

**Investigative Frontiers Integration of
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**Ink and Intent: Questioned Document
Examination and Handwriting Analysis in the
Modern Era**

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Abstract

Questioned document examination (QDE) is a crucial area of forensic science that utilizes scientific knowledge and sophisticated analytical methods to establish the authenticity, authorship and integrity of a questioned document. This review “Ink and Intent: Questioned Document Examination and Handwriting Analysis in the Modern Era” provides a basic introduction to the principles of handwriting identification and the various aspects of individuality, natural variation, specimen collection, handwriting characteristics and common forgery methods. It also investigates the current scientific and instrumental methods, including microscopy, Video Spectral Comparator (VSC), Electrostatic Detection Apparatus (ESDA), Raman spectroscopy, FTIR, XRF, chromatography and mass spectrometry, for the authentication of documents and the characterization of materials. The review also addresses the effect of Artificial Intelligence, Machine Learning, Deep Learning and Digital Forensic Technologies in Handwriting Comparison, Signature Verification and Digital Document Analysis. Lastly, it underscores the various forensic uses, evidential value, and growing challenges with sophisticated document forgeries and AI-generated documents, while urging for uniform approaches and ongoing technological development to ensure reliable forensic evidence in today's judicial systems.

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1 Introduction

The term "Ink and Intent" refers to the scientific study of the physical and graphical evidence found in written documents to determine their authenticity, origin, and intent. Questioned document examination (QDE) is a key forensic field that plays a vital role in the fight against document fraud, signature forgery, identity theft, financial crimes, and the verification of legal and historical documents.

Questioned Document Examination is the scientific examination of documents in which the authenticity, authorship or integrity is questioned. They can contain handwritten notes, signatures, wills, contracts, cheques, passports, certificates, money and digitally created documents. Forensic document examiners employ scientifically validated methods to examine handwriting, ink, paper, printing processes, erasures, alterations, and other aspects of a document and determine if it is genuine, forged, or altered. Handwriting examination is a type of handwriting analysis that is specifically concerned with comparing the natural features and variations of handwriting to determine the author.²

It is important to note that, forensic handwriting examination is not synonymous with graphology. Forensic handwriting examination is a science relying on standardized comparison techniques to determine or exclude writers for legal purposes, whereas graphology is a less scientific study based on the assumption that handwriting conveys personality characteristics, which has not yet been sufficiently validated for forensic purposes.³

Questioned document examination is an important aspect of criminal and civil investigations that includes the examination of counterfeit or altered documents, financial or legal records in question, identification of forgery of signatures and the verification of disputed documents. QDE continues to grow in the effectiveness of the documentary evidence and remains an essential

² P. Kumar, A. Deshmukh, P. Sharma, and D. Bhandari, *Forensic Examination Of Questioned Documents*, vol. 3. Iterative International Publishers (IIP), 2024. doi: <https://www.doi.org/10.58532/V3BJSO19P2CH13>.

³ M. Can, C. Işık, M. Cengiz, and M. Cengiz, "AI-Based Quantitative Handwriting and Signature Feature Analysis: Development and Validation of a Mobile Application for Forensic Document Examination—A Preliminary Study," *Forensic Document Examination — A Preliminary Study*, pp. 1–11, 2026, doi: <https://doi.org/10.3390/forensicsci6020041>.

instrument to the administration of justice with the use of sophisticated analytical instrumentation, digital imaging and computer-assisted techniques.

2 Fundamentals of Questioned Document Examination and Handwriting Identification

The principles of questioned document examination (QDE) are scientifically based and have been proven to help identify the authenticity, authorship and integrity of any questionable document. The discipline incorporates the observational abilities and analytical techniques that have been proven to investigate handwriting, signing, inks, papers, printing processes and alterations to documents. Hand-writing identification is based on the assumption that hand-writing is a learned motor habit, with consistent and characteristic features that are present, but with natural variations. Standardized examination methods and widely accepted guidelines guarantee objective results, repeatability, and proper legal proceedings.

