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A Survey of Computer Methods in Forensic Handwritten Document Examination

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Abstract

Forensic document examination is at a cross-roads due to challenges posed to its scientific basis as well as due to the availability of revolutionary computer methods. This paper surveys recent efforts in the areas of establishing a scientific basis of forensic handwriting examination, software tools to assist document examiners and software systems that automate some of the examination process. This includes tools that compute features and provide visualization to assist the document examiner, verification methods to provide the degree of match between a questioned and known document, identification methods that narrow-down the search from a repository of documents with known writers, and software architectures that allow a variety of forensic tools to be integrated.

I. Introduction

The analysis of handwriting from the viewpoint of identification of the writer has a long history perhaps dating to the origins of handwriting itself. Crime involving documents, ranging from fraud and anonymous letters to armed robbery and murder, is dealt with by Questioned, or Forensic Document Examiners. Much of this forensic work involves the comparison of handwriting and handwritten signatures. Numerous techniques have been developed and employed during the past century in the examination of handwriting to establish (i) the identity of the writer of a questioned document from one or a set of known handwritings; (ii) whether the handwriting is forged (the author is not who he claims to be) or (iii) whether the handwriting is disguised (the author is trying to disclaim the writing). There exist numerous text-books describing the general methodology employed by forensic document examiners in various developed countries, e.g., [1], [2], [3], [4], [5].

Whether handwriting can be used to identify a person is of great importance to justice and law enforcement systems. Other branches of forensic examination of evidence, such as DNA analysis, analysis of fibers and other material is supported by a wealth of chemical and biological scientific knowledge which has been demonstrated and proven by scientific study. During the last decade numerous challenges have been made regarding presenting expert forensic document examination testimony in the courts (Daubert vs Merrell Dow Pharmaceuticals, 1993, United States vs Starzecypzel, 1995). The challenges are based on whether handwriting evidence has a scientific validation of its individuality. Long-established forensic handwriting examination has only recently faced this question and it has been found that there are inadequate scientific studies for the individuality argument. Such challenges, known in the United States as Daubert challenges, have led to a need for a scientific demonstration of the individuality of handwriting. The problem is that forensic document examination employs many reasonable but scientifically unproven techniques. The acceptability of expert opinion is strongly based on the credibility and standing of the document examiner rather than on the scientific evidence supporting their opinion.

Over the past 30 years there has been a limited amount of research into using computers to enhance and automate the analysis performed by forensic document examiners [6], [7], [8]. Much of the research centered on pattern recognition techniques for extracting static and dynamic features from handwriting

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and hand written signatures as well as enhancing document images and ESDA lifts ([9]). These were primarily software tools to assist a document examiner rather than establishing any scientific basis for their work.

In recent years forensic document examiners in various countries, and particularly in the USA, have been seeking to strengthen their standing through Accreditation and Certification schemes, formalized training and other means (FSAB, 2003).

More recently, computer scientists have begun to apply various computer-vision and pattern recognition techniques that have been developed during the past 40 years [10], to the problems of writer identification and the authenticity/individuality of handwriting.

In this paper we review some the key techniques and results that have been published over the past few years in providing scientific support and computer-based tools to assist forensic document examination. This paper focuses on articles published in English, although it is recognized that some key relevant work is published in other languages. The paper is organized as follows. Section 1 is a description of studies concerning psycho-motor aspects of handwriting that have a bearing on forensic handwriting examination. Section 2 consists of work relevant to establishing the individuality of handwriting and studies establishing the expertise of handwriting examination. Section 3 describes computer-based tools that have been developed for use in forensic laboratories. Section 4 describes comprehensive systems that incorporate a variety of tools and procedures for document examination. Signature verification is dealt with separately in Section 5 due to its special nature and importance in document examination.

II. Psycho-motor aspects of handwriting

The study of handwriting covers a very broad field dealing with numerous aspects of this very complex task. It involves research concepts from several disciplines : experimental psychology, neuroscience, physics, engineering, computer science, anthropology, education, forensic document examination, etc.

From a generation point of view, handwriting involves several functions. Starting from a communication intention, a message is prepared at the semantic, syntactic and lexical levels and converted somehow into a set of allographs (letter shape models) and graphs (specific instances) made up of strokes so as to generate a pen-tip trajectory that can be recorded on-line with a digitizer or an instrumented pen. In many cases, the trajectory is just recorded on paper and the resulting document can be read later with an off-line system.

The understanding of handwriting generation is important in the development of handwriting examination systems, particularly in accounting for the variability of handwriting. So far, numerous models have been proposed to study and analyze handwriting. These models are generally divided into two major classes : top-down and bottom-up models [10]. Top-down models refer to approaches that focus on high-level information processing, from semantics to basic motor control problems. Bottom-up models are concerned with the analysis and synthesis of low-level neuromuscular processes involved in the production of a single stroke, going upward to the generation of graphs, allographs, words, etc. An ink-deposition model in the formation of signatures [11] can also be thought of a bottom-up model.

