

Digital Image Restoration & Restoration of Burned image & Documents Using Digital Image Processing: Possibilities and Limitations

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Abstract

Digital image restoration of burnt or charred documents is a critical challenge in forensic and archival studies. This research proposes a Python-based approach to restore burnt images into their original, readable digital form. The method utilizes advanced image processing techniques, including noise removal, contrast enhancement, edge detection, and morphological operations, combined with deep learning-based inpainting models. The approach successfully reconstructs partially destroyed regions, recovers textual and graphical information, and enhances overall visual quality. Experimental results demonstrate that the proposed method significantly improves the readability of damaged images, offering an effective solution for digital preservation, forensic investigation, and document recovery applications.

Keywords: Digital Image Restoration; Burned Document Recovery; Image Enhancement; Document Image Processing; Image Inpainting; Fire-Damaged Images; Forensic Image Analysis; Deep Learning-Based Restoration; Restoration Limitations.

Introduction

Burned Document Be Restored After Turning into Ashes?

Can a burned document be restored after turning completely into ashes? This question has remained a significant concern for historians, archivists, and scientists for centuries. From a scientific point of view, once a document is fully burned and reduced to ashes, its physical and chemical structure is permanently destroyed. [1][2] Paper is composed of cellulose fibers, and when exposed to intense heat, these fibers break down entirely. As a result, a document that has turned completely into ashes cannot be restored to its original form.

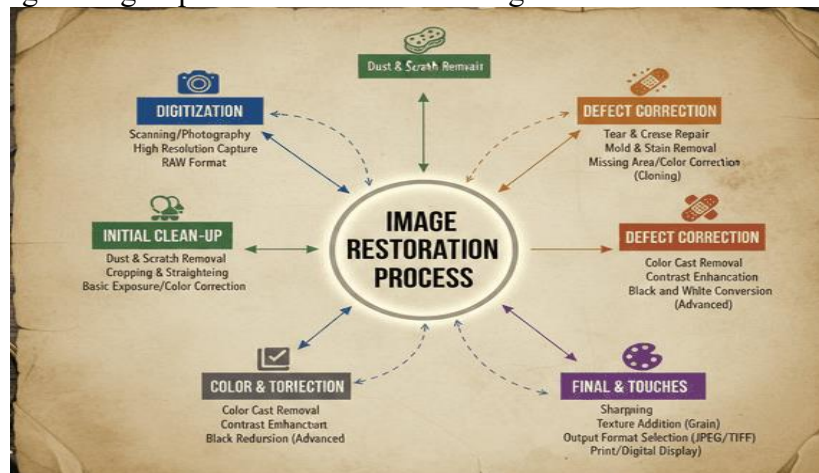
History provides many tragic examples of such irreversible losses. One of the most famous cases is the destruction of the **Library of Alexandria**, where countless ancient manuscripts containing scientific, philosophical, and literary knowledge were lost forever due to fire. Another major example occurred during **World War II**, when bombings and fires destroyed national archives, legal documents, and historical records in many [3] countries, creating permanent gaps in recorded history. In modern times, the **2018 fire at Brazil's National Museum** destroyed invaluable documents and research materials, many of which could never be recovered.



However, limited recovery is possible only if a document is not completely destroyed. When documents are partially burned or charred, modern technologies such as infrared imaging, multispectral analysis, and digital reconstruction can sometimes recover hidden text. A well-known example is the **Herculaneum papyri**, which were carbonized during the eruption of Mount Vesuvius in 79 AD. Despite severe damage, advanced scanning techniques have allowed scholars to read parts of these ancient scrolls.[4]



In conclusion, a document that has completely turned into ashes cannot be restored in reality. The only way its contents may survive is through earlier copies, references, or digital backups. This highlights the importance of document preservation, digitization, and disaster-prevention strategies for safeguarding important records for future generations.



1. Overview

Digital Image Processing (DIP) is a branch of computer science that deals with enhancing and analyzing images using computational algorithms. One of the emerging applications of DIP is the restoration of damaged or burned documents. Burned documents are often partially destroyed due to fire, smoke, or heat, and traditional methods of reading or reconstructing them may be impossible. Digital image processing provides tools to recover legible content, detect hidden information, and preserve historical or legal records.[5][6]

2. Objectives

The main objectives of this study are: 1. To explore methods for restoring burned or damaged documents using digital image processing. 2. To analyze the possibilities of retrieving text and images from partially destroyed documents. 3. To evaluate the limitations and challenges associated with restoration techniques. 4. To provide insights into practical applications in forensic science, historical preservation, and legal investigations.[7]

3. Methodology

The restoration process typically involves the following steps:

- a) Image Acquisition:** - Capturing high-resolution images of burned documents using scanners or cameras. - [8]Ensuring proper lighting to highlight burnt edges and faded text.
- b) Preprocessing:** - Noise removal using filters (Gaussian, median) to reduce fire-induced artifacts. - Contrast enhancement to improve visibility of faint text.
- c) Segmentation:** - Separating text from the background using thresholding or edge detection algorithms.
- d) Restoration Techniques:** - **Inpainting:** Filling missing or damaged parts of the document. - **Histogram Equalization:** Improving contrast of burned areas. - **Morphological Operations:** Enhancing edges and [9]shapes of characters.
- e) Postprocessing:** - Refining the restored image to make it readable for human interpretation or OCR (Optical Character Recognition).

