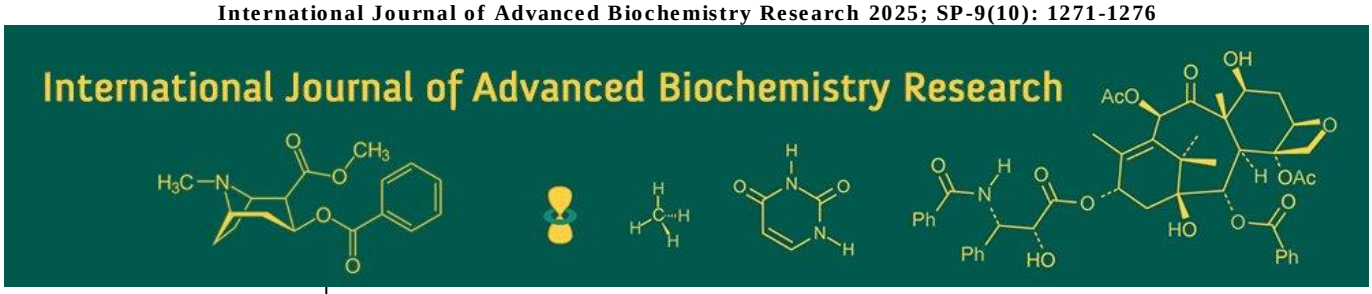

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Decipherment of homogenous ball ink altered handwriting through stereomicroscope and specific image enhancing tools

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Abstract
Handwriting is complex neuromuscular activity influenced by an individual's motor skills, cognition and learned habits, making it unique for each writer. Handwriting examination is a critical component of forensic document analysis. This study examines the effectiveness of stereomicroscopy and image enhancement techniques by analysing 6 different types of document alteration: addition, interlineation, modification, overwriting, writing with correction pen, and mechanical alteration. A total of 90 samples with six different types of alterations are used to see how well the used methods could find and describe the alterations. A stereomicroscope was used to carefully observe all the samples to make sure that the visualizations of the physical changes and ink layering were identified. However, detection was challenging due to a number of small or overlapping changes. To get around these limitations, the samples were followed with image enhancing techniques, which significantly improved the visibility and resolution of the alterations, making it simpler to differentiate between the original and altered text, particularly in cases where the changes were complex or subtle. The results showed that the two-method approach facilitates the process of identifying all the various types of alteration changes that have been made and improves comprehension of the steps that were taken to make and discover those changes.

Keywords: Stereomicroscopy, alteration, visualization, dual-method, enhancement, digital analysis

1. Introduction
Handwriting is the automatic, unconscious process of writing with flawless hand-muscle coordination sent to them by reflex action [1]. It is the process of creating letters and words on paper with various instruments, including a pen, pencil, chalk, and marker. Because it enables us to write in a way that other people can understand. People acquire a particular writing style that is highly distinctive to them as a result of this reflex action and departure from copybook style [2]. A crucial component of forensics is handwriting analysis, which can reveal a variety of information ranging from identifying the suspect who may have written ransom notes to confirming the documents' legitimacy [3]. Examining handwriting usually entails comparing handwriting evidence from disputed or questioned documents with known specimens. Three stages are included in the examination-Analysis, evaluation and comparison of handwriting traits [4]. An alteration is any change made to a document by physical, chemical, or mechanical means, including but not limited to erasure, addition, overwriting, or obliteration. Critical entries may occasionally appear after documents have been signed or paragraphed. Forged documents have been created by adding, deleting, or replacing words or images [5]. The differences between Individual and class characteristics of writing will be determined by the writer if different writing characteristics have been added by different writers.
Variety of techniques including alternate light source, magnification detection of indented impression, side lightening, transmitted lightening and others in a non-destructive method can be used to examine documents for characteristics indicative of alterations. When an alteration or addition has been made to a document, sometimes after it has been written there will usually be differences in the ink used. Alterations can be done by simple addition, erasures or removing any part of written portion [6].