III. Studies in handwriting individuality

Establishing the scientific basis of forensic document examination has been approached recently in two different ways. The first of these is to establish that the performance of expert forensic document examiners is superior to that of lay people. This has been done by performing controlled tests with human subjects [12], [13], [14], [15]. Kam et al. concluded that forensic document examiners are significantly better at identifying valid and forged handwriting than the lay person. This indicates that the training and methods used by professional document examiners is indeed a sign of expertise. However, their ability and performance was only gauged on proficiency tests. There is no clear scientific evidence on which they can fully support their decision.

Another approach to establishing a scientific basis for handwriting examination is through the development of an information processing model of the task. An information processing model of a cognitive task, e.g., biological vision, consists of a computational theory, representations/algorithms and implementations. A computational theory consists of determining as to what is to be computed and the approach to be taken. An information processing model has the advantage of repeatability, i.e, the same results are obtained when applied to the same documents. Also, large numbers of tests can be performed to establish statistically significant error rates.

Such an information processing model and a particular realization through specific algorithms and software implementations were developed for handwriting [16]. The computational theory of handwriting examination posits the tasks of handwriting identification as well as for handwriting verification. In identification the goal is to determine the closest match among a set of known writers and in verification it is one of determining whether two documents were written by the same individual or by different individuals [16], [17], [18]. At the level of representations, the discriminating elements of handwriting consisted of macro-features, obtained at the global level from the entire document, and micro-features, obtained at the level of individual handwritten characters. The implementation was in the form of a software system whose performance could be evaluated in a batch processing mode with a completely autonomous control structure. Error rates on samples representative of the general population as well as that of cohorts were used quantify the individuality of handwriting.

The degree to which handwriting is individual has been explored in the context of handwritten numerals[19], alphabets and words [20]. In these studies the degree to which numerals, alphabets and words are useful in discriminating between individuals are given.

The stability of features used by document examiners for letter-level comparison have also been examined [21], [22], [23] as well as overall writer identification methods [24]. The letter-level studies, based on five different lower case letters ('a', 'd', 'f', 't' and 'y'), indicate that there is stability and individuality in some of these features, thus supporting the observations of Kam et al. and the techniques employed by professional forensic document examiners.

IV. Handwriting Examination Tools

This section describes computer-based tools for questioned documentation. These are interactive tools that enhance documents to ease the work of the human document examiner.

A number of tools were researched and developed for separation of the handwriting from the background (paper) in scanned document images to ensure that the detail of the handwritten strokes is retained [25], [26], [27], [28], [29], [30] as well as perform semi-automatic line, word and letter segmentation of the handwritten script for comparison chart generation [31], [32]. Tools were also provided to perform global feature extraction and provide visualization for the individual letters/words of the handwriting [33], [34], [35].

Current commercial products available to assist document examiners include the WriteOn and Pikaso software systems.

V. Handwriting Examination Systems

There are several systems with multiple functionality that include both interactive tools to aid the document examiner and automated writer recognition functionality. These are described in the following.

A. FISH System

Several computer software tools to assist document examiners (but not provide scientific support) in their analysis techniques were developed in the 90's. One particularly effective system (known as FISH, for Forenisc Information System Handwriting) was developed by German law enforcement [36]. FISH enabled interactive work with the document examiner so as to enable retrieval of the closest match from a large database of examples of handwriting.

B. WANDA Architecture

As a successor to the FISH system, German, Dutch and American researchers and practitioners have jointly developed a generic framework for forensic handwriting examination and writer/signature identification services known as the WANDA Workbench [37], [38], [39]. WANDA is an open software and system architecture based on the following considerations: (i) allow integration of computer-based methods and facilities currently in use in forensic laboratories, (ii) allow future updates with state-of-the-art technology, and (iii) have an open plug-in concept to promote newer computer-aided examination and identification procedures to be developed by independent research groups and industrial entities. The framework enables integration of routines for other script systems, e.g., Kanji, Arabic, etc., which can focus on a specific processing target, yet take advantage of common data management [37], [38] and preprocessing [40], [41].

The client-server system provides generic interfaces for plug-in applications of GUIs and processing modules. The applied plug-in concept supports a functional extension of the framework without programming effort onto the WANDA framework itself. Currently available plug-ins support the acquisition and preprocessing of handwriting and signature samples [41], [40], the semi-automatic measurement and recognition of allographs [42] as well as in the automatic feature extraction and writer identification on the base of digitized piece of handwriting [43]. Future steps comprise the integration and elaboration of signature analysis procedures [44], [37], [45], [46].