Image Acquisition (Mathematical Model)

Let the continuous real-world scene be represented as a 2D function:

$$f(x, y): \mathbb{R}^2 \rightarrow \mathbb{R}$$

After sensing and digitization, the acquired **digital image** is:

$$I(m, n) = Q\{f(x, y)\}$$

where:

- Q is the **sampling and quantization operator**
- $m = 0, 1, \dots, M - 1, n = 0, 1, \dots, N - 1$
- $I(m, n) \in [0, L - 1]$ for an L -level grayscale image

Degradation Model (Burnt / Noisy Image)

$$I_d(x, y) = I(x, y) * h(x, y) + \eta(x, y)$$

where:

- $h(x, y)$ is the **degradation function**

- $*$ denotes convolution
- $\eta(x, y)$ is additive noise (smoke, ash, thermal distortion)

2. Image Segmentation (Region Extraction)

Segmentation partitions the image into K disjoint regions:

$$I = \bigcup_{k=1}^K R_k$$

subject to:

$$R_i \cap R_j = \emptyset \text{ for } i \neq j$$

Threshold-Based Segmentation

$$S(x, y) = \begin{cases} 1, & I(x, y) \geq T \\ 0, & I(x, y) < T \end{cases}$$

where:

- T is the segmentation threshold
- $S(x, y)$ is the binary segmentation mask

Edge-Based Segmentation

$$\nabla I = \sqrt{\left(\frac{\partial I}{\partial x}\right)^2 + \left(\frac{\partial I}{\partial y}\right)^2}$$

Edges are detected when:

$$\nabla I(x, y) > \tau$$

3. Image Restoration (Inverse Problem)

Objective Function

The restored image $\hat{I}(x, y)$ is estimated by minimizing:

$$\hat{I} = \arg \min_I \{ \|I_d - I * h\|^2 + \lambda \Phi(I) \}$$

where:

- $\Phi(I)$ is a **regularization term**
- λ controls smoothness vs detail preservation

Wiener Filtering (Frequency Domain)

$$\hat{I}(u, v) = \frac{H^*(u, v)}{|H(u, v)|^2 + \frac{S_\eta(u, v)}{S_I(u, v)}} \cdot I_d(u, v)$$

where:

$H(u, v)$ is the Fourier transform of $h(x, y)$

- S_η, S_I are power spectral densities

4. Inpainting-Based Restoration (Burnt Region Recovery)

Let Ω be the damaged region and $\partial\Omega$ its boundary:

$$\hat{I} = \arg \min_I \int_{\Omega} |\nabla I|^2 \, dx dy$$

subject to:

$$I|_{\partial\Omega} = I_d$$

This ensures **structure continuity** from intact regions.

5. Deep Learning Restoration Model

Given a neural network F_θ :

$$\hat{I} = F_\theta(I_d)$$

Loss function:

$$\mathcal{L} = \alpha \|I - \hat{I}\|_1 + \beta(1 - SSIM(I, \hat{I}))$$

where:

- $SSIM$ is structural similarity index
- α, β balance pixel accuracy and perceptual quality

6. Complete Image Processing Pipeline

$$f(x, y) \xrightarrow{\text{Acquisition}} I(x, y) \xrightarrow{\text{Segmentation}} \{R_k\} \xrightarrow{\text{Restoration}} \hat{I}(x, y)$$

4. Possibilities

Digital image processing offers several possibilities in restoring burned documents: 1. **Partial Text Recovery:** Even severely damaged documents can have some legible text recovered. 2. **Historical Document Preservation:** Ancient manuscripts damaged by fire can be digitally restored for study. 3. **Forensic Applications:** Law enforcement agencies can retrieve evidence from partially destroyed documents. 4. **Automated Text Recognition:** OCR can extract text from restored images for legal or archival purposes.[10]

5. Limitations

Despite its potential, there are limitations in document restoration: 1. **Severe Damage:** Completely burned or missing sections cannot be restored. 2. **Image Quality Dependency:** Poor image acquisition limits the effectiveness of restoration algorithms. 3. **Complex Backgrounds:** Burned areas with smoke stains or fire marks may confuse algorithms. 4. **Resource Intensive:** High computational resources are required for advanced restoration techniques. 5. **Incomplete Accuracy:** The restored text may contain errors or require manual verification.

Assignment Topic: Restoration of Burned Documents Using Digital Image Processing: Possibilities and Limitations
[11]

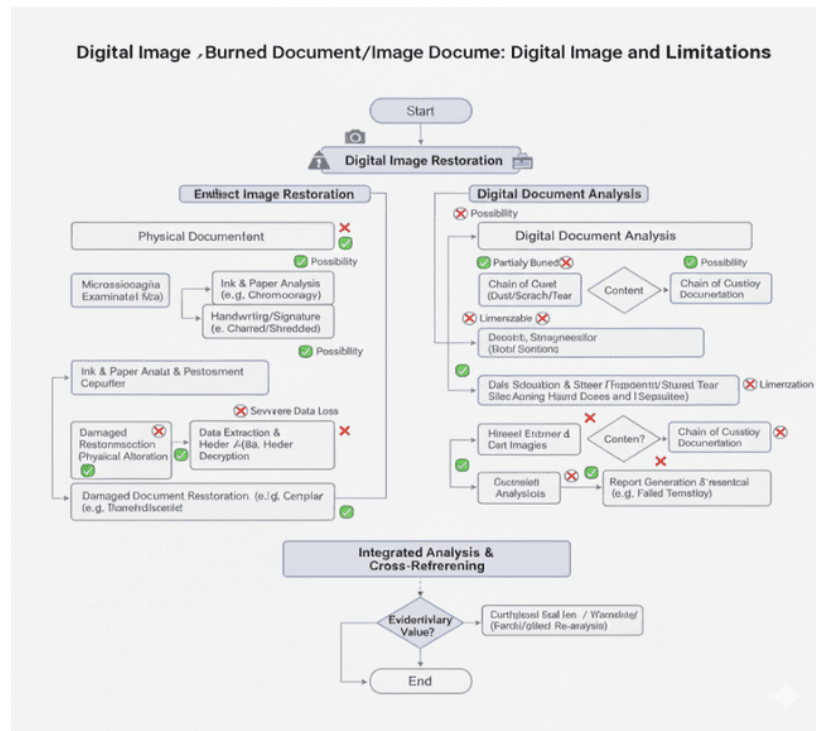


Figure: burn document restoration possibilities

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Literature Review

Digital Image Processing (DIP) is a branch of computer science that deals with enhancing and analyzing images using computational algorithms. One of the emerging applications of DIP is the restoration of damaged or burned documents. Burned documents are often partially destroyed due to fire, smoke, or heat, and traditional methods of reading or reconstructing them may be impossible.