But if writer is different the writing characteristics of the added document will also be different to those of main document. Differences will be found in the size and spacing of letter [7]. The effective use of oblique and transmitted light is crucial for identifying and evaluating modifications in documents. Transmitted light that penetrates the document can disclose inconsistencies in ink density, paper texture, and underlying inscriptions that may indicate tampering [8]. Image enhancement techniques further highlight these subtle traits, allowing forensic experts to clarify and differentiate between authentic and altered handwriting. Transmitted light saturates the evidence, reducing all darkness in the backdrop and attaining the intended look. The transmission angle can be easily modified from 90 degrees to 45 degrees [9]. Oblique lighting, which is angled across the surface of a document, helps reveal indentations, erasures, and alterations that may not be visible under normal lighting conditions. Low angle light is used in oblique lightening which highlights all the details by casting shadow on the evidence surface [10].

As a way to fix up digital pictures, contrast enhancement is often used to change the overall contrast and brightness [11]. It is important for the forensic document analysis to improve images and use different types of filters, like black point, contrast, brightness, highlights and saturation. One can change the document's color strength by changing the saturation, which brings out differences in the paper or the ink alteration done. By changing the brightness, one can bring out details that aren't as bright and make places that are darker brighter for better identification [12]. Increased contrast makes it easier to tell the difference between dark and light areas, drawing attention to small differences that could mean changes like added text or erased areas or overlapped writing [13].

When used collectively, these filters help forensic experts see and understand every aspect in a document, which makes it easier to find and analyze any changes or tampering that may have been done [14]. Using a stereo microscope and image enhancement filters together to find alterations is a good technique to fill in research gaps in forensic document inspection. They can also notice tiny details like pressure imprints, ink deposits, and surface irregularities which shows that someone has tampered with it [15]. This two-method approach helps to create new standards and methods for forensic identification that will help to improve the accuracy and reliability of alteration detection. Researchers can detect patterns of changes that were missed before, enhance methods for spotting forgeries help to learn more about document fraud by carefully looking at documents with these technologies. Which fills in the key gaps in the forensic literature. [16].

2. Materials and Methodology

For the consistency across the experiments, the standard document size of A4 (210 × 297mm) was used. Which ensured uniformity in image acquisition, processing and comparison thereby minimizing size related variations in the enhancement process. On standardized paper 15 different types of handwriting samples were made with each sample containing 6 types of alteration, making a total of 90 ball ink pen writing samples.

- **Addition Alteration:** The original writing was enhanced by adding lines or strokes.
- **Modification Alteration:** When the original words, letters and lines were changed [17].
- **Interlineation Alteration:** Insertion of words and lines into the original text.
- **Overwriting:** The original text was overwritten to change its appearance.
- **Correction Pen Use:** Parts of the writing were obscured or changed with a correction pen.
- **Mechanical Erasure:** To erase any particular portion mechanical erasing methods like scraping or using an eraser were used.

Each alteration type was carefully carried further to simulate common methods of tampering or modification in written documents.

A. Stereo Microscope Examination

All 90 samples were examined using a stereo microscope applying transmitted and oblique lighting for a three-dimensional inspection of the materials to detect microscopic discrepancies in ink application, surface irregularities, and other signs of modification, hence the utilization of the stereo microscope. The primary objective of this research was to visually determine the presence and characteristics of the changes. Subsequent to observation, samples were documented using a Nikon DSLR 3100 and a Samsung S24 Ultra (model [18].

B. The HP310 Scanner

All the Physical documents were firstly converted into the digital format by scanning the images using an HP 310 scanner. The HP 310 scanner is a crucial tool for forensic document analysis and modification identification. Successful forensic analysis depends upon high-resolution scanning, digital improvement, archiving, and comparison capabilities. By preserving the original document's integrity while facilitating a comprehensive investigation of its digital counterpart [19].

C. Image Capture and Enhancement

After the microscopic analysis, digital images of all the samples were taken. After that using a reliable image processing software, these photos followed a number of enhancing procedures. Among which the methods of improvement were:

Saturation Adjustment: To highlight the variations in ink colour whether the saturation levels were raised or lowered. Brightness and Contrast Adjustment: These adjustments are used to change the level of contrast between altered and original areas, making the alterations visible. Black Point Adjustment: The visibility of minute features in the ink were improved by adjusting the black point, especially in locations where changes were suspected [20]. Other Filters: Additional filters were applied as necessary to highlight specific features of the alterations.

D. Analysis of Alteration

To identify the changes done, a thorough examination of the altered images was conducted. Several important aspects were included to focus on the analysis, Finding out if the changes were obvious and differentiable from the original text, Named as "alteration detection" Evaluating how much the image enhancement methods enhanced the visibility and ability to identify the changes [21].