The Wanda project has defined the WandaML standard for specifying the content of documents in human readable XML form [38]. This is described in the following.

A document annotation file always start with a root element <wandoc/>:

```
<wandoc
     id="20032004"
     label="Anthrax example case"
     xmlns="DTD-HOME.html" />
```

where *id* is a machine generated unique document annotation identifier, *label* is provided by the user and the name space *xmlns* points to the wandoc language definition. In the example of Figure 1, the <wandoc/> element contains a single page:

Fig. 1. Wanda document annotation using regions. Two envelopes from the recent anthrax case illustrate Wanda regions: A region of interest is delineated, isolating one envelope from the page. A filter is applied to the region to clean the data. A hierarchy of regions (e.g. in address block, lines, words, and characters) is defined and annotated. Source: US Federal Bureau of Investigation.

```
<wandoc ...>
      <pages numberOf="1">
<page id="2003_5"
label="frontpage"
          next=""/>
      </pages>
</wandoc>
```

To shorten the description here, the tag attributes are replaced by ”...”. The page contains one call to a filter, two annotations, and one region:

```
<page ...>
      <filters number_of="1"/>
      <annotations number_of="2"/>
      <regions number_of="1"/>
</page>
```

The ¡filters ...¿ tag is expanded below. In this example, a filter imports an image from a scanner using the a scan software called ”IBIS” and returns a link to the resulting image. In the wandoc framework,a document consists of one or several pages, each of which may be represented by an image. There is no need for a special tag <image/>. Images are imported through defined filters, e.g. the scan filter.

```
<filters number_of="1">
    <filter type="import"
label="ibisScan">
       <inputs>
           <input type="stream"
                  number="1"
                  xmlns="scan.dtd">
               <scan/>
           </input>
       </inputs>
       <module type="extern"
               exec="ibis.exe">
           <meta version="3.51" />
       </module>
       <outputs>
          <output type="file">
              <wanda\_link
              href="copy5.tif" />
          </output>
       </outputs>
    </filter>
</filters>
```

Annotations are entered by an expert (e.g. with a GUI):

```
<annotations number_of="2">
    <annotation
        type="content"
        xmlns="content.dtd">
        <whole_document
            type="envelope"
```

```
            intent="personal"/>
    </annotation>
    <annotation
        type="writer"
        xmlns="writer.dtd">
        <writer id="2015">
            <properties
                handedness="left"
                skill="ok"/>
        </writer>
    </annotation>
</annotations>
```

The region content is the following:

```
<regions number_of="1">
    <region
        id="2003_1"
        label="Letter to Tom Brokaw"
        next="2">
        <points>
            <point x="0" y="0" />
            <point x="0" y="124" />
            <point x="76" y="124" />
            <point x="76" y="124" />
        </points>
        <annotations number_of="3"/>
        <filters number_of="1"/>
    </region>
</regions>
```

A region is defined by a unique id (presumably machine generated). Ids allow users and programs (filters) to refer to regions. Otherwise, by default, filters apply to their parent region, page or document. Additionally, regions may possess a user-defined label, the intent of which is to facilitate searching through regions. The attribute next" is used to indicate a logical ordering of the regions, which are at the same hierarchical level. Such ordering is used, for instance, to indicate reading order. Regions are delineated by a polygon defined by a set of points. The origin is at the upper left corner. The unit, if not specified, is the pixel. The region in the example possesses three annotations and one filter. The filter corresponds to some measurements and returns features (not shown).

C. CEDAR-FOX System

As a result of a US NIJ sponsored study on handwriting individuality, an information processing model of handwriting examination was developed [47]. This led to a system for forensic document examination known as CEDAR-FOX . This system contains several tools for interactive handwriting examination as well as methods for autonomous operation. In the autonomous mode it can perform several operations incuding writer verification, writer identification and signature matching.

The goal of identification is to identify the writer of a questioned document given a repository of writing exemplars of several known writers. The goal of verification is to provide a level of confidence as whether a questioned document and a known document are from the same writer. Central to both identification and verification is the need for associating a quantitative measure of similarity between two samples. Such a quantitative measure brings in an assurance of repeatability and hence a degree of objectivity.

Several methods for comparing strings of binary feature vectors representing handwritten characters were evaluated [48], [19] with the result that a correlation measure is used within the system. Two documents for verifying writership are shown in Figure 2 and a screenshot of CEDAR-FOX comparing the two documents are shown in Figure 3. The result shows a score representing the strength of evidence.

(a) **(b)**

Fig. 2. Exemplars for writer verification: two document portions for comparison from a case.