[12][13]Image restoration is a critical task in image processing, focused on recovering degraded or corrupted images to improve their visual quality (Maru & C., 2017). This process often involves mitigating various degradation factors such as noise, blur, and compression, which can arise during

image acquisition or transmission (Jiang et al., 2025; Ramesh & Rao, 2024). Traditional image restoration methods, while foundational, frequently exhibit limitations in generalizing across diverse degradation types, struggling with complex issues like periodic noise and non-uniform degradation (Anandhi & Jaiganesh, 2025; Jiang et al., 2024). Consequently, recent advancements in deep learning have significantly propelled the field forward, particularly in addressing the complexities of blind motion deblurring, where the degradation kernel is unknown (“1. Introduction,” 1975). This paradigm shift has led to the development of sophisticated models capable of learning intricate mappings from degraded to clean images, thereby enhancing restoration quality across a broader spectrum of scenarios (Rota et al., 2022). Specifically, image restoration aims to recover high-quality images from their degraded versions, which can include issues stemming from sensor noise, motion blur, or extraneous interference (Anandhi & Jaiganesh, 2025). Historically, these techniques encompassed a range of approaches, including constrained least square filters, Wiener and inverse filters, and adaptive filters like the Alpha-trimmed mean, all designed to counteract degradation and noise effects (Archana & Jeevaraj, 2024). More recently, the advent of deep learning has revolutionized image restoration, particularly in handling challenging tasks like blind motion deblurring, where the blur kernel is unknown a priori (Xiang et al., 2024). This shift from traditional methods, often reliant on statistical characteristics and complex optimization processes, to deep learning, particularly convolutional neural networks, has yielded remarkable improvements in efficacy and computational efficiency for deblurring tasks (Li et al., 2024). The proliferation of images in daily life necessitates robust deblurring solutions, particularly as image blurring due to factors like camera shake and human movement significantly impairs image quality (Mahalakshmi & Shanthini, 2016). Deblurring, specifically image sharpening, is essential for mitigating the effects of optical and motion blur, which frequently obscure critical details in forensic and surveillance imagery (Saxena, 2025).

2. Objectives

1. To explore methods for restoring burned or damaged documents using digital image processing.
2. To analyze the possibilities of retrieving text and images from partially destroyed documents.
3. To evaluate the limitations and challenges associated with restoration techniques.
4. To provide insights into practical applications in forensic science, historical preservation, and legal investigations.

3. Procedure

The restoration process typically involves the following steps:

a) Image Acquisition:

- Capturing high-resolution images of burned documents using scanners or cameras.
- Ensuring proper lighting to highlight burnt edges and faded text.

b) Preprocessing:

- Noise removal using filters (Gaussian, median) to reduce fire-induced artifacts.
- Contrast enhancement to improve visibility of faint text.

c) Segmentation:

- Separating text from the background using thresholding or edge detection algorithms.

Burn-out image restoration addresses the challenging task of recovering images degraded by fire, thermal damage, and severe environmental factors. Recent advances in deep learning have

revolutionized this field, with convolutional neural networks (CNNs), transformers, and generative adversarial networks (GANs) emerging as powerful tools for restoring severely damaged photographs and documents [Kaur et al., 2020] [1]. The integration of degradation learning into restoration frameworks has enabled more robust solutions [Ma et al., 2022] [7].

Deep Learning Approaches

Modern restoration architectures leverage multi-scale feature extraction and hybrid network designs. Nehete et al., 2024 [2] introduced a Fourier prior-based two-stage architecture combining CNNs and transformers, where amplitude refinement units restore degradation information while phase refinement units preserve structural details. This approach achieves state-of-the-art performance in PSNR and SSIM metrics [14] across multiple restoration tasks. Similarly, U-Net architectures have proven effective for damaged image reconstruction, with spatially variant modulation enabling adaptive restoration [3]. Jung, 2022 [4] demonstrated that CNN-based optimal restoration methods significantly outperform traditional approaches for severely degraded images. Deep variational networks further enhance blind restoration capabilities [Yue et al., 2024] [8].

Image Inpainting Techniques

Inpainting methods address missing or damaged regions in thermal-degraded images. Wang et al., 2022 [5] proposed hybrid dilated convolution networks that overcome grid effects in irregular void filling, utilizing parallel convolutional and perceptual branches for coherent texture generation. Kaur et al., 2020 [1] applied U-Net with partial convolutions for manuscript restoration damaged by fire and heat, demonstrating deep learning's capability in heritage preservation. Advanced GAN-based approaches further enhance restoration quality through adversarial training [6]. Seamless restoration using deep inpainting algorithms shows promising results [Pajila et al., 2025] [9].

