Comparative Forensic Analysis of Ai-Generated Handwriting Samples: Implication for Digital Trace Forgery Detection.

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***Abstract*— The advent of Generative Artificial Intelligence like ChatGPT, Gemini, Grok, Perplexity, DeepSeek, and other Large Language Models has completely changed the way documents are created and interpreted. New AI tools are not only able to create text on their own, but improvements in architectures and algorithms have also increased their efficiency. It can produce digital documents with texts that closely resemble human handwriting and signature making it increasingly difficult to distinguish genuine documents from AI-generated ones. As a result, questions about authenticity and credibility have become central concerns in academics, administration, research, crimes including but not limited to case of suicide, property dispute, threat and cyber harassment, identity theft.With the advancement in generative AI, new issues have been raised in questioned document examination. For instance, generative AI can create realistic digital handwritten signatures that only mimic the appearance of writing and do not have physical characteristics like embossed features and indentation features caused by pen pressure. The possible threat is that this realistic handwritten signature can be used to create tracing on actual documents. This is another area where there is an urgent need to deal with AI-assisted forgeries.**

This research examines the role of digital forensics in identifying and validating the authenticity of documents produced with the help of various LLMs. This study explores the possibility that a handwritten document, when captured using a camera device and subsequently processed or regenerated with the assistance of AI, can reproduce an almost identical visual representation. The AI-generated output may show a striking resemblance to real handwriting samples by maintaining the pictorial features and incorporating natural variations. The study also looks at potential abuses of documents produced by AI, such as academic dishonesty, evidence fabrication, identity fraud, and official record manipulation.

This study aims to offer some helpful guidelines for determining whether any AI intervention has occurred in a document by examining current forensic practices and creating an investigation framework. The ultimate goal of this research is to assist forensic specialists, educators, and law enforcement in preserving the integrity of documents in a world where it is becoming more difficult to distinguish between content created by artificial intelligence and that written by humans.

***Index Terms*— AI Softwares/Applications, digital forensics, hand written documents, Large Language Models, traced forgery.**

I. INTRODUCTION

Artificial intelligence has progressed to the point where machines can replicate human handwriting appearance in addition to mimicking human writing style. These days, tools like ChatGPT, Gemini, and other large language models can generate documents that feel and look remarkably natural. AI systems can replicate text in a manner that closely resembles human expression and visual traits when given carefully constructed prompts such as “Rewrite this content in natural handwritten style with slight variations,” or “Generate a handwritten version that resembles an authentic personal note”.

This study's objective is to examine and comprehend the fundamental distinctions and parallels between real human handwriting and handwriting generated by artificial intelligence. Our goal is to observe the seriousness of the situation, flaws in LLMs, and conflicting legal opinions regarding the same.

Our goal is to see if AI systems can replicate human handwriting's subtle flaws as well as its overall style and structure. This investigation is crucial from the standpoint of digital forensics because, although AI systems can accurately mimic human handwriting, they could be abused to falsify personal notes, forge signatures, fabricate evidence, or alter written correspondence. Finding trustworthy forensic indicators that differentiate AI-generated handwriting from authentic writing is therefore essential for legal, scholarly, and investigative work.

During this tracing process, pressure from the writing instrument can produce embossed marks on the paper. Therefore, while generative AI can act as a useful tool for creating realistic handwriting samples for forgery, forensic document examiners may still detect the fraud by examining the physical embossing impressions and other tracing indicators on the questioned document.

Basic forgery in handwriting refers to the unsophisticated and unskilled attempt to imitate another individual's handwriting for the purpose of deception. It can be done by freely writing the individual's name, tracing the signature, and practicing to imitate the actual handwriting. Basic forgery in handwriting can be characterized by hesitation marks, tremors, inconsistency in the formation of characters, abnormal pressure of the pen on the paper, and lack of natural rhythm. Unlike natural handwriting, basic forgery in handwriting is characterized by slowness and mechanical appearance. In comparison to natural handwriting, basic forgery in handwriting can be easily identified by forensic experts.