A. Principles of Individuality and Natural Variation in Handwriting

Handwriting is a repeated practice skill and is a personal neuromuscular skill. No two writers write the same handwriting; no one person writes the same handwriting all the time. The differences are normal, and can be attributed to the following: writing speed, writing position, health, writing instrument, and environment. These differences are called natural variation. Expected differences are differentiated by forensic examiners from significant differences that can suggest simulation, disguise or forgery.⁴

B. Collection of Known and Questioned Specimens

The key to good handwriting comparison is to obtain proper specimens. Questioned documents are documents of which the authorship or authenticity is in question, while known documents are documents that have been collected from a known writer. If possible, use the same writing materials and repeat text to produce writings in similar conditions as the questioned document, to capture natural variation.

C. Handwriting Characteristics, Techniques, and Standards

Forensic handwriting analysis considers class characteristics (those that have been taught in a similar manner) and individual characteristics (those that are unique to an individual writer). The examination of letter formation, proportions, spacing, slant, pen pressure, connecting strokes,

⁴ Y. C. Chang, “‘Variation’ vs ‘individuality’: Redefinition in handwriting examination,” *Nowa Kodyfikacja Prawa Karnego*, 2022, doi: <https://doi.org/10.19195/2084-5065.64.8>.

rhythm, line quality and movement is done through visual comparison, stereomicroscopy, digital imaging and video spectral comparison. Examinations are performed in compliance with internationally accepted quality assurance practices and standards, including ASTM International and the Scientific Working Group on Forensic Document Examination (SWGDOC), to provide consistency, transparency and reliability.⁵

D. Common Document Forgery Methods

Document forgery can include traced signatures, freehand simulation of a signature, disguised handwriting, altered entries, documents erased or obliterated, documents substituted, document counterfeiting, and digitally manipulated documents. Handwriting, ink, paper and printing examination are all brought together in today's forensic examination to detect these fraudulent changes and determine the authenticity of challenged documents.⁶

3 Scientific Methods and Instrumental Techniques in Document Examination

Modern scientific techniques and analytical instruments have greatly improved the effectiveness of questioned document examination. Although visual examination is still a vital part of the forensic document examination, many of the current forensic lab tools utilize non-destructive and minimally destructive methods, which are used to analyze handwriting, inks, papers, printing materials and document alteration. These techniques give objective and repeatable evidence and can help forensic experts identify forgeries, determine the age of documents, discover the materials and instruments used to create and produce documents, and authenticate documents.

A. Microscopic and Optical Examination

The initial step in document analysis is to examine the document under a microscope, including stereomicroscopy. It allows for detailed study of handwriting, line quality, pen lifts, crossing strokes, erasures, alterations, paper fibres and printing defects. Video Spectral Comparator (VSC) uses ultraviolet (UV), infrared (IR) and filtered visible light to expose obliterated and erased entries, differentiate inks, scrutinize counterfeit security features, and reveal latent alterations. Electrostatic Detection Apparatus (ESDA) helps to identify indented writing on

⁵ M. K. D. B. Bhatt, M. A. Sharma, and M. K. J. Mehta, "Handwriting Characteristics as Indicators of Psychological States in Forensic Document Examination," *J. Harbin Eng. Univ.*, vol. 46, no. 12, pp. 303–311, 2025.

⁶ J. Jenifer, G. Sathiyapriya, R. Agalya, V. Supriya, and S. B. S, "Document Forgery Detection," *Int. Res. J. Adv. Eng. Hub*, vol. 04, no. 5, pp. 3585–3594, 2026, doi: <https://doi.org/10.47392/IRJAEH.2026.0467>.

underlying documents without harming them; thereby, it is useful for determining writing sequences.⁷

B. Spectroscopic and Chemical Techniques

Spectroscopic methods offer the possibility of detailed chemical characterisation of document materials. Raman spectroscopy, Fourier Transform Infrared (FTIR) spectroscopy and X-ray Fluorescence (XRF) can be used to determine the molecular and elemental composition of inks, pigments, toners, papers and security features, without altering the evidence significantly. Complementary techniques like chromatography and mass spectrometry can separate and identify dye constituents, solvents, and additives, and can aid in the analysis of volatiles from the degradation of the dyes, which can assist in the characterization of inks and dating documents.⁸