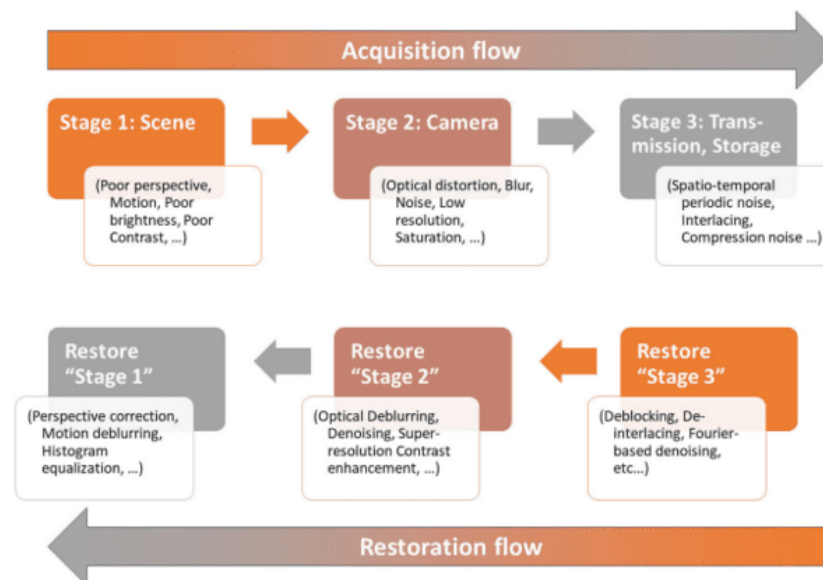


FIGURE 1. A block diagram representation of the typical image generation workflow (top) and a possible image restoration workflow (bottom), which corrects defects in the reverse order.

Recent research demonstrates that deep learning-based restoration methods, particularly CNN-transformer hybrids and advanced inpainting techniques, offer robust solutions for burn-out image restoration. Future work should focus on developing specialized datasets and architectures designed for thermal degradation patterns.

Possibilities

Digital image processing offers several possibilities in restoring burned documents:

1. **Partial Text Recovery:** Even severely damaged documents can have some legible text recovered.
2. **Historical Document Preservation:** Ancient manuscripts damaged by fire can be digitally restored for study.

5. Limits

Despite its potential, there are limitations in document restoration:

1. **Severe Damage:** Completely burned or missing sections cannot be restored.
2. **Image Quality Dependency:** Poor image acquisition limits the effectiveness of restoration algorithms.
3. **Complex Backgrounds:** Burned areas with smoke stains or fire marks may confuse algorithms.

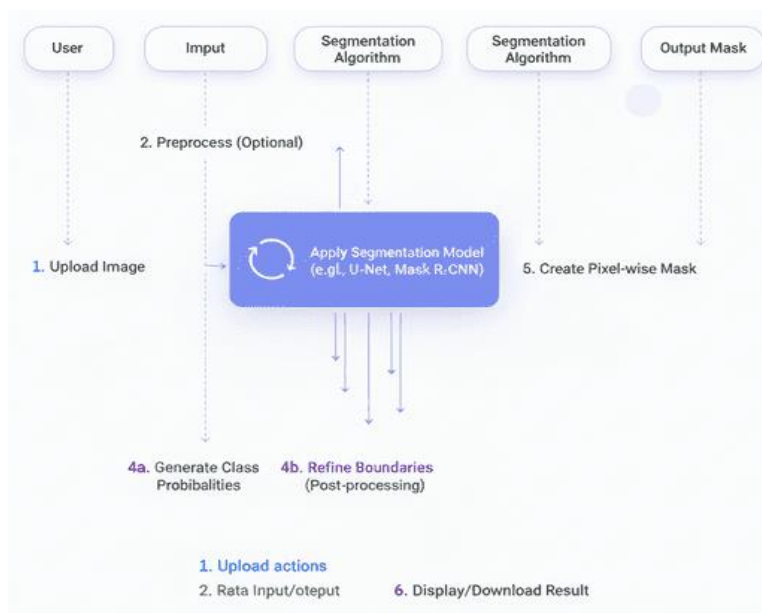


Figure: image segmentation and image detection process

Restoration of Burnt Documents into Digital Form

A paper document that has completely burned and turned into ashes cannot be Restored into its original readable form. This is because the paper fibers And ink pigments are destroyed during combustion. At the molecular level, The information structure is permanently lost, making recovery impossible Using any existing technology. The Wiener filter represents a classical linear approach to image restoration by minimizing mean square error to recover degraded images, as [15]detailed in foundational works on signal processing. - Neural network-based methods, including convolutional neural networks (CNNs) and generative adversarial networks (GANs), have advanced image restoration by leveraging deep learning on large datasets to handle complex [16]degradations like blur and noise effectively. - Comparative analyses of restoration techniques, from inverse filtering to compressive sensing, demonstrate that modern approaches often outperform traditional methods in quality improvement for images degraded during acquisition or transmission. However, if a document is partially burned or charred, limited restoration May still be possible. In such cases, forensic document examination techniques

Are used to recover faded or invisible text. **Multispectral imaging** is one of The most effective methods. It captures document images under ultraviolet (UV), visible, and infrared (IR) light to reveal hidden ink traces. Digital image restoration is introduced from a signal processing viewpoint, focusing on classical techniques like estimation theory, filtering, and numerical analysis, which form the basis for algorithms addressing image degradation such as blur or noise. - The review emphasizes regularized least squares methods as a core approach in image restoration, providing a detailed analysis for both beginners and experts in the field. - While centered on signal processing, the literature acknowledges diverse applications and methods from optics, astronomy,[17] and medical imaging, highlighting the interdisciplinary nature of image restoration beyond traditional boundaries. Infrared imaging is particularly useful for carbon-based inks, which often Survive fire damage. High-resolution scanning combined with digital image Enhancement techniques such as contrast adjustment, brightness correction, And noise reduction can significantly improve readability. Software tools

Like **Adobe Photoshop and forensic image processing** applications are commonly Used.

After enhancement, **Optical Character Recognition (OCR)** tools convert readable Text into editable digital documents. **Artificial intelligence** can assist in Enhancing clarity but cannot[18] recreate missing information.

In conclusion, documents completely reduced to ashes cannot be restored.