AI-based forgery in handwriting is vastly different from traditional pen-based forgery in terms of characteristics and identification. Unlike traditional pen-based forgery in handwriting, AI-based forgery in handwriting is done by a machine using artificial intelligence. It can be characterized by physical attributes such as hesitation marks, tremors, inconsistency in the formation of characters, abnormal pressure of the pen on the paper, and lack of natural rhythm. In contrast, AI-based handwriting forgery is created digitally using artificial intelligence systems trained to replicate handwriting styles. Instead of physically writing, the AI system will produce a forged handwritten image or simulate patterns of strokes. The forgery produced by the AI system may not necessarily contain characteristics of hesitation and tremors. However, it can contain other characteristics.

Therefore, the physical characteristics of pen-based forgery are different from those of AI-based forgery. Pen-based forgery has physical characteristics related to motor skills, while AI-based forgery has characteristics related to digital and programming skills. The forgery created by using traditional methods can be detected using handwriting examination techniques. In addition, AI-based forgery can be detected using forensic document investigation and digital forensic investigation techniques. In AI-based forgery, a prompt acts as a command that instructs the AI system on what to write and how to write. When generating similar handwriting, the prompt provides details regarding the tone and style.

One such example, where a prompt might say:

"Generate this text in a cursive handwriting style similar to a 25-year-old male writer, with slight natural variations and moderate slant."

The AI does not recognize handwriting in the way a human does. Rather, the AI has learned from vast data sets that contain different kinds of handwriting. The AI recognizes patterns like the shape of strokes, the space between strokes, slant, thickness, and the formation of characters. The AI understands the prompt as a set of parameters for its output. The output generated by the AI will be based on the prompt provided. In advanced models, the user can upload a handwriting sample along with a prompt like: "Replicate this handwriting style while maintaining natural variation."

The AI recognizes features like proportion, curvature, pressure, and alignment. Then, the features are used to create new content. Although the prompt can be used to get the AI to produce handwriting that is very similar to the original, the generated result is still a simulated version of the handwriting. This is important when discussing forensic science, as natural variation and stroke patterns are crucial factors used to determine authenticity. In this research, we are going to focus on the forensic analysis of AI-generated handwritten documents. To understand the level of similarity between the handwriting of humans and the handwriting of AI, we collected handwriting samples (S) from different people. These handwriting samples are the real handwriting of humans, which includes all the variations, inconsistencies, and errors that come

while writing by hand. We then used different AI tools to write the same information in the style of the collected handwriting samples, which helps us compare the handwriting of humans and the handwriting of AI.

Through the exploration of the capabilities and limitations of the current state of LLMs, this research hopes to help create a better pathway for the detection of AI, ensuring the integrity of the document, and helping the investigators in a world where the line between human and machine is getting blurred very quickly.

II. MATERIALS AND METHODS

For this study, we employed a combination of AI-generated and human-produced documents to create questioned samples. The following materials were used:

1. Sample Collection

Handwriting samples of 24 individuals were collected to obtain natural handwritten specimens for the study. Each participant was asked to write a short sentence on plain white paper using a blue ballpoint pen were written on standard A4 paper. The samples were written under normal writing conditions to ensure that the handwriting represented the natural writing characteristics of the individuals. Few of the original handwritten specimens (as shown in Figure 1) served as the reference material for further digital processing and comparison in the study.

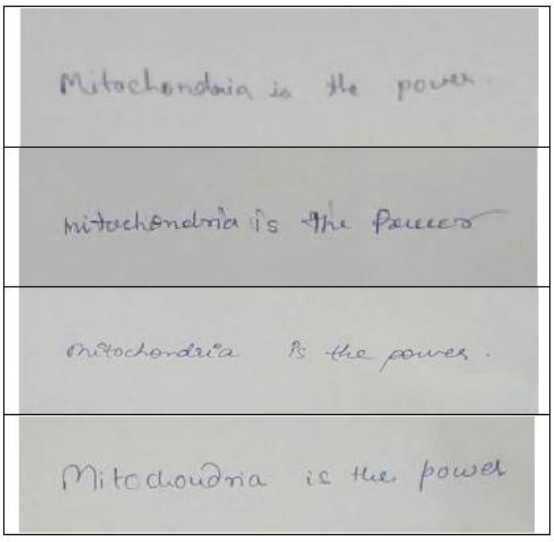


Figure 1: Sample of few handwritten incomplete sentences taken from individual (source)

2. Digital Capture of Handwriting Samples

The device used for capturing the original sample and conducting the experimental procedures was a Realme Pad (Model: RMP2102). The device operates on Android 11 and is powered by the MediaTek Helio G85 chipset, with a security patch level dated 05 February 2024.

