Role of Automation in the Examination of Handwritten Items

Sargur N. Srihari
CEDAR, Department of CSE, University at Buffalo
The State University of New York, Buffalo, NY 14260 USA

Kirsten Singer
Office of the Inspector General, Department of Veteran's Affairs
Washington DC 20007, USA

***Abstract*—During the last few years the pattern analysis and machine intelligence community has developed automation tools for forensic document examination (FDE), in particular for determining whether a given handwriting specimen can be attributed to known writing. As with other expert systems, such as for medical diagnosis, current automation tools are useful only as part of a larger manually-intensive procedure. Defining a computational approach for the overall problem not only places these tools in context but also helps validate and improve existing manual procedures. We consider the standard work flow in FDE of handwritten items and annotate the steps where automation is available or possible. A well-known ransom note case is considered as an example, where there are multiple questioned documents, testing for multiple writers of the same document, determining whether the writing is disguised, known writing is formal while questioned writing is informal, etc. The findings for the particular ransom note case using the tools are given. Observations are made for developing a more fully automated approach to FDE.**

***Keywords*-handwriting examination, forensic document examination, writer verification, writer identification,computational forensics,expert system validation**

I. Introduction

The examination of handwritten items is the most common task in forensic document examination (FDE). The examiner has to deal with various aspects of documents, with writership being the central issue. Procedures for handwriting FDE have been described over the course of a century[1], [2], [3], [4], [5]. Several computational tools for FDE have been developed over the last two decades by the pattern analysis and machine intelligence community [6], [7]. Specific tools include FISH[8], CEDAR-FOX[9], [10], and FLASH-ID[11]. Such tools, which have the capability of extracting handwriting features for the purpose of side-by-side comparison, have been used to establish scientific foundations such as the individuality of handwriting [9], [11] and quantifying the strength of evidence as a likelihood ratio [12]. Yet, handwriting examination practice continues to be a largely manual intensive effort based on FDE training.

The situation is not dissimilar to expert systems where automation is only a part of the process, e.g., medical diagnosis, where the stakes are high. Thus there is a need to systematize human procedures so that they can be better understood, validated and improved. Such procedure specification has been referred to as computational thinking [13]. The need for validation is also vital to the forensic sciences [14]. Applying computational thinking to forensic procedures is computational forensics[15].

The necessary ground-work has already been laid down with the ASTM document *Standard Guide for Examination of Handwritten Items* [16] listing steps that must be followed. Hereafter referred to as the *standard procedure*, it represents the knowledge engineering necessary for an expert system. For the validation purpose, the standard procedure has been vetted and accepted by the FDE community.

Following the standard procedure, the examiner often needs to make several decisions, since every case has special needs, e.g., *ransom notes* could be written by multiple writers thus requiring comparison of document sub-parts, with *historical manuscripts* different writers may be more similar to each other than with contemporary writers thus requiring recalibration of individualizing characteristics [17].

We describe the standard procedure and annotate steps where existing and future computational tools are useful. As a concrete example, we consider the well-known Lindbergh ransom note case familiar to the forensic community. It illustrates the range of problems to be tackled, including extended writing, addressed envelopes, disguise, poor quality images, writer training, and finally expression of an opinion.

II. Terminology

Two distinct terminologies need to be integrated:

A. Questioned Document (QD) terminology

absent character: present in one and not in the other
character: language symbol: letter, numeral, punctuation
characteristic: a feature, quality, attribute or property
class characteristics: properties common to a group
comparable: same types, also contemporaneous, instruments
distorted: unnatural: disguise, simulation, involuntary
handwritten item; cursive, hand-print or signatures
individualizing characteristics: unique to individual
item: object or material on which observations are made
known (K): of established origin in matter investigated.
natural writing: without attempt to control/alter execution
questioned (Q): source of question, e.g., common with *K*
range of variation: deviations within a writer's repetitions
significant difference: individualizing charac. outside range
significant similarity: common individualizing characteristic