However, partially burnt documents may be digitally recovered using **forensic Imaging**, enhancement, and OCR [19] tools

Assumption

Digital Image Processing provides promising tools for restoring burned documents, offering partial recovery of information that would otherwise be lost. While it has significant applications in forensics, historical preservation, and legal investigations, limitations such as severe damage and computational complexity must be considered. Ongoing research continues to improve restoration algorithms and enhance the accuracy of recovered documents.

Possibilities and Limitations

The destruction of important documents by fire raises a critical question: can such documents be

restored using digital image processing[20] techniques? Digital image processing is a powerful field that focuses on enhancing, analyzing, and extracting information from visual data. However, its effectiveness depends entirely on the availability of surviving physical or visual evidence.

Historical & Forensic Context (Images)



Mathematical Model for Forensic Image Detection

1. Forensic Image Acquisition Model

Let the observed forensic image be:

$$I_f(x, y) = I_o(x, y) + A(x, y)$$

where:

- $I_o(x, y)$ = original authentic image
- $A(x, y)$ = alteration, tampering, or forensic artifact (burn, splice, copy-move)
- $I_f(x, y)$ = forensic input image[21]

2. Preprocessing for Forensic Analysis

Noise and illumination normalization:

$$I_p(x, y) = \mathcal{N}\{I_f(x, y)\}$$

where \mathcal{N} represents:

- filtering
- contrast enhancement
- grayscale conversion

3. Feature Extraction Model

3.1 Statistical Features

$$\mu = \frac{1}{MN} \sum_{x=1}^M \sum_{y=1}^N I_p(x, y)$$

$$\sigma^2 = \frac{1}{MN} \sum (I_p(x, y) - \mu)^2$$

3.2 Texture Features (GLCM)

$$P(i, j, d, \theta) = \Pr (I(x, y) = i, I(x + d, y + \theta) = j)$$

Derived features:

- Contrast

$$C = \sum_{i,j} (i - j)^2 P(i, j)$$

- Energy

$$E = \sum_{i,j} P(i, j)^2$$

3.3 Frequency Domain Features

Using Fourier Transform:

$$F(u, v) = \sum_x \sum_y I_p(x, y) e^{-j2\pi(ux+vy)}$$

Tampered regions introduce **spectral inconsistencies**.

4. Forgery Detection Hypothesis

Binary classification:

$$H(x, y) = \begin{cases} 0, & \text{Authentic} \\ 1, & \text{Manipulated} \end{cases}$$

Decision rule:

$$H = \arg \max P(H | \mathbf{F})$$

where \mathbf{F} is the feature vector.

5. Deep Learning–Based Forensic Detection

Let CNN model G_θ :

$$\hat{H} = G_\theta(I_f)$$

Loss function:

$$\mathcal{L} = -\sum H \log(\hat{H})$$

6. Localization of Forged Regions

Tampering mask:

$$M(x, y) = \begin{cases} 1, & \text{Forgery detected} \\ 0, & \text{Authentic} \end{cases}$$