3. AI Platforms Used for Handwriting Generation

The digitized handwriting samples were provided as prompts to several Generative Artificial Intelligence platforms, including ChatGPT, Grok, Gemini, Perplexity AI, Meta AI, DeepSeek and Claude. A half-written sentence from the original handwriting sample was provided as a prompt, and the AI systems were instructed to complete the remaining portion of the sentence while imitating the same handwriting style. The AI-generated outputs were obtained in digital form.

4. Digital Extraction and Report Generation

The AI-generated handwriting samples were further processed using the digital forensic extraction tool Cellebrite UFED version7.73.0.162 and report was generated using Cellebrite Physical Analyzer version 7.71.0.42. The extraction process generated a UFED report containing details of the digital files and metadata related to the generated samples. The report was carefully examined to understand the digital characteristics and traceability of the AI-generated content.

5. Printing and Tracing Procedure

The digitally generated handwriting samples were printed using a color printer to produce physical copies. These printed samples were then manually traced using a ballpoint pen in order to simulate a trace forgery scenario. During the tracing process, normal writing pressure was applied to replicate the conditions that may occur during fraudulent document preparation.

6. Visual Comparison and Examination

Finally, the traced handwriting samples were visually as well as forensically compared with the original handwritten specimens. The study was focused on interpreting similarities and differences in writing features, as well as potential indicators of trace forgery relevant to questioned document examination.

Images underwent the following:

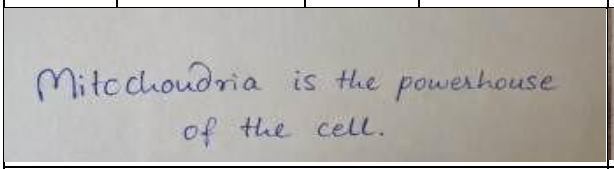
- Exif and metadata extraction (creation timestamp, software traces)
- Image authentication

III. OBSERVATIONS

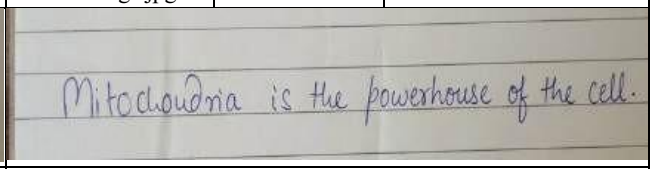
It can be observed that the method is applicable only when the image has been created or modified and stored on the same device. Furthermore, the metadata/EXIF data of both the LLM-downloaded sample and the original sample is examined and compared based on the specified parameters as mentioned in Table 1, Table 2, Table 3 and Table 4

Table 1: Difference in the original image and the images generated from different AI.

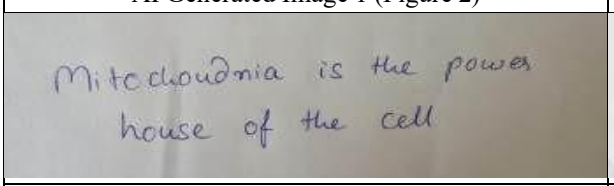
Sample	Name of the image file	Size (bytes)	Date of Creatio n	Path	MD5	Camera Details
OriginalimageUploaded in AI	IMG_20260313_105338_109.jpg	2632832	13-03-202610:53:38	Media/Internal shared storage/DCIM/Camera /IMG_20260313_105338_109.jpg	bd14c87cd7de0c85bd428fda55b74ce6	Meta Data: Camera Make: realm Camera Model: realmePadCapture Time: 13-03-2026 10:53:37 Pixel resolution:2448x3264Resolution: 72x72 (Unit: Inch) Orientation: Horizontal (normal)
Generated Image 1	file_00000000b924720ba2c84a1c546364cc.png	1965014	13-03-2026 12:58:29	Media/Internal sharedstorage/Pictures/file_00000000b924720ba2c84a1c546364cc.png	c3f1162ad9ed094924095c12ff37bf8e	Not Available
GeneratedImage 2	1773380323776.png	1083625	13-03-2026 11:08:43	Media/Internal sharedstorage/Pictures/1773380323776.Png	d7686f1caf8d68fa4a33b385831cfcca	Not Available
GeneratedImage 3	image.jpg	132170	13-03-2026 12:43:55	Media/Internal sharedstorage/Download/image.jpg	abee9d4160eb6a210c56f18bb91e234	Not Available