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sufficient quantity: volume required o assess writers' range
type of writing: hand-print, cursive, numerals, signatures
variation: deviations introduced by internal (illness, medication) and external (writing conditions, instrument)

B. Pattern Recognition (PR) terminology

bigram: a pair of characters, usually common ones, e.g., *th*
cropping: process of specifying boundary of a region
distance: measure of difference between two feature sets, reciprocal of similarity measure
features: characteristics of writing, e.g. macro (spacing, slant, etc), micro (character or bigram shape)
image processing: enhancement processes, e.g., noise removal, thresholding
log-likelihood ratio (LLR): strength of evidence that two items were written by the same or by different individuals: logarithm of the ratio of two probabilities
region of interest (ROI:) region of document to be compared
resolution: number of pixels per inch, typically 300
scanning: conversion of item to digital image by specifying resolution and number of gray levels
transcript mapping: automatically associating text in a transcript with each word image
truthing: associating image of character/word with text
word segmentation: process of separating images of words

III. Standard Procedure

The standard (human expert) procedure for examining handwritten items [16] involves making several decisions and item comparisons, which need not be sequential.

1) Determine if comparison is *Q v. Q*, *K v. K*, or *Q v. K*. The first when there are no suspects or to determine number of writers. The second to determine variation range. The third to confirm/repudiate writership.
2) Determine whether Q and K are original or copies. If not original, evaluate quality of best reproduction and check whether significant details are reproduced with sufficient clarity. If not discontinue procedure.
3) Determine whether Q and K are distorted.
4) Determine the type of writing. If more than one, separate into groups of single type.
5) Check for internal inconsistencies in groups. If inconsistencies suggest multiple writers, divide groups into consistent subgroups. For K, if there are unresolved inconsistencies, stop procedure and report accordingly.
6) Determine range of variation for each group/subgroup.
7) Detect presence/absence of individualizing characteristics.
8) Evaluate comparability of Q and K. If not comparable request new K and repeat.
9) Compare bodies of writing.
10) Compare and analyze differences and similarities to form conclusion. The recommended terminology for expressing FDE conclusion is [18]: 1-Identified as same, 2-Highly probable same, 3- Probably did, 4- Indications did, 5- No conclusion, 6- Indications did not, 7- Probably did not, 8- Highly probable did not, 9-Identified as Elimination.

IV. CEDAR-FOX: An FDE Tool

The CEDAR-FOX system [12] is an interactive tool for FDE which assists in performing several steps of the standard procedure. First Q and K documents are scanned[1]. Images may be noisy (salt/pepper noise) or have unwanted elements, e.g., stamps and seals. Several interactive tools are available for prepareng the document for processing: ROI can be isolated by cropping, noise reduction to remove speckles, adaptive thresholding to extract writing from background, eraser to remove unwanted artifacts, and automatic rule line removal. After this, document processing is enabled which yields many intermediate outputs, e.g., cursive/handprint determination, line/word segmentation, in addition to feature values (described below). Any errors in automatic word segmentation can be manually corrected using the polygon or lasso tool. Text is associated with word images (truth) by either automatic transcript mapping (done by providing a plain text transcript), or manual truthing of hand-segmented words; transcript mapping result can be manually corrected.

For each item examined, a set of macro or global features are computed[9]; they refer to global attributes such as slant, spacing, thickness, pixel distribution, etc, which can be turned on/off individually. Micro features are computed for characters; these are a set of 512 bits known as GSC features [12]. Similar features are computed for bigrams, and words; for words a 1024 bit string is used. Two additional features are *th* features and lexeme features. The special treatment of *th* is because it is the most common bigram in English and also has the highest discriminating power among letters and bigrams; its features are computed by first skeletonizing the image and obtaining a small set of descriptive features.