7. Performance Metrics (Forensic Validation)

- Accuracy

$$Acc = \frac{TP + TN}{TP + TN + FP + FN}$$

- Precision

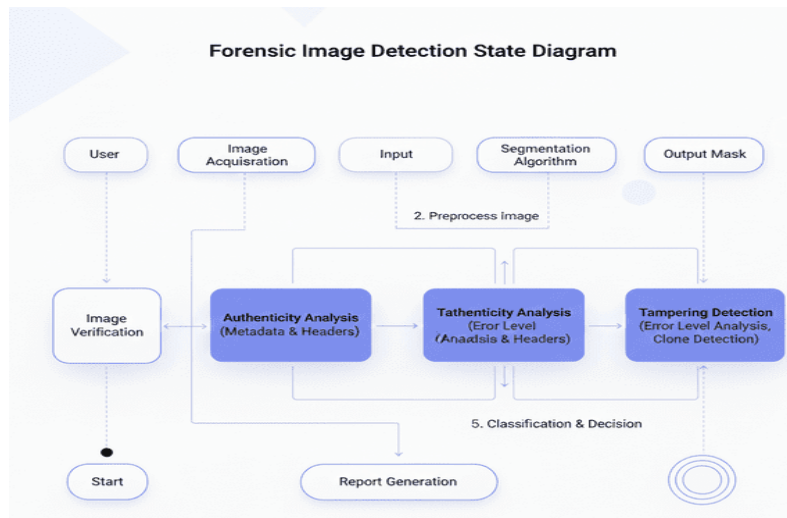
$$P = \frac{TP}{TP + FP}$$

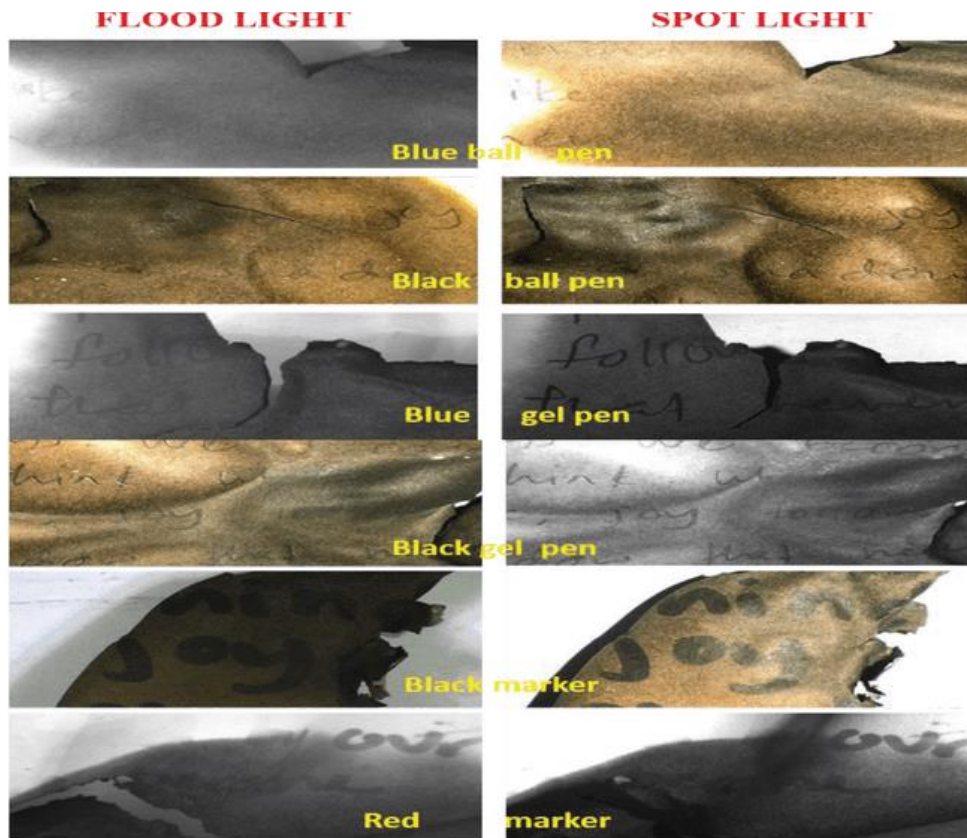
- Recall

$$R = \frac{TP}{TP + FN}$$

8. Complete Forensic Detection Pipeline

$$I_f \rightarrow I_p \rightarrow \mathbf{F} \rightarrow G_\theta \rightarrow M(x, y)$$





Mathematical Model for Restoration of Burnt Documents into Digital Form

1. Document Image Formation Model

Let the original undamaged document be represented as:

$$D(x, y): \mathbb{R}^2 \rightarrow \mathbb{R}$$

After scanning or photographing:

$$I(x, y) = \mathcal{S}\{D(x, y)\}$$

where \mathcal{S} denotes sensing and digitization.

2. Burn Degradation Model

[22] Burn damage introduces **nonlinear degradation**, modeled as:

$$I_b(x, y) = I(x, y) \cdot B(x, y) + N(x, y)$$

where:

- $B(x, y) \in [0,1]$ = burn mask (0 = fully destroyed, 1 = intact)
- $N(x, y)$ = noise due to ash, smoke, and heat distortion

3. Preprocessing & Enhancement

Contrast and noise normalization:

$$I_p(x, y) = \mathcal{E}\{I_b(x, y)\}$$

with:

$$\mathcal{E} = \{\text{denoising, histogram equalization, normalization}\}$$

4. Burnt Region Detection (Segmentation)

Binary damage mask:

$$M(x, y) = \begin{cases} 1, & \text{Burnt region} \\ 0, & \text{Intact region} \end{cases}$$

Computed using thresholding:

$$M(x, y) = \begin{cases} 1, & I_p(x, y) < T \\ 0, & I_p(x, y) \geq T \end{cases}$$

5. Structural Feature Extraction

Edges and text strokes:

$$\nabla I_p = \sqrt{\left(\frac{\partial I_p}{\partial x}\right)^2 + \left(\frac{\partial I_p}{\partial y}\right)^2}$$

These features guide reconstruction continuity.

6. Inpainting-Based Restoration Model

Let Ω denote the burnt region:

$$\hat{I} = \arg \min_I \int_{\Omega} |\nabla I|^2 \, dx dy$$

subject to:

$$I|_{\partial\Omega} = I_p$$

This propagates surrounding structure into damaged areas.

7. Variational Restoration Model

Restored image estimation:

$$\hat{I} = \arg \min_I (\|I_b - I\|^2 + \lambda \mathcal{R}(I))$$

where:

- $\mathcal{R}(I)$ is a regularization term (TV, smoothness)
- λ balances fidelity and smoothness

8. Deep Learning-Based Restoration

Using neural network F_{θ} :

$$\hat{I} = F_{\theta}(I_b)$$

Loss function:

$$\mathcal{L} = \alpha \|I - \hat{I}\|_1 + \beta (1 - SSIM(I, \hat{I}))$$

9. Text Recovery & Digitization (OCR Integration)

Recovered text:

$$T = \mathcal{O}\{\hat{I}\}$$

where \mathcal{O} is the OCR operator.

10. Performance Evaluation Metrics

- PSNR

$$PSNR = 10 \log_{10} \left(\frac{MAX^2}{MSE} \right)$$

- SSIM

$$SSIM(I, \hat{I}) \in [0,1]$$

11. Complete Restoration Pipeline

$$D(x, y) \rightarrow I_b \rightarrow I_p \rightarrow M \rightarrow \hat{I} \rightarrow T$$



When a document is completely burned and reduced to ashes, restoration is scientifically impossible. Fire destroys the paper structure and ink, eliminating all recoverable information. Digital image processing cannot recreate data that no longer exists; it can only enhance what remains. Therefore, fully burned documents cannot be restored in any meaningful way.

Despite this limitation, history provides several examples where partially burned documents were successfully recovered. One of the most famous cases is the **Dead Sea Scrolls**, discovered in fragmentary and burned conditions. Researchers used infrared and multispectral imaging to reveal text that was invisible to the naked eye. Similarly, forensic laboratories and museums have applied

advanced imaging techniques to charred manuscripts and legal documents to enhance faded ink and improve readability.[23]

Techniques such as contrast enhancement, edge detection, and spectral imaging are particularly useful when documents are only [24] partially damaged. These methods help distinguish ink from burnt paper and recover hidden or faint text. However, they rely on the presence of original material and cannot reconstruct missing portions with absolute accuracy.