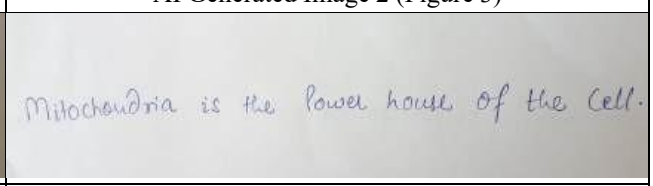
AI Generated Image 1 (Figure 2)



AI Generated Image 2 (Figure 3)



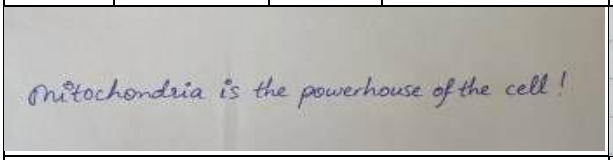
AI Generated Image 3 (Figure 4)



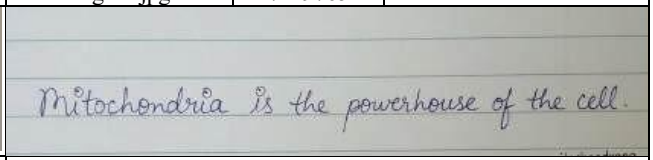
Original Full (Figure 5)

Table 2: Difference in the original image and the images generated from different AI.

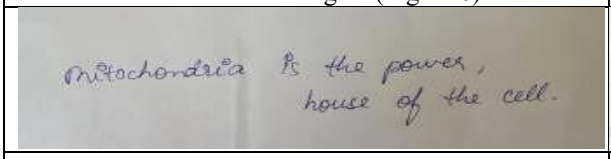
Samp le	Name of the image file	Size (byte s)	Date of Creation	Path	MD5	Camera Details
Origina l image Upload ed in AI	IMG_2026 0313_105 357_348.j pg	24838 35	13-03-2026 10:53:57	Media/Internal sharedstorage/DCIM/C amera/IMG_20260313 _105357_348.jpg	e9d1afe690b3a c19fe017b9191 1d409a	Meta Data:Camera Make: realme Camera Model: realmePadCapture Time: 13-03-2026 10:53:56 Pixel resolution:2448x3264 Resolution: 72x72 (Unit:Inch) Orientation: Horizontal (normal)
Genera Ted Image1	file_000000007 7a8720b8b34e5 efc452e0fc.png	1856648	13-03-2026 14:38:37	Media/Internal sharedstorage/Pictures/f ile_0000000077a8720b 8b34e5efc452e0fc.png	5d839355094fd 49b1de90bed66 b16dbe	Not Available
GeneratedI mage2	177338096000 9.png	1018187	13-03-2026 11:19:20	Media/Internal sharedstorage/Pictures/ 1773380960009.png	b33db1322059 139fefa488bf2b 904e18	Not Available
Generated Image3	image-1.jpg	116044	13-03-2026 12:44:23	Media/Internal shared storage/Download/im age-1.jpg	8b3246746d6 0fbacdedb1d8 71c97651	Not Available



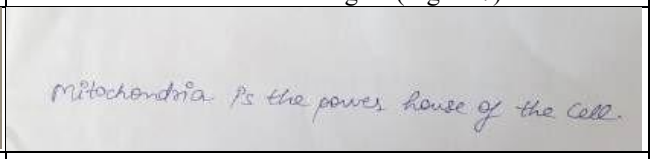
AI Generated Image 1 (Figure 6)