Distances between writing elements in Q and K are determined, e.g. overall slant, the letter *a*, etc. Distance for a macro feature is typically the absolute difference, for micro features it is a binary string correlation distance [19]. Note that there can be a very large set of corresponding pairs of elements. The ratio of probabilities of the distance in same/different populations is computed, where each probability is determined from parametric statistical models. The logarithm of this ratio is an LLR. Using a naive Bayes model, which assumes independence of features, the LLRs of writing elements are added. A positive LLR favors same

[1]At a resolution of 300 dpi. Higher resolution 600 dpi images are internally converted to 300 dpi images before computation. Images are to converted to 8 bits per pixel gray-scale.

writership and a negative value indicates different writers; higher absolute values indicating greater strength[20]. The total LLR is mapped to an opinion scale.

A. Use of FDE Tools in Workflow

Step 1: Determined by problem specification.
Step 2: Quality can be determined either visually or by evaluating results of automatic processing.
Step3: Distortion is detected manually. In the future it can be done using rarity measures[21].
Step 4: Type determination is done using a continuous scale between hand-print and cursive.
Step 5: This is to check for internal consistency within groups, e.g., multiple authors. Performed by comparisons between documents within groups.
Step 6: This is to determine the range of variation for a given writer. It can be accomplished by analyzing the range of LLR values for the same writer, with negative values indicating wide variability.
Step 7: Currently CEDAR-FOX takes into account all characteristics and not just individualizing characteristics. In future software releases individualizing characteristics will be isolated using the rarity of writing elements [21].
Step 8: This is to evaluate comparability of bodies of writing. With automated tools we can compare two documents even if they are not of same type but results will be less accurate.
Step 9: Before comparison, image regions are selected by cropping and removing extraneous information. With care so as to not affect writing where text overlaps seals and paper creases. The image is thresholded to remove background noise. Writing elements are provided with truth. Document level comparison can be refined by paragraph and word level results.
Step 10: The results of comparison are LLR values. The LLR captures both similarities and differences between corresponding writing elements. Small LLR values reflect a higher difference in writing. Similarly high LLR values reflect high degree of similarity of corresponding elements. The LLRs can be mapped to the nine-point opinion scale of the standard procedure. This mapping is a function of the total LLR value as well as the quantity of handwritten material compared[20].

V. Illustrative Case

A. Background

At approximately 9:00 p.m., on March 1, 1932, Charles Augustus Lindbergh, Jr., 20-month-old son of the famous aviator Charles Lindbergh and Anne Morrow Lindbergh, was kidnapped from the nursery on the second floor of the Lindbergh home near Hopewell, New Jersey. The child's absence was only discovered at about 10:00 p.m. by the child's nurse, Betty Gow. A search of the premises revealed nothing but a ransom note demanding $50,000 on the nursery window sill. The brief handwritten ransom letter contained many spelling mistakes and grammatical errors. The kidnappers also left a mark on the ransom letter, two overlapping circles colored blue and a red circular seal colored in the region of overlap between blue circles. This mark was prove the authenticity of the kidnappers in the ransom letters that followed.

On March 6, 1932, Charles Lindbergh received a second ransom letter in which the ransom demand was increased to $70,000. A third ransom letter was received by Lindbergh's attorney on March 8 which said that an intermediary appointed by the Lindberghs would not be accepted and requesting a note in a newspaper. On the same day, Dr. John F. Condon a retired school principal published in a newspaper an offer to act as go between and to pay an additional $1000 ransom. The next day Dr. Condon received a fourth ransom note which indicated the kidnapper's acceptance of him acting as an intermediary. Subsequently, Lindbergh also accepted.

Following the kidnapper's instructions Dr. Condon met an unidentified man who called himself "John" with who he discussed payment of the ransom money. A baby's sleeping suit along with a ransom letter were received by Dr. Condon on March 16. By this time a total of seven ransom letters were received. The suit was later identified as Lindbergh Jr.'s. By the ninth ransom letter the ransom demand had increased to $100,000. By the twelfth ransom note, Condon met "John" to reduce the ransom amount to $50,000. This amount was handed to "John" in exchange for a final note containing instructions to find the kidnapped child. However, searches for the baby were unsuccessful.