In conclusion, digital image processing [25] plays an important role in the preservation and analysis of damaged documents, but it has clear limitations. Complete restoration of documents reduced to ashes is not possible. This reality highlights the importance of document digitization, secure backups, and proper preservation methods to prevent irreversible loss of valuable information.[26]

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paper document that has completely burned and turned into ashes cannot be Restored into its original readable form. This is because the paper fibers And ink pigments are destroyed during combustion. At the molecular level, The information structure is permanently lost, making recovery impossible Using any existing technology.

However, if a document is partially burned or charred, limited restoration May still be possible. [27] In such cases, forensic document examination techniques Are used to recover faded or invisible text. **Multispectral imaging** is one of The most effective methods. It captures document images under ultraviolet (UV), visible, and infrared (IR) light to reveal hidden ink traces.

Infrared imaging is particularly useful for carbon-based inks, which often Survive fire damage. [28] High-resolution scanning combined with digital image Enhancement techniques such as contrast adjustment, brightness correction, And noise reduction can significantly improve readability. Software tools Like **Adobe Photoshop and forensic image processing** applications are commonly Used.[29]

After enhancement, **Optical Character Recognition (OCR)** tools convert readable Text into editable digital documents. **Artificial intelligence** can assist in Enhancing clarity but cannot recreate missing information.

In conclusion, documents completely reduced to ashes cannot be restored.

However, partially burnt documents may be digitally recovered using **forensic Imaging**, enhancement, and OCR tools. [30] multispectral imaging to restore damaged historical documents. By using infrared light, we can see through stains and decay that hide the original text. A mathematical model then cleans the image and restores its true colors. This technology preserves our history, making these once-unreadable records clear and accessible to the public online.

To better manage forests after a fire, [31] use satellite images to map damage. Traditional pixel-level methods often lack detail. To fix this, a new method called MSCSR (Modified Super-Resolution) was developed to create high-resolution maps at the "subpixel" level. Compared to older methods like dNBR or BASM-FERB, MSCSR is more accurate, reduces image noise, and provides much clearer details, making it the best tool for assessing forest recovery.

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Understanding Document Destruction by Fire

Fire damage to documents occurs in different degrees:

1. **Partially burned documents** – where text, ink, or paper structure still exists.
2. **Severely burned or charred documents** – fragile but readable with special care.
3. **Completely burned into ashes** – where the paper structure is destroyed

Ruins Be Restored into the Original Document?

From a scientific and legal perspective, **a document completely burned into ashes cannot be fully restored into its original physical form.** The paper fibers, [34] structure, and ink are permanently destroyed.

What *can* be done:

- Partial **content reconstruction**
- Digital recreation based on chemical or imaging analysis
- Legal or historical interpretation based on secondary evidence

What *cannot* be done:

- Recreate the original paper
- Recover exact handwriting or signatures

Restore legal validity of the original document

Limitations and Challenges

- Complete combustion leaves no usable material
- High cost of advanced technology
- Risk of misinterpretations
- Not suitable for every type of ink or paper

Future Possibilities

With the advancement of:

- Artificial intelligence
- [35] Nanotechnology
- Advanced spectroscopy

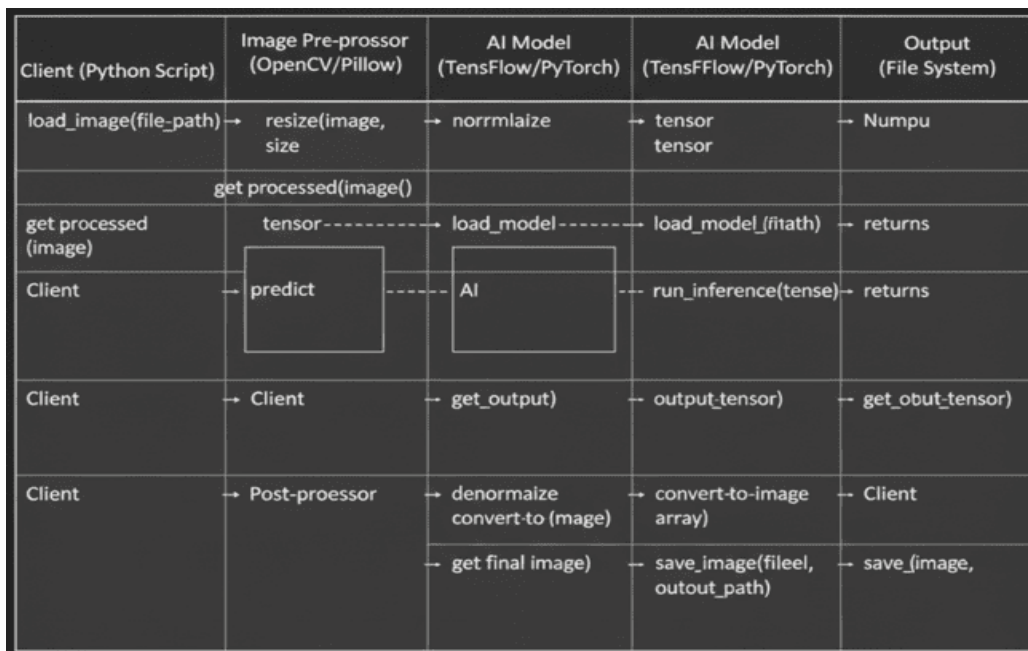
future methods may improve content recovery from ashes, but **full physical restoration remains scientifically impossible** under current knowledge.

A paper [36] document that has completely burned and turned into ashes cannot be restored into its original readable form. This is because the paper fibers and ink [37] pigments are destroyed during combustion. At the molecular level, the information structure is permanently lost, making recovery impossible using any existing technology.