3. Results and Discussion

Referring to Fig-1, similar to which, all the 90 altered collected sample were carefully observed under stereomicroscope with transmitted and oblique lightening. Altered Sample such as addition, modification where alteration was done on surface were observed with oblique lightening as slanting angle reveals features with high contrast was better to study surface writings. Differences were carefully analyzed and compared to identify individual and class characteristics. Altered samples of correction fluid, overwriting on correction fluid where alteration was done beneath the surface were observed using transmitted light. Differences observed under the stereomicroscope were photographed using DSLR Nikon 3100 camera and Samsung S24 ultra for better examination. For better connectivity and versatile working all the images were digitized using HP 310 scanner. Thereafter to modify digital pictures and to enhance their appearance and make additional analysis easier to extract quantitative information image enhancement is done [22].

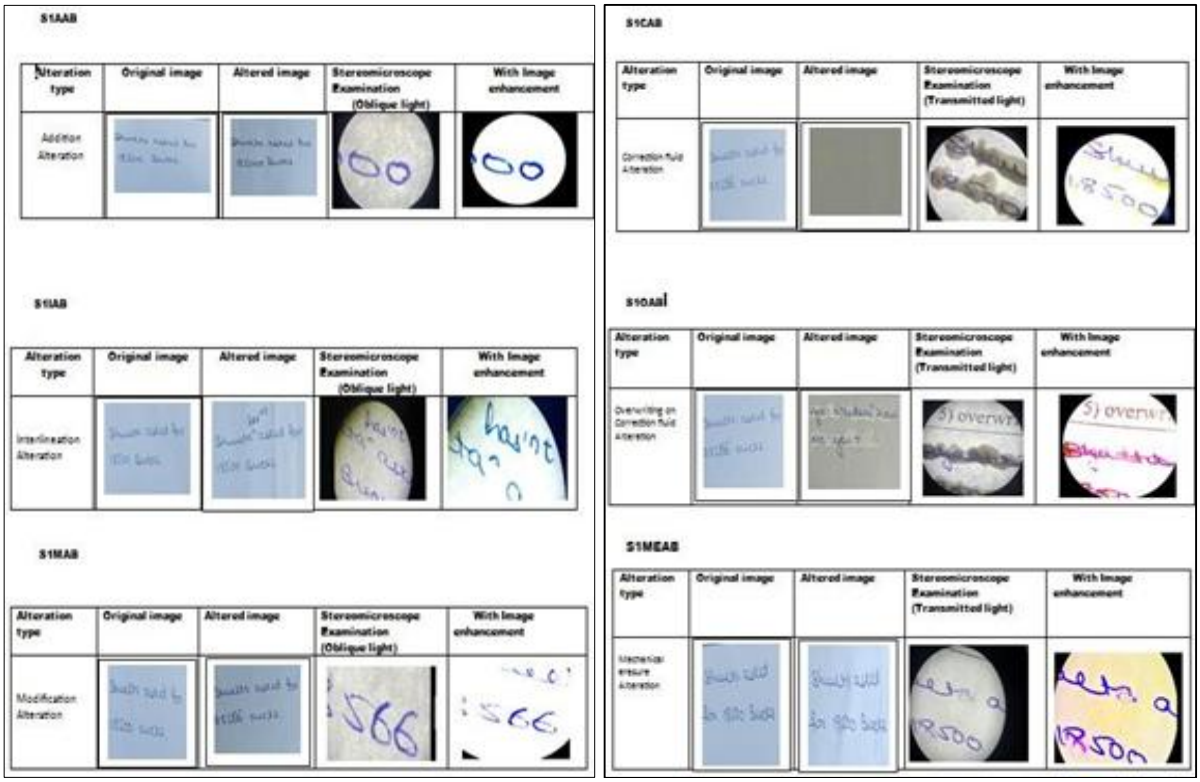

Fig 1: Shows collection of Sample 1 image in original, altered, in stereomicroscope and after image enhancement.

Tabulation of Observations

A table was created to systematically document the observations. The table was divided into four columns:

- **Column 1:** Original image of the sample.
- **Column 2:** Altered image of the sample.
- **Column 3:** Observation of the sample under stereomicroscope.
- **Column 4:** Observations after image enhancement.

Each row of the table corresponds to a specific sample, providing a side-by-side comparison of the initial and enhanced observations.