On May 12, 1932, the body of Lindbergh, Jr., was found about four and a half miles away from the Lindbergh home. A Coroner's examination showed that the child had been dead for about two months. The cause of death was ascertained to be a blow to the head. Some handwriting experts at the time believed all the ransom notes were written by the same person. They further believed the writer was of German nationality but would have spent some time living in America. However this has been challenged by some others.

On September 19, 1934, Bruno Richard Hauptmann was arrested by way of tracking the gold certificates which was paid as ransom money. Hauptmann however stated that the money had been left behind by his friend and former business partner Isidor Fisch, who had died on March 29, 1934. Hauptmann was charged with extortion and murder. He was convicted of the crimes and sentenced to death. Four years after the kidnapping, on April 3, 1936 Bruno Richard Hauptmann was electrocuted.

Throughout the years, the Lindbergh case has been the subject of much controversy and many hoaxes. As with most famous and notorious crimes the Lindbergh kidnapping has attracted its fair share of alternative theories. One such theory pertains to the involvement of a person named John Knoll as one of the perpetrators. A German immigrant and a deli clerk, he is believed to have an uncanny resemblance

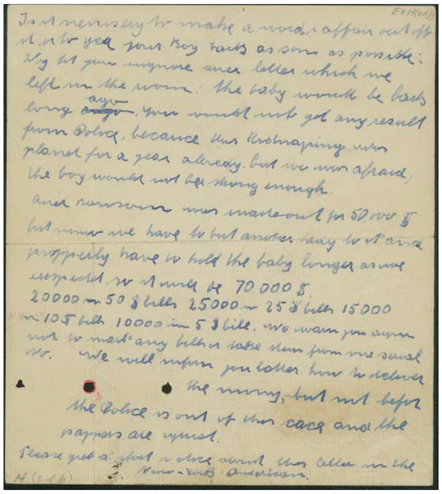

It is necessary to make a world affair out of it to get your boy back as soon as possible. Why did you ignore our letter which we left in the room. the baby would be back long ago. You would not get any result from Police, because this kidnapping was planed for a year already. but we was afraid, the boy would not be strong enough.
And ransom was made out for 50000 $ but now we have to put another lady to it and propperly have to hold the baby longer as we expected. so it will be 70000 $.
20000 in 50 $ bills 25000 in 20 $ bills 15000 in 10 $ bills 10000 in 5 $ bills. we warn you again not to mark any bills or take them from one serial No. We will inform you latter how to deliver the mony, but not befor the Police is out of this case and the pappers are quiet.
Please put a short notice about this letter in the New-York American.

Figure 1: A ransom Note: QR_2.

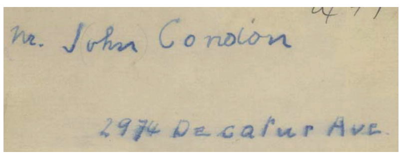
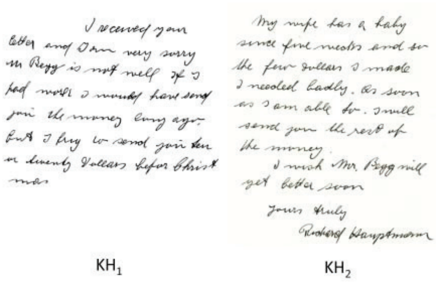


Figure 2: A ransom envelope: QE_7.

to the unknown intermediary "John". However, it is unclear if John Knoll had any part to play in writing the ransom letters. We examine here the possibility of John Knoll having written a part or parts of the ransom letters using computational methods.

B. Given Documents

There are two sets of *questioned document* images: six ransom notes QR_1–QR_6 (Fig.1) and twelve ransom envelopes QE_1–QE_{11} (Fig. 2). There are two sets of *knowns*: two halves of a Hauptmann letter addressed to Mrs. Begg: KH_1, KH_2 (Fig. 3) and four self-addressed first day covers of Knoll: KK_1–KK_4 (Fig. 4).