AI Generated Image 2 (Figure 7)



AI Generated Image 3 (Figure 8)

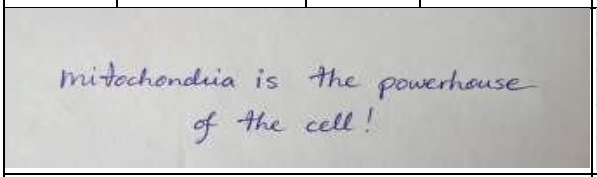


AI Original Full (Figure 9)

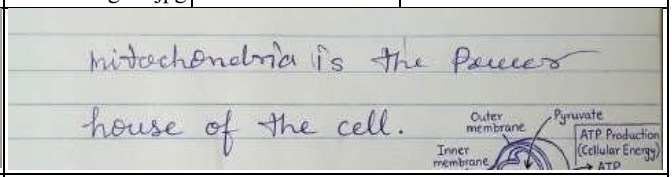
Table 3: Difference in the original image and the images generated from different AI.

Samp le	Name of the image file	Size (byte s)	Date of Creation	Path	MD5	Camera Details
Original image Uploaded inAI	IMG_20260313_10 5420_315.jpg	2611006	13-03-2026 10:54:20	Media/Internal shared storage/DCIM/Cam era/IMG_20260313 _105420_315.jpg	72506f11fb32a38cb3 ec62e1ff20f810	Meta Data:Camera Make: realmeCamera Model: realmePadCapture Time: 13-03-202610:54:19Pixel resolution:2448x3264Resol ution: 72x72 (Unit:Inch)Orientation: Horizontal(normal)
GeneratedI mage1	file_0000000033e8 720b87484cf679cb 108d.png	2049688	13-03-2026 14:43:57	Media/Internal sharedstorage/Pictu res/file_000000003 3e8720b87484cf67 9cb108d.png	e3f78c0f3c64807ad4 4de3b39c1352b5	Not Available
GeneratedI mage2	1773381124625.pn g	1122069	13-03-2026 11:22:04	Media/Internal sharedstorage/Pictu res/1773381124625 .Png	dff73cb07eaf82328d 6e3b54b871d4d0	Not Available

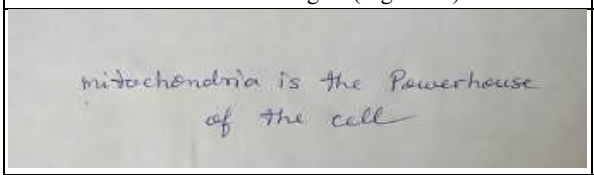
GeneratedImage3	image-2.jpg	119677	13-03-2026 12:45:10	Media/Internal sharedstorage/Download/image-2.jpg	056887f96c2afd3fbca33e6de53fe1b7	Not Available



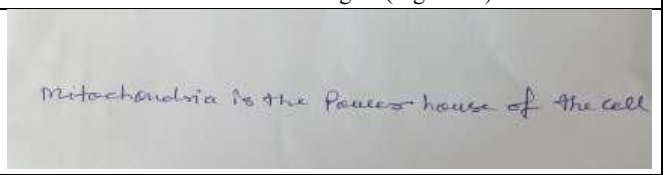
AI Generated Image 1 (Figure 10)



AI Generated Image 2 (Figure 11)



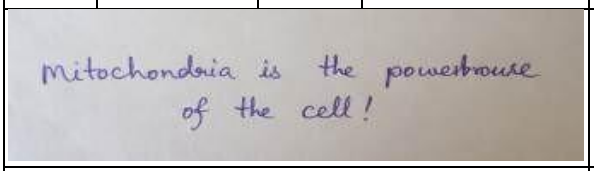
AI Generated Image 3 (Figure 12)



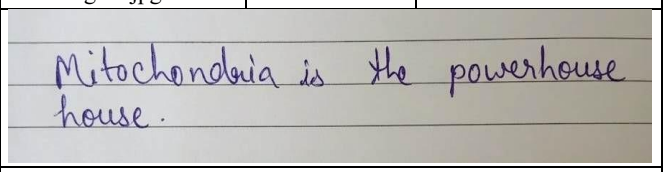
Original Full (Figure 13)

Table 4: Difference in the original image and the images generated from different AI.