The table allows for a direct comparison between what was observed under the stereomicroscope and what was visible after image enhancement by analysing the differences, the effectiveness of image enhancement in improving the detection and clarity of alterations was assessed. The table serves as a key tool in concluding the role of image enhancement. It demonstrates how image enhancement techniques can reveal alterations that might not be visible under standard stereomicroscopic observation alone, thereby improving the overall quality of forensic document examination. This approach not only ensures accurate documentation but also facilitates a clear and structured analysis of the impact of image enhancement on the visibility of document alterations.

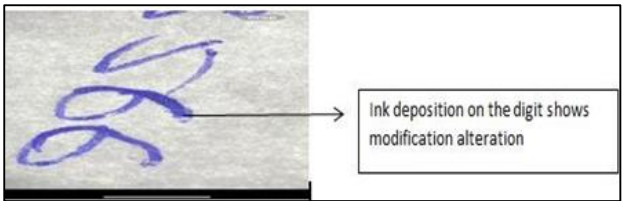

Fig 2: Ink deposition on digit observed under stereomicroscope

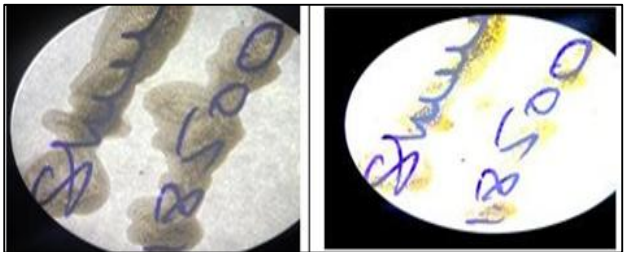

Fig 3: Sample with correction fluid alteration under stereomicroscope and after image enhancement

4. Statistical Findings

Overall Scoring	Image enhancement Ball Pen		Stereomicroscope Ball pen		P-value
	N	%	N	%	
High Decipherment	11	68.8%	5	31.3%	0.048
Low Decipherment	0	0.0%	3	100.0%	
Moderate Decipherment	4	36.4%	7	63.6%	

Fig 4: Shows overall scoring of image enhancement and stereomicroscopic images

Used Fisher Exact Test

The overall scoring results show a statistically significant difference (P=0.048) in decipherment effectiveness between the image enhancement of ball ink handwriting and the stereomicroscope observation of ball ink handwriting. A greater proportion of high decipherment cases (68.8%) were achieved using the image enhancement method compared to only 31.3% with the stereomicroscope. Notably, low decipherment occurred exclusively in the stereomicroscope group (100%), indicating a clear shortcoming in that method's effectiveness. Although moderate decipherment was more common with the stereomicroscope (63.6%), the image enhancement method still accounted for 36.4% of such cases. These findings suggest that the image enhancement on ball ink significantly improves the likelihood of achieving high decipherment quality and reduces the risk of poor results compared to the stereomicroscope approach.

The comparative analysis of decipherment quality between the image enhancement method and the stereomicroscope method across different types of document alterations reveals notable findings. For addition alterations, a statistically significant difference was observed (P=0.003), with the image enhancement method achieving a much higher percentage of "Very Good Decipherment" (76.5%) compared to the stereomicroscope method (23.5%), while the latter also had two cases of "No Identification". A significant difference was also noted in overwrite on correction fluid alterations (P=0.001), where the image enhancement technique again outperformed, achieving 81.3% "Very Good Decipherment" versus only 18.8% in the stereomicroscope group. For correction fluid, interlineation, mechanical, and modification alterations, the differences were not statistically significant (p>0.05), though slight variations in decipherment quality were observed. These findings suggest that the image enhancement method is particularly effective for deciphering certain complex alterations like additions and overwrites on correction fluid, offering a clear advantage over the stereomicroscope technique in these scenarios.

Used Independent T-test

The group statistics indicate that the mean overall scoring for image enhancement on ball ink was 15.53±1.302, while for the stereomicroscope it was 14.13±1.457. The associated p-value of 0.004 shows a statistically significant difference between the two groups. Image enhancement method yielding higher overall scores. Suggesting that image enhancement significantly improves the observed outcomes as compared to using a stereomicroscope alone.