I received your letter and I am very sorry Mr Begg is not well. If I had work I would have send you the money long ago. But I try to send you ten or twenty Dollars befor Christ mas

My wife has a baby since five month and so the few dollars I made I needed badly. As soon as I am able to, I will send you the rest of the money. I wish Mr. Begg will get better soon.
Yours truly
Richard Hauptmann

Figure 3: Known Hauptmann (Mrs. Begg): KH_1, KH_2.

Figure 4: A John Knoll first-day cover: KK_1.

C. Comparisons to be Performed and Results

1) *Internal consistency and range of variation of knowns (steps 5,6 of workflow): KH_1 v. KH_2.* Range of variation from LLR *similarity matrix*. Similarly KK_i v. $KK_j, i, j \in \{1, .., 4\}$.
2) *Internal consistency and range of questioned: QR_i v. QR_j*, $i, j \in \{1, .., 6\}$. Similarly QE_i v. QE_j
3) *Q v. K:* QR_i v. KK_j, $i = 1, 2, ..6$, $j = 1, .., 4$. Similarly QR_i v. KH_j, $i = 1, 2, ..6$, $j = 1, 2$

1) KH_1v. KH_2: This is to check the internal consistency and range of Hauptmann letters to Mrs. Begg. The single comparison of the two halves of the letter are shown in a screen shot of CEDAR-FOX in Fig. 5. The characters were manually cropped and truthed in each document. All the default features were enabled for the comparison. The pop-up results screen has the following LLR values: macro (9.93), character (22.2), bigram(12.2), th (0), word (1.2), and lexeme (0.85). The total (46.3) is a high enough positive value to indicate internal consistency. The range is highest at the word level.

2) KK_iv. KK_j: This is to test internal consistency of the Knoll self-addressed first day covers. Since there are only three lines of text some macro features were disabled. Results in Table I show that the total LLR is positive in all cases indicating consistency. Macro LLR values have the lowest values thus indicating highest range, of variation. Low bigram scores can be attributed to small amount of text. The character LLRs are highly positive. Since the total values are highly positive we conclude there is sufficient consistency.

Table I: KK_i vs KK_j LLR values.

	Total	Macr	Word	Bigr	Char	Opinion
K_1v.K_2	81.4	-2	30.5	5.7	46.8	ID As Same
K_1v.K_3	18.8	-4.7	4.9	0.8	14.8	Prob Did
K_1v.K_4	33.2	-11.4	12.9	9.5	21.7	High Prob Same
K_2v.K_3	43.8	7.1	3.6	8.5	18.4	High Prob Same
K_2v.K_4	43.2	-2	14.7	1.5	26.6	High Prob Same
K_3v.K_4	32.4	1.0	14.3	1.6	16.5	High Prob Same

3) QR_i v. QR_j: This is to check internal consistency of the ransom notes. The document matrix of total LLRs between all pairs of documents is given in Table II. Since there