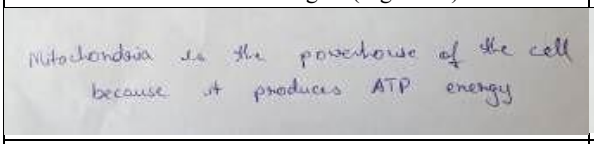
Sample	Name of the image file	Size (bytes)	Date of Creation	Path	MD5	Camera Details
Original imageUploaded inAI	IMG_20260313_105440_679.jpg	2482216	13-03-2026 10:54:40	Media/Internal sharedstorage/DCIM/Camera/IMG_20260313_105440_679.jpg	2eb1284a4c1960f05db19abff9b27196	Meta Data:Camera Make: realmeCamera Model: realmePadCapture Time: 13-03-202610:54:40Pixel resolution:2448x3264Resolution: 72x72 (Unit:Inch)Orientation: Horizontal(normal)
GeneratedImage1	file_0000000007 10720bb0a14f24 cd1ad689.png	1860635	13-03-2026 14:46:47	Media/Internal sharedstorage/Pictures/file_000000000710720bb0a14f24cd1ad 689.png	6d18b6fa87840b24b71113063305b847	Not Available
Generated Image 2	1773381225785.png	11915 71	13-03-2026 11:23:45	Media/Inter nal shared storage/Pictures/1773381225785.png	c9962535c290d80c9fbe4ace14b52fd5	Not Available
Generated Image 3	image-3.jpg	129409	13-03-2026 12:45:55	Media/Inter nal shared storage/Download/image-3.jpg	a2bb5b5b6ed76e5113806f7923b42f91	Not Available



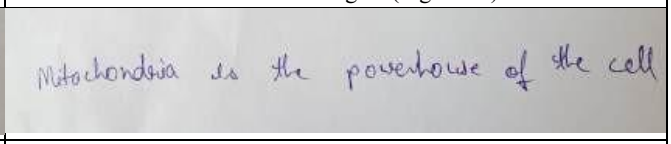
AI Generated Image 1 (Figure 14)



AI Generated Image 2 (Figure 15)



AI Generated Image 3 (Figure 16)



Original Full (Figure 17)

IV. RESULTS, LIMITATIONS, AND CHALLENGES IN AI-GENERATED IMAGES

Based on the conducted experimentation and comparative analysis across multiple Large Language Model (LLM) platforms capable of generating images, several advantages, limitations, and practical challenges were identified.

1. Presence of Watermarks in Generated Images

One significant observation is that certain AI platforms automatically insert watermarks in the generated outputs. Platforms such as Grok and Google Gemini were observed to include a watermark (as shown in Figure 18), typically located at the bottom portion of the generated image. In contrast, platforms such as ChatGPT and Perplexity AI generally produce images without visible watermarks. This variation across platforms may influence the usability and authenticity of generated images.

Figure 18: Watermarks present in the bottom right corner of the AI-produced image

2. Reduction in Generated Image File Size Compared to the Original Sample

Another limitation that was identified during the course of the experimentation was that the generated image files had a relatively smaller size when compared to the original reference image provided in the prompt. This reduction in the overall size of the image may result in the loss of detailed visual features, which can be crucial for applications involving detailed visual analysis, like document analysis and handwriting analysis.

3. Inconsistent Generation of Image Files across Platforms

It was also identified that some of the AI systems failed to produce image outputs even after receiving relevant image prompts. Some of the platforms, like Claude and DeepSeek, sometimes failed to produce the desired image files. In some cases, these platforms provided responses without any image outputs, as shown in Figure 19. This shows that there are some differences in the image creation capabilities of different AI systems.