C. Paper, Ink, Printing, and Document Dating

Paper features such as fibre composition, fillers, coatings, optical brighteners and watermarks are used to aid in the identification of the document's origin and authenticity. Ink characterization identifies similar and different inks and finds additions or alterations at various times. Examinations for printers and toners involve assessing the printing processes, toner ingredients and common printer/copier malfunction to identify documents that can be matched with specific printers or copiers. Ink aging studies and solvent analysis provide document dating techniques to help estimate when the documents were produced. Many forensic documents are unique legal evidence, and modern laboratories generally prefer not to damage the document and use non-destructive analytical methods to obtain the results they need in a scientifically reliable manner.⁹

4 Digital Transformation in Handwriting and Document Forensics

Questioned Document Examination is a discipline that has undergone significant changes in the last twenty years, with the emergence of computer assisted, Artificial Intelligence (AI), and new imaging technologies. Computer-assisted handwriting comparison and document authentication

⁷ V. Gupta, K. Saini, and H. Aniket, *Forensic Importance and Advancements in Microscopic Examination of Questioned Documents*. 2025.

⁸ U. Mirzanli, P. Guzel, and N. Akbay, "Spectroscopic techniques and chemometrics for ink analysis: Document analysis application," *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.*, vol. 326, p. 125167, 2025, doi: <https://doi.org/10.1016/j.saa.2024.125167>.

⁹ B. J and S. K. R. G, "Forensic Examination Of Questioned Documents: Detection, Analysis, And Legal Admissibility," *INDIAN J. Leg. Rev.*, vol. 6, no. 1, pp. 1087–1098, 2026.

techniques have become a more common tool for forensic labs in recent years, providing greater accuracy, consistency and efficiency. The rise of electronic documents, digital signatures and automated content creation has broadened the territory of forensic document examination as well as raised new questions of authenticity and manipulation and evidential reliability.¹⁰

A. Computer-Assisted Handwriting Comparison and Artificial Intelligence

Computer-assisted handwriting examination uses a process of image processing to measure handwriting characteristics, thereby minimizing the subjectivity in manual comparison. The collection of handwritten data was used to develop a set of unique writing features, which are analyzed by machine learning (ML) and artificial intelligence (AI) to classify writers and to aid forensic writers in making decisions. The technologies are not substitutes for experts but are used as decision support tools to increase the objectivity and repeatability of handwriting analysis.¹¹

B. Deep Learning for Writer Identification and Signature Verification

In the field of automated writer identification and signature verification, deep learning models, especially convolutional neural networks (CNNs), have significantly enhanced the accuracy of the system. These learn discriminative features directly from handwriting images and are able to make high accuracy genuine or forged signature discrimination. In addition, research distinguishes between offline handwriting analysis, looking at the scanned image of the finished writing, and online handwriting analysis, which tracks the dynamic aspects of handwriting, like pen pressure, writing speed, stroke sequence, and pen trajectory, using a digital tablet. These lively characteristics enhance the verifiability of biometric signatures for identity verification.¹²

C. Digital Document Forensics and Emerging Challenges

With the growing prevalence of digital documents, forensic investigations have become more extensive, incorporating printer and scanner forensics, image enhancement, and automated

¹⁰ W. Yin, "Bridging tradition and technology: a theoretical framework for integrating handwriting and AI-enhanced digital stroke practice in online Chinese character instruction," *Innov. Lang. Learn. Teach.*, 2026, doi: <https://doi.org/10.1080/17501229.2026.2654186>.

¹¹ G. Marano et al., "Writing the Future: Artificial Intelligence, Handwriting, and Early Biomarkers for Parkinson's Disease Diagnosis and Monitoring," *Biomedicines*, vol. 15, no. 1764, pp. 1–32, 2025, doi: <https://doi.org/10.3390/biomedicines13071764>.