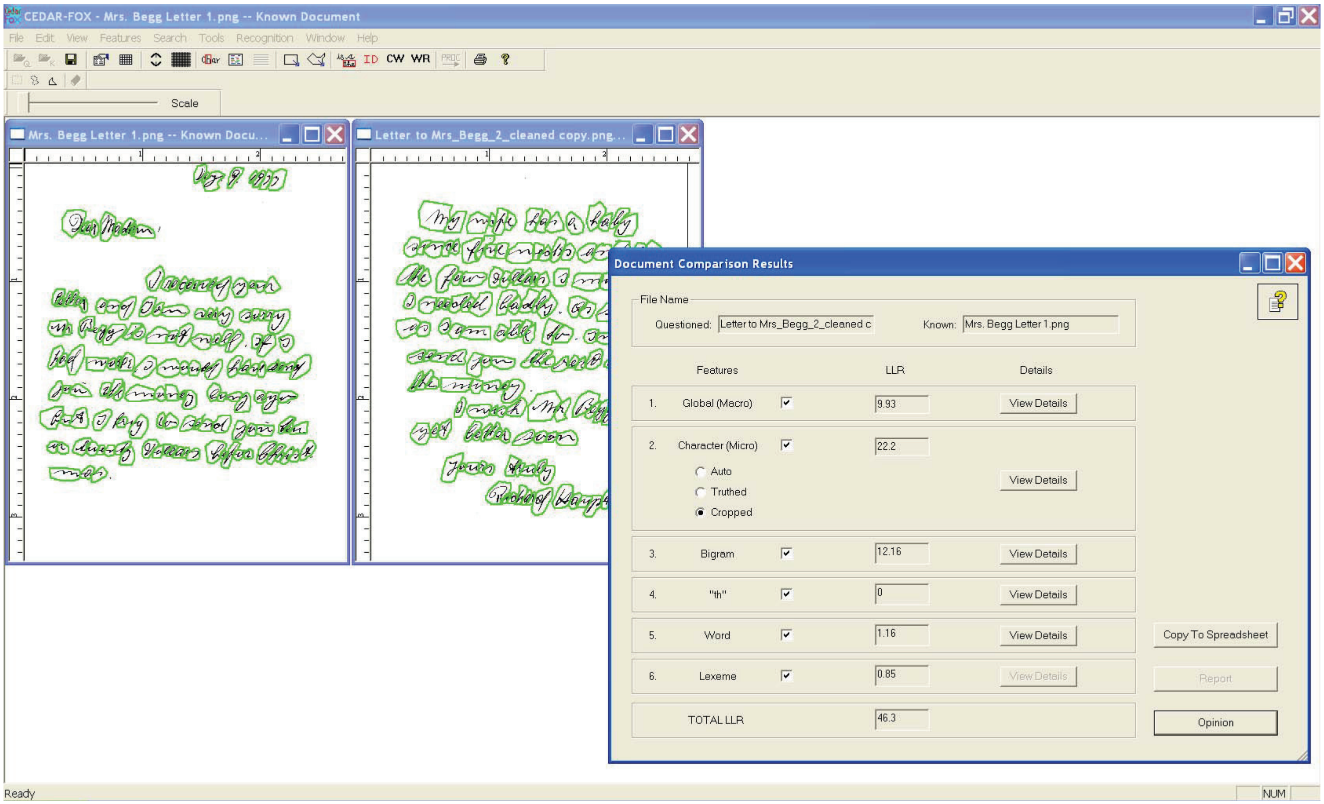


Figure 5: Comparison of Hauptmann knowns (halves of Mrs. Begg letter) using CEDAR-FOX: $KH_1 v.KH_2$.

is wide variability, it raises the possibility of multiple writers or disguise. One of the documents QR_5 has only positive values indicating that it would serve as the best model for this writing. When we look at only the bigram level (Table III), there is significant similarity. Thus reflecting internal consistency but a high range of variability.

Table II: QR_i vs QR_j: Document LLR

	QR_1	QR_2	QR_3	QR_4	QR_5	QR_6
QR_1	-	13.3	-0.6	-96.6	28.7	-19.3
QR_2	13.3	-	49.3	-29.7	73.2	-15.4
QR_3	-0.6	49.3	-	0	55.1	-16.5
QR_4	-96	-29.7	0	-	78.4	-44.2
QR_5	29	73.16	55.1	78.4	-	29.3
QR_6	-19	-15.4	-16.5	-44.2	29.3	-
Total	-74.5	90.6	87.3	-92.0	264.6	-35.3

4) QR_i v. KH_j: The two halves of the Hauptmann known (Mrs. Begg letter) were compared to the ransom notes with the following LLRs: First half: {-50, -45, -40, -91, -41, -41}, Second half: {-29, -50, -37, -94, -6, 3}. Thus there is strong indication that Hauptmann was not the writer of the ransom notes.

