. This can be explained by an adaptation delay for the use of BIDIF, making participants more efficient in the second set of exercises, and/or an added value of the profiling method, allowing students to detect more quickly relevant characteristics and links. Given the students' expressed feelings and comments on BIDIF's ease-of-use, the second explanation was at least partially supported.

After the introduction of the profiling method, participants profiled 6, instead of 5 cases within 30 min. In average, they spent 5,4 +/- 1,5 instead of 6,4 +/- 1,5 min per case (RSD of 24 and 27% respectively).

In addition to increased efficiency, the method provided a higher percentage of true positive and lower rate of false negative results (see Table 3 and Fig. 17). Only the false positive rate was not significantly improved. This may be explained by the lack of experience of the students or the lack of time available to confirm the highlighted links. The globally low rates of false positives and negatives indicated that the credibility and integrity criteria were met in a profiling perspective.

Most of the links and series correctly detected by the participants were those that were previously identified within BIDIF (49 out of 64, 77%), while the number of links and series was lower for the isolated documents (22 out of 38, 58%). It was not surprising that it was more difficult to detect a new series than to assign a document to a pre-existing series for which the characteristics were already described and illustrated.

Moreover, as expected, some participants linked A6 and B2 documents with the wrong series (containing the same type of documents with very similar characteristics). While such false links were counted as false positives, the given series could have been counted as two sub-series composing a same series overall. In practice, once the students found the link, they stopped consulting other series and thus missed the correct attribution. This observation supported the concept of sub-series to solve such issues to which examiners might also be confronted in practice.

4. Conclusion

In this study, a profiling method to be used by forensic document examiners was developed and tested to support a more efficient forensic intelligence approach. The method aimed to systematically compare fraudulent identity documents to detect series that reveal the activity of criminal networks and prolific forgers who produce, disseminate and/or use fraudulent identity documents. The method was built, refined and assessed using documents from the Interstate Database of Fraudulent Identity Documents (BIDIF) implemented in Switzerland. The method significantly increased the series detection rate within the database and decreased the rate of undetected series. The implementation and test of the method contributed to identifying 15 new series and to detect new links between 56 additional documents within BIDIF (16 documents from the development set, 2 from the test set, and 38 from previously isolated documents).

Tests conducted on forensic document examiners and Master students in forensic science showed that performance was significantly increased after being taught the profiling method, in terms of speed, true positives and false negatives. The impact was not significant on false positives. The method also allowed examiners to explain through which observation they detected links.

In conclusion, the method meets the criteria required for an efficient profiling method, namely credibility, integrity, timeliness and flexibility. Forensic document examiners may use this method as a guide for processing databases of fraudulent travel and identity documents, such

Table 3
Results for the profiling of 18 documents by 17 students (306 possible links to be searched in BIDIF).

Prior to the profiling method being taught	**Profiled FID**	**True positive**	**False negative**	**False positive**
After the profiling method being taught	**n= Number of possible cases**	**n= Number of profiled cases**		
Series	**n=94**	**n=56**		
	56 (60%)	33 (59%)	19 (34%)	4 (7%)
	n=93	**n=64**		
(i.e., When similarities observed between two or more documents indicate a common origin)	64 (69%)	49 (77%)	10 (16%)	5 (8%)
Isolated (i.e., not belonging to a previously detected series)	**n=59**	**n=29**		
	29 (49%)	4 (14%)	21 (72%)	4 (14%)
	n=60	**n=38**		
	38 (63%)	22 (58%)	14 (37%)	2 (5%)
All (i.e., series and isolated)	**n=153**	**n=85**		
	85 (56%)	37 (44%)	40 (47%)	8 (9%)
	n=153	**n=102**		
	102 (67%)	71 (70%)	24 (24%)	7 (7%)

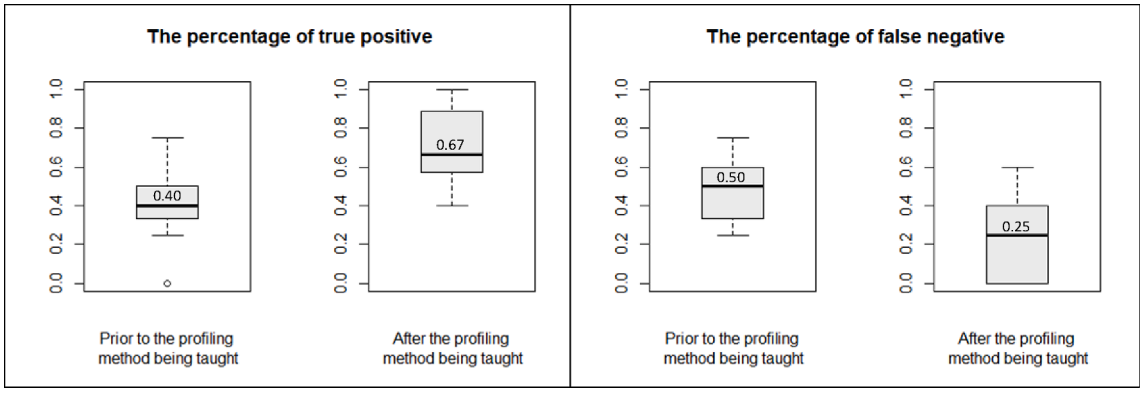

Fig. 17. Boxplots of the percentage of true positive (left) and false negative (right).

as BIDIF, to highlight series. The ISF ProFID project funded by the Internal Security Fund – Police of the European Commission (ISFP-2020-AGPOLCOP n°101036247) serves currently as a framework to further develop and disseminate the forensic profiling method presented here amongst law enforcement agencies throughout Europe. Document examiners from a dozen European countries have already been trained to take advantage from the method, and more are to come.

The current method does not allow comparing different types of documents, thus the comparison of the colour code of laser printed documents may be a useful additional characteristic. The question of series and sub-series should also be investigated further as documents can easily be classified in the wrong sub-series if the operator did not identify related series.

Further research should assess the impact of the profiling method in a fully operational environment, and its integration with automatic image comparison capacities such as that available in BIDIF.

CRediT authorship contribution statement

Solène Lugon Moulin: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft. **Céline Weyerman:** Supervision, Validation, Writing – review & editing. **Simon Baechler:** Conceptualization, Data curation, Methodology, Project administration, Supervision, Validation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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