¹² C. K. Sonkar and D. V. Kumar, "Review of Artificial Intelligence Methods in Handwriting Identification Using CNN-RNN for Textural Features," in *International Conference on Cognitive Computing in Engineering, Communications, Sciences and Biomedical Health Informatics (IC3ECSBHI)*, 2025.

feature extraction techniques for the detection of alterations, identification of printing devices, and recovery of obscured information. With these advancements in generative AI technology, however, it has become more difficult to detect forgery, as highly realistic handwritten text, synthetic signatures, and manipulated digital documents can be created. To enhance the detection of AI-generated and manipulated documents and preserve the scientific integrity of digital evidence, forensic laboratories are incorporating explainable AI, cutting-edge imaging techniques, metadata examination, and standardized validation procedures.¹³

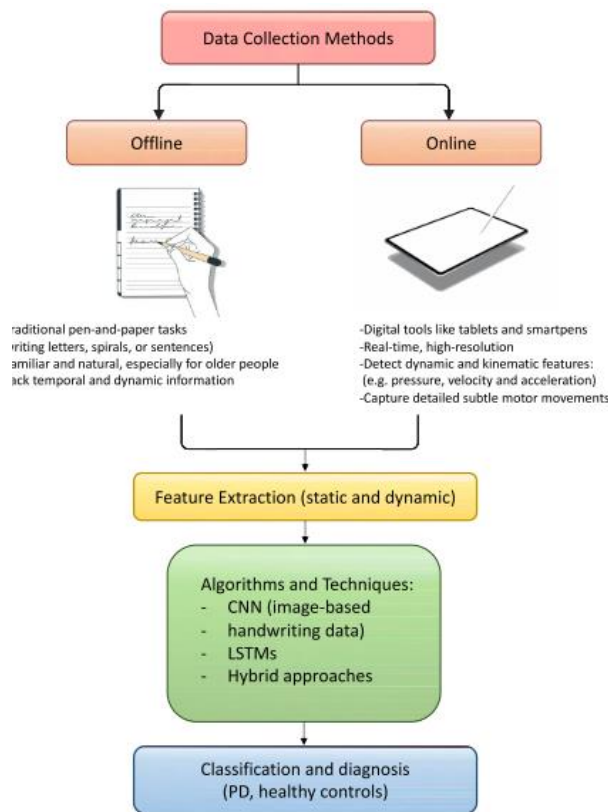


Figure 9: Schematic representation of AI-based handwriting analysis in PD¹⁴

¹³ M. A. M. Zia and O. M. Adedayo, “Tool type identification for forensic digital document examination,” *Forensic Sci. Int. Digit. Investig.*, vol. 54, p. 301972, 2025, doi: 10.1016/j.fsidi.2025.301972.

¹⁴ G. Marano et al., “Writing the Future: Artificial Intelligence, Handwriting, and Early Biomarkers for Parkinson’s Disease Diagnosis and Monitoring,” *Biomedicines*, vol. 15, no. 1764, pp. 1–32, 2025, doi: <https://doi.org/10.3390/biomedicines13071764>.

5 Applications, Evidential Value, and Challenges in Modern Questioned Document Examination

Questioned document examination (QDE) is now a part of forensic science that is used in the scientific analysis of questioned documents to assist in criminal investigations, civil litigation, and administrative inquiries. Forensic document examiners can use traditional handwriting comparison analysis along with more advanced analytical and digital techniques to arrive at conclusions about document authenticity, alterations, writer identification and document linkage. Document examination is a discipline that is becoming more important as technology advances, but also has its own challenges because of advances in forgery techniques and digital manipulation.¹⁵

A. Applications of Questioned Document Examination

Modern QDE has diverse applications in forensic and legal investigations, including:

- i. Forgery detection involving signatures, handwritten entries, and official records.
- ii. Authentication of legal documents, such as wills, contracts, deeds, affidavits, and agreements.
- iii. Financial crime investigations, including forged cheques, counterfeit currency, insurance fraud, and banking fraud.
- iv. Identity document examination, including passports, visas, driving licences, and national identity cards.
- v. Detection of document alterations, erasures, additions, obliterations, and substituted pages.
- vi. Printer, copier, and scanner identification through analysis of printing characteristics and toner features.
- vii. Historical document authentication for manuscripts, archival records, artworks, and cultural heritage documents.
- viii. Cybercrime investigations, including digitally created or manipulated documents and electronic signatures.
- ix. Anonymous letter and threatening communication investigations through handwriting comparison and linguistic examination.