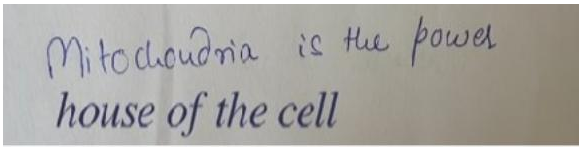


Figure 19: Irrelevant file generated from Claude

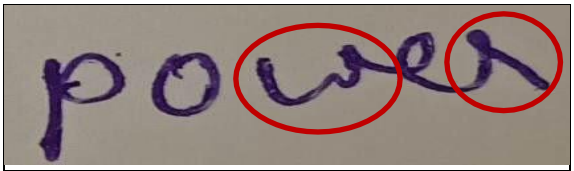
4. Policy-Based Restrictions in Image Generation

In some cases, the AI platforms failed to create images based on the prompt provided, stating that the request violated their platform policies, as shown in Figure 20. However, it was identified that if the prompt was modified, the image creation process was successful. This shows that the content policies are based on the overall interpretation of the prompt provided and the detection of relevant keywords.

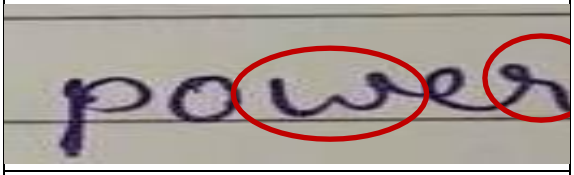
Figure 20: Policy-Based Restriction in Perplexity

5. Minor Modifications Introduced by AI during Image Generation

In the generation of the images, the AI platforms have a tendency to make some alterations to the original sample, which might include changes to the shape, positioning, and continuity of strokes, spacing, or style, as shown in Figure 21 above. Even though the alterations are quite small, they can impact the accuracy and originality of the generated image in comparison to the original reference material.



Original Handwriting Sample



Ai Enhanced Handwriting

Figure 21: Difference in the original handwriting sample and AI enhanced handwriting.

6. Handwriting Characteristics Observed After Manual Tracing of AI-Generated Images

After generating the images using the different platforms, the images were traced to assess the visual and structural characteristics of the images, as shown in Figure 22 above. The images presented some handwriting irregularities, which are likely to be observed in questioned documents, including uneven pen lifts, hesitation marks, irregular stroke pressures, tremors, variation in stroke widths, distortion of proportions, and retouching of strokes.

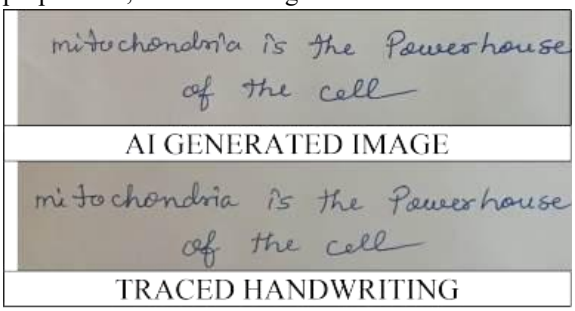


Figure 22: Difference in the AI generated image and traced handwriting.

Despite the limitations associated with the images, the traced images presented a similar overall pictorial look as the original images, indicating that the images generated by the AI platforms can have a similar look to the original images despite the alterations.

7. Increasing Sophistication of Potential Forgeries

Another problem that might arise due to AI-generated handwriting or document images is that it might become easier to forge documents in an extremely realistic manner. With advancements in AI technology, it is likely that an individual might be able to forge documents in an extremely realistic way that mimics genuine handwriting styles.

8. Influence of Image Capture Quality Camera resolution, lighting, focus, as well as the angle of view of the document image,

might significantly impact the quality of the input image. If the quality of the image is poor, it might directly impact the amount of information that is available to AI systems.

9. Variations in Image Clarity After Processing

It was further noted that there were slight to moderate differences in clarity in the images that were generated or downloaded in comparison to the original image. These might include differences in sharpness, contrast, pixel density, as well as visual clarity. Such factors might directly impact the interpretation of minute details in images, particularly in handwriting analysis.