Table III: QR_i vs QR_j: Bigram LLR

	QR_1	QR_2	QR_3	QR_4	QR_5	QR_6
QR_1	-	11.5	5.2	18.45	20.2	2.6
QR_2	11.5	-	7.8	20.9	27.1	3
QR_3	5.2	7.8	-	6	8.5	4
QR_4	18.5	20.9	6	-	21.9	1.1
QR_5	20.2	27.1	8.5	21.9	-	9.2
QR_6	2.5	3	4	1.1	9.2	-

5) $QE_i v.KK_j$: Here Q consisted of ransom note *envelope* addresses. K consisted of the Knoll self-addressed first day covers. It yields largely negative results (Table IV). The only common word in both Q and K is "John". The results of word comparison are given in Table V. The values are both poshtive and negative leading to an inconclusive decision.

Table IV: QE_i vs KK_j LLR values.

	E1	E2	E3	E4	E5	E6	E7	E8	E9
K_1	-8.8	-6	-13	-28	-17	-14	-17	-5	-19
K_2	-10	-4.6	-13.4	-28	-17	-13	-15	-9	-18
K_3	-0.1	-2.7	-9.5	-16	-10.7	-10.8	-7	-3	-13
K_4	-10	-9.5	-15	-28	-19	-21	-21	-8	-24

6) QR_i v. KK_j: Here Q consists of the ransom notes and K consists of the Knoll first day cover addresses. Document level comparisons all have negative total LLR (Table VI) indicating non-match. The first day covers have a small quantity of formal handwriting while the ransom notes contain many pages of text.

Table V: QE_ivs KK_j: Single word: *John*

	QE_3	QE_5	QE_6	QE_7	QE_8	QE_9	QE_{10}
K_1	−2.	0.6	1.46	0.1	−0.28	6.7	3.6
K_2	−2	0.9	5.4	0.3	−0.1	2.28	3.9
K_3	−4.1	−6.5	1.6	−3.04	−2.5	2.5	0.4
K_4	−9	−6	−3.12	−7.9	−7.2	1.15	−6.1

Table VI: QR_i vs KK_j: Document LLR

	QR_1	QR_2	QR_3	QR_4	QR_5	QR_6
K_1	−54.3	−52.6	−42.4	−62.5	−26.5	−16.3
K_2	−50.5	−48.6	−39.1	−57.6	−23.8	−14.1
K_3	−29.3	−36.3	−23.8	−47.6	−17.5	−5.2
K_4	−60.5	−58.1	−44.2	−73.2	−41.1	−27.5

VI. Discussion

The standard FDE procedure for handwriting can be cast in computational terms. It can be used to systematize and validate expert human procedures. Automation tools available to perform the steps include preparing the parts of the document to compare and obtaining quantitative results of comparison. In following the procedure many limiting factors can be identified at the outset and the process can continue or stop. Most time is spent in making comparisons such as K vs K, Q vs Q and Q vs K which can be very large when all possibilities are considered. The log-likelihood ratio based on distance is useful to quantify similarity and difference. It also measures the range of variations required to be measured within the standard FDE procedure.

The illustrative case provides a good example on how the work-flow of a document examiner can include an automation tool, e.g., in making comparisons at several levels (document, paragraph, word,and bigram) and interpreting the LLR values. We were able to draw the following conclusions: (i) K consisting of the Hauptmann knowns (Mrs. Begg letters) is inconsistent (does not match) with Q consisting of the ransom notes. (ii) We considered the hypothesis whether John Knoll was involved in writing the ransom letters. Here the only knowns (K) are self-addressed first day covers with formal writing while Q consists of the full set of ransom notes/envelopes. At the outset there is insufficient data for comparison. The results of CEDAR-FOX comparison also does not support this hypothesis.

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