¹⁵ U. Mirzanli, P. Guzel, and N. Akbay, "Spectroscopic techniques and chemometrics for ink analysis: Document analysis application," *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.*, vol. 326, p. 125167, 2025, doi: <https://doi.org/10.1016/j.saa.2024.125167>.

B. Evidential Value

The evidential value of questioned document examination is essentially that it renders scientifically valid opinions on the authenticity, authorship and integrity of disputed documents. Based on a systematic comparison of handwriting characteristics, ink, paper, printing methods and document features, using validated analytical techniques.¹⁶ When conducted to the internationally recognized standards, such as those set by ASTM International and Scientific Working Group on Forensic Document Examination (SWGDOC), the results of a QDE procedure provide reliable expert evidence which can help a court to resolve a criminal and civil dispute. However, this is not the only type of evidence used when making a forensic conclusion, it's evaluated in conjunction with other physical, digital and testimonial evidence.¹⁷

C. Challenges

Although technology has advanced over time, questioned document examination has its own challenges. Sophisticated forgery is now being used, combined with high resolution printing, digital editing software and artificial intelligence, making it harder to determine if a document is genuine or not. Examinations may be complicated by limited or poor quality comparison specimens, handwriting disguise (intentionally written differently), natural variation in handwriting, and degraded or damaged specimens. With the growing prevalence of electronic documents and AI-driven handwriting, new forensic issues about authenticity, validation, and explainability have emerged. Continued research, standardized methods, examiner proficiency testing and the use of advanced imaging and computational methods are therefore necessary to ensure the scientific integrity and the legal evidence of questioned document examination.¹⁸

6 Conclusion

Questioned document examination is a specialized area of forensic science that uses traditional handwriting analysis, analytical instrumentation, and digital technology to analyze and compare disputed documents to determine their authenticity and to identify possible alterations. The use of microscopic examination, spectroscopic techniques, document dating methods and non-

¹⁶ R. R. Gupta, "Evidential proof as questioned document examination report for criminal cases," *IP Int. J. Forensic Med. Toxicol. Sci.*, 2020, doi: <https://doi.org/10.18231/j.ijfmts.2020.021>.

¹⁷ H. J. Lai, L. H. Tsai, K. Y. Hsu, and W. C. Yang, "The Research on the Handwriting Stability in Different Devices and Conditions," *Sensors*, pp. 1–17, 2026, doi: <https://doi.org/10.3390/s26020538>.

¹⁸ T.-Y. Kang, H. Kim, S. Yook, and J. Lee, "A study on factors that affect error rates in handwriting examinations of Korean characters by forensic document examiners and non-experts," *Forensic Sci. Int.*, vol. 334, p. 111266, 2022, doi: <https://doi.org/10.1016/j.forsciint.2022.111266>.

destructive analytical techniques has greatly enhanced the accuracy and reliability of forensic document analysis. Moreover, advancements in artificial intelligence, machine learning and deep learning have improved writer identification, signature verification and digital signature authentication of documents, which helps forensic scientists in making decisions. However, with the advent of advanced forgery methods, AI-generated handwriting, and digitally altered documents, it has become increasingly difficult to meet such challenges, necessitating ongoing research, standardized approaches, and strict validation procedures. The scientific validity of questioned document examination will be enhanced by adherence to internationally recognised standards of quality and the use of computational methods that are easy to explain. Document fraud is a constantly changing phenomenon in both the real and electronic world, and QDE will continue to be a vital forensic field for assisting criminal investigations, litigation, and the administration of justice.

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