10. Contextual Completion by Generative Models

Considering the fact that the study also entails the use of generative models of large language models, the AI models are able to demonstrate the ability to interpret the given incomplete text provided in the sample image. Even if the text provided is incomplete and only contains a portion of the sentence, the AI models are able to generate the contextual meaning of the text and produce an image with a complete and grammatically correct sentence. In certain cases, the AI models are also able to add other words or phrases that are contextually correct with regard to the provided text. In certain cases, the AI models are also able to add other visual content, such as diagrams, which are not initially provided in the sample image (as shown in Figure 23).

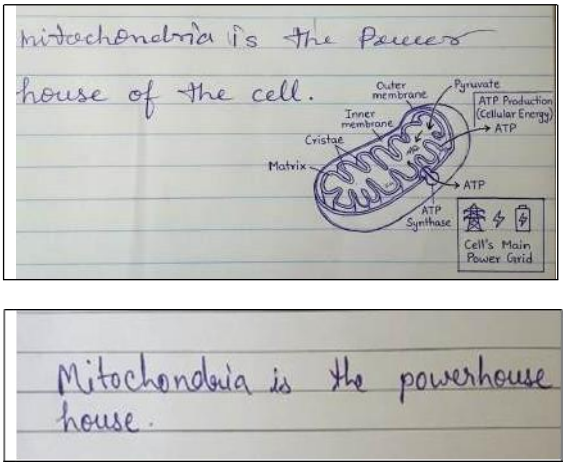


Figure 23: Additional diagrams and words generated by LLMs.

11. Differences in File Properties Between Original and Generated Images

A notable difference was also observed in terms of the metadata and technical properties of the original uploaded sample and the AI-generated image. When the image is created and downloaded from the AI system, a new digital file is created. Therefore, differences in terms of file name, file path, hash values, and file size are observed. This also reveals

that the AI-generated image is not a derivative of the original file but is a new form of a digital image created by the AI system.

12. Absence of Camera Metadata in AI-Generated Images

Another notable observation was made in terms of the metadata properties of the original images. Original images captured using digital devices have EXIF properties that contain additional details about the images. This includes details about the camera used to capture the images, the camera model, date and time of capture, exposure settings, and GPS settings. However, in the AI-generated images, none of this camera-related information was observed.

13. Variation in File Naming Conventions Across AI Platforms

It was also noted that different AI platforms have different file naming conventions for the images that are created. For instance, images created using the ChatGPT platform have file names that read file_00000000b924720ba2c84a1c546364cc. On the other hand, images created using the Google Gemini platform have file names that read 1773380323776. Images created using the Grok platform have file names that read image-2. This is quite different from images created using digital cameras and other mobile devices that have structured file naming conventions that read IMG_20260313_105323_655. This can be quite useful in differentiating AI-created images from images created using other devices.

V. CONCLUSION AND FUTURE SCOPE

The current study has demonstrated the emerging threat that generative AI is posing to the field of questioned documents. AI platforms such as ChatGPT, Grok, Gemini, Perplexity AI, Meta AI, and Claude have demonstrated the capability to produce images that resemble handwriting. However, AI-generated images do not have the natural physical characteristics that are produced during natural handwriting.

When printed and traced onto paper, images produced by AI can be used to create forged handwritten documents. Despite such visual similarity resulting from tracing, it is still possible to detect signs of forgery by identifying embossed marks, tracing indicators, and inconsistencies in writing characteristics. Thus, it is clear that even though AI can assist in making such handwriting templates appear realistic, traditional methods of forensic document examination can still identify such fraudulent practices.

VI. FUTURE IMPLEMENTIONS

The rapid advancements in generative artificial intelligence tools such as ChatGPT, Grok, Gemini, Perplexity AI, Meta AI, and Claude indicate that AI-assisted handwriting generation is likely to become even more sophisticated in the future. With such advancements in AI-assisted handwriting generation tools, there is an increased probability of such AI-generated handwriting being used in document forgery in the future. This is likely to pose new challenges in document examination by forensic experts. As such, there is an increased need to develop advanced forensic examination methods that can identify AI-assisted forgery and tracing indicators more effectively in the future. Future research in this area could also involve integrating digital forensic examination methods with traditional methods of document examination, including the use of tools to analyze digital indicators of AI-generated content.

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