Group Statistics	Image enhancement Ball Pen	Stereomicroscope Ball pen	P-value
Overall Scoring	15.53±1.302	14.13±1.457	0.004

Fig 5: The table shows overall scoring of both image enhancement and stereomicroscope

Used Pearson Correlation Test

The correlation analysis between image enhancement of Ball ink and observations under a stereomicroscope yielded a correlation coefficient (r) of -0.040 with a p-value of 0.887. This very weak negative correlation suggests that there is essentially no linear relationship between the two variables. Furthermore, the high p-value indicates that the result is not statistically significant, meaning the observed correlation could easily be due to random chance. Therefore, we cannot conclude that image enhancement on ball ink has any meaningful effect, positive or negative, on the observations made with a stereomicroscope.

Correlations			
		Image enhancement Ball Pen	Stereomicroscope Ball pen
Image enhancement Ball Pen	r	1	-0.040
	P-value		0.887

Fig 6: The table shows Correlation analysis between image enhancement method and stereomicroscope method.

5. Discussion

The study examined six different document alteration types: mechanical alteration, addition, modification, interlineation, overwriting, and writing with a correction pen. A total of 90 samples in all represents six different types of alterations that were generated and examined using both stereomicroscopy and image enhancement methods.

- **Addition Alteration:** In this alteration, stereomicroscopic examination showed obvious changes in the texture of the paper and the consistency of the ink. These changes were further highlighted by image enhancement, which helped to find altered additional text from the original.
- **Modification Alteration:** Under a stereomicroscope, some changes, like letters or numerals, were identified, while other changes blended in with the original text. By emphasizing the variations in ink density and strokes, image enhancement greatly increased clarity and made it easier to spot the alterations done.
- **Interlineation Alteration:** Because of variations in the ink flow and spacing, the additional text between lines was easily visible under the stereomicroscope. These changes were more noticeable with image enhancement, making it simpler to recognize the interlineated text.
- **Overwriting Alteration:** Under the stereomicroscope, overwriting was identified as a thicker and more asymmetrical ink deposition. Particularly when the overwriting was done with a comparable ink, the image enhancement technique made it easier to identify the overwritten portions apart from the original writing.
- **Correction Pen:** Writing on the top of already written text where underlying repair material were visible under the stereomicroscope, dissolves the ability of correction

pen and image enhancement method makes the portion more visible by increasing the contrast and brightness.

- **Mechanical Alteration:** Under the stereomicroscope, alterations involving physical modifications on the paper, like erasure or indentation, were easily identified. Additional contrast and detail from image processing helped to clearly identify the affected areas and made the changes more noticeable.

6. Conclusion

In the present study, the proposed image enhancement techniques significantly outperformed the existing methods in terms of clarity, contrast and feature visibility. Significant variations in the efficiency of detecting and describing changes were found when two step method identification was done. The enhanced images exhibited improved readability of minute details such as line strokes, pressure variations and overlapped writings, which were otherwise indistinguishable in the original or conventional processed images. The physical features of the changes, including texture, ink layering, and surface disruption, were clearly visible with the help of stereomicroscopy [23]. Some minor changes, though, were hard to spot, especially when they overlapped or were hidden by other changes. On the other hand, image enhancing techniques significantly increased the visibility and clarity of these changes, particularly when they were subtle or minute. Improved photos made it easier to identify between the original and modified text, facilitating the identification of the precise type and degree of alteration [24].

Stereomicroscopy and image enhancement together proved to be a beneficial method for forensic document analysis, enabling a more thorough and precise identification of changes. In addition to improving the accuracy of document tampering detection. This dual-method approach gave a more thorough understanding of the altering techniques employed [25]. The results highlight how crucial it is to use both digital and physical analysis methods in forensic investigations to guarantee accurate and comprehensive analysis of document modifications.

Image enhancement significantly improved the visibility and identification of alterations, particularly in challenging cases, even though the stereomicroscope provided a detailed picture of physical and textural changes [26]. All things considered, stereomicroscopy and image enhancement worked well together to precisely detect and describe every kind of change in the 90 samples.

7. Ethical Consideration

The study complied with ethical standards for experimental research. All of the samples were made purely for study and had nothing to do with actual forensic cases. The study was carried out with a dedication to uphold scientific impartiality and honesty, and no personal information was used.

8. Limitation of research

The six types of changes made to ballpoint pen writing on a particular kind of paper are the only ones covered in this study. To build on the findings, future studies could examine a wider variety of altering methods, various writing tools, or different kinds of papers. Furthermore, more research may be done to determine how successful various kinds of picture enhancing filters are.

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