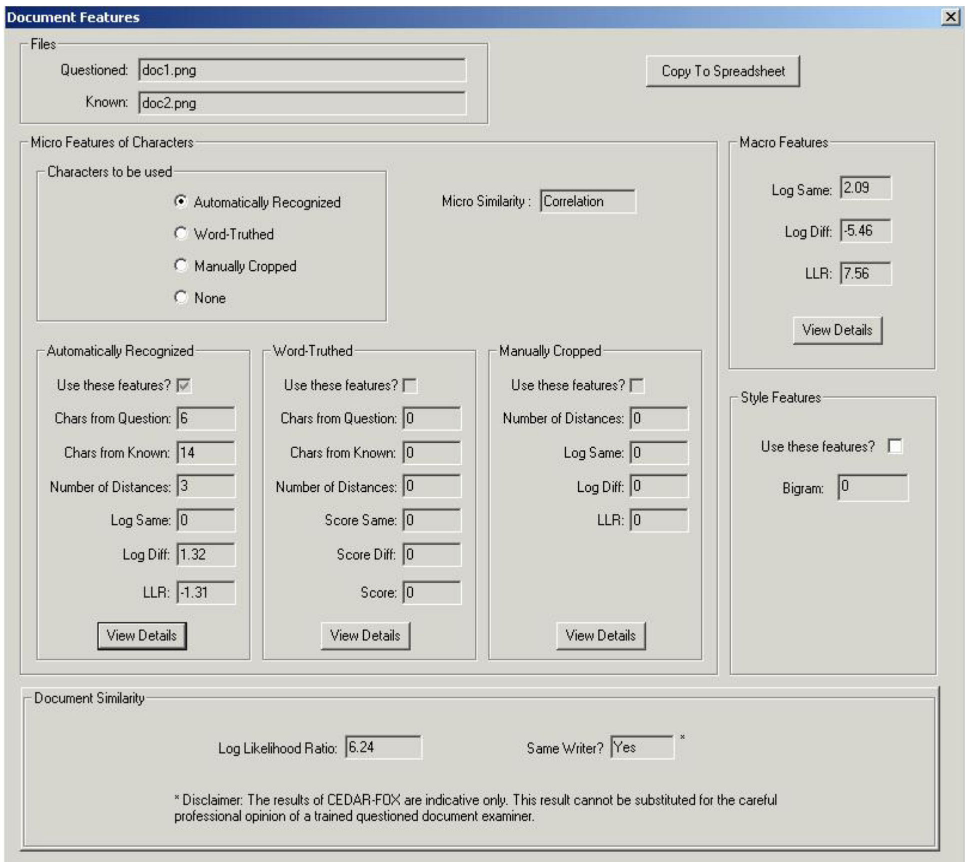

Fig. 3. CEDAR-FOX writer verification: screenshot showing the result of comparison of documents of Figs. 2(a) and 2(b).

The writer verification system has two separate modules available: the first is writer-independent and the second is writer-dependent. In the writer-independent approach no training on a specific writer is needed. In the writer-specific mode the system is trained on a set of documents from a given writer.

CEDAR-FOX also has several capabilities for searching a digital repository of handwritten documents. Search can be performed in several modes including word spotting– where a certain word image is used to find other similar words in the document(s), word recognition – where a given word shape is used to rank a lexicon, and text-based search – where a text word query is used to find the best match.

VI. Signature Verification

Identification and verification of handwritten signatures is an important part of day-to-day forensic casework. While computer-aided systems available today are mostly designed for the processing for handwritten text only, increase in white-collar crime such as check fraud has created a need for more extensive approaches to automatic and semi-automatic signature processing.

The effects of different writing instruments on signatures on paper documents have been taken into account for computer-based analysis at the Fraunhofer IPK in Germany. The variability, incompleteness and uncertainty inherent to signatures led to the use of soft biometric technologies such as fuzzy logic, artificial neural networks and evolutionary computation[46]. Resulting modules and systems for signature preprocessing, feature extraction and evaluation are now operating in banks worldwide as well as in forensic laboratories. The scientific and technological contributions of this effort are as follows:
(1) design and evaluation of image processing operations using soft computing technologies [41], [49], [50].
(2) adaptive and knowledge-based algorithms for the preprocessing of documents in forensic contexts [41], [40].
(3) static signature verification methods, particularly for the evaluation of signature topology [51].
(4) pseudo-dynamic signature analysis under consideration of different writing instruments [44], [45], [37].

The CEDAR-FOX signature verification system is currently based on matching shapes of signatures [52]. Both person- independent training as well as person-dependent training are available.

VII. Future research directions and challenges

Research into computer methods in forensic document examination is still at an early stage. The research reviewed is only concerned with techniques and tools for the comparison of writing samples to identify authorship. There is considerable further research required to provide detailed scientific evidence of the nature of handwriting individuality.

Further research is also needed to provide scientific evidence and tools to identify disguised writing, forged handwriting and well as altered or modified writing. In addition, computers could provide impressive assistance in the restoration or decipherment of damaged or partially destroyed documents.

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