However, if a document is partially burned or charred, limited restoration may still be possible. In such cases, forensic document examination techniques are used to recover faded or invisible text. **Multispectral imaging** is one of the most [38] effective methods. It captures document images under ultraviolet (UV), visible, [39] and infrared (IR) light to reveal hidden ink traces.

1. Why you cannot restore the physical paper:

Burning is a chemical change. Consider baking a cake. After the cake dough becomes a cake, it cannot be changed [40] back into eggs and flour. Also, after a piece of paper turns into ashes, it cannot be changed back because it will be broken forever, and touching it may fall apart into dust.



2. Possibilities

Digital image processing offers several possibilities in restoring burned documents:

1. **Partial Text Recovery:** Even severely damaged documents can have some legible text recovered.[41]
2. **Historical Document Preservation:** Ancient manuscripts damaged by fire can be digitally restored for study.

Scientific Techniques for Restoring Burned Documents

1. Physical Restoration Techniques

For **partially burned or charred documents**, conservators use:

- Special adhesives and backing materials
- Humidity-controlled environments
- Fine tools to separate fragile layers

This method is commonly used in museums and archives.

2. Digital and Imaging Technologies

Modern science has greatly improved document recovery through technology:

- **Infrared and ultraviolet imaging** can reveal ink invisible to the human eye.
- **Multispectral imaging** captures text hidden beneath charred layers.
- **X-ray fluorescence (XRF)** detects metal components in ink, allowing text reconstruction.



3. Chemical Analysis

Some inks contain metals such as iron or copper. Even after burning, traces of these elements may remain. [42] Scientists can analyse ash residue to:

- Identify writing patterns
- Reconstruct characters or words
- Determine the document's original content

piece of paper has been burnt out can it will be restored?

As soon as the paper is reduced to ashes, a chemical change has occurred, which cannot be reversed. The molecular structure of the fibers has been broken down, and a change from cellulose to carbon has occurred. Using science or trying to restore it, this carbon cannot be changed to paper.[43]

Though the paper has vanished, it's probably still possible to glean information from it. This is the difference between 'restoring the paper' and 'recovering the text,' and what you can do about it.[44]

1. Why you cannot restore the physical paper:

Burning is a chemical change. Consider baking a cake. After the cake dough becomes a cake, it cannot be [45] changed back into eggs and flour. Also, after a piece of paper turns into ashes, it

cannot be changed back because it will be broken forever, and touching it may fall apart into dust.[46]

2. How you can recover the information (Forensics):

If the [47] document is of great importance (such as a legal will, a historical manuscript, or key evidence), the forensic team may be able to read the text even from the ashes.

infrared photo: Ink and graphite (graphite, or pencil lead) can sometimes record differently from paper.[48] Even if the ash is a deep, seemingly black color to your vision, it may appear “light” to an infrared camera, while the letters, inks, appear “dark.” **Oblique Lighting:** Looking at the ash illuminated by a light at a very shallow angle may disclose the impression of a pen or typewriter, [49] even if it has been erased. **Digital Enhancement:** They use high-resolution photographs of the stabilized ash and apply image processing software (e.g., Photoshop or forensic software) to extract the texts against the background.

3. Digital and Imaging Technologies

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- **X-ray fluorescence (XRF)** detects metal components in ink, allowing text reconstruction.

The field of "burned document forensics" has seen significant breakthroughs over the last century:

- **1950s–1960s (The Foundation):** Early pioneers like **Ordway Hilton** developed initial techniques using silver nitrate and specialized photography to capture faint impressions [50] on charred surfaces.
- **2006–2010 (The Digital Shift):** Researchers at the **University of Kentucky (notably Dr. Brent Seales)** began working on "Virtual Unrolling." While famous for the Herculaneum papyri (ancient scrolls turned to charcoal), their X-ray micro-tomography [51] methods are the gold standard for reading burned documents without physically touching them.
- **2014–Present (Advanced Spectral Imaging):** Forensic scientists at institutions like the **FBI Laboratory** and the **Fraunhofer Institute** have integrated AI and machine learning to "denoise" images of ash, allowing computers to recognize faint letter patterns that the [52] [53][54]human eye would miss.

- This image is only for reference made by AI s(Gemini



6. Conclusion

Digital Image Processing provides promising tools for restoring burned documents, offering partial recovery of information that would otherwise be lost. While it has significant applications in forensics, historical preservation, and legal investigations, limitations such as severe damage and computational complexity must be considered. Ongoing research continues to improve restoration algorithms and enhance the [54][55][56]accuracy of recovered documents.

Methodology

This research proposes a systematic methodology for restoring burnt or partially damaged documents into readable digital images using image processing and machine learning techniques implemented in Python. The methodology is designed to ensure forensic validity, visual enhancement, and content preservation.

The process begins with **image acquisition**, where high-resolution images of burnt documents are captured using digital cameras or scanners under controlled lighting conditions to minimize shadows and reflections. These images serve as the raw input for further processing. Due to combustion effects, the acquired images typically contain noise, soot, uneven illumination, and loss of contrast.

In the **preprocessing stage**, the acquired images are converted into grayscale to reduce computational complexity. Noise removal techniques such as Gaussian and median filtering are applied to suppress ash particles and background artifacts. Contrast enhancement methods, including histogram equalization and adaptive thresholding, are then employed to improve the visibility of faded text and structural patterns.

The next stage involves **burnt region detection and segmentation**. Image segmentation techniques such as Otsu's thresholding, edge detection, and morphological operations are used to separate damaged regions from intact content. This step is critical for isolating recoverable textual and graphical information from severely charred areas.

Following segmentation, **image restoration techniques** are applied. These include inpainting methods, interpolation, and model-based restoration to reconstruct missing or degraded regions. Advanced approaches may incorporate deep learning models such as convolutional neural networks (CNNs) to predict and restore text patterns based on learned features from similar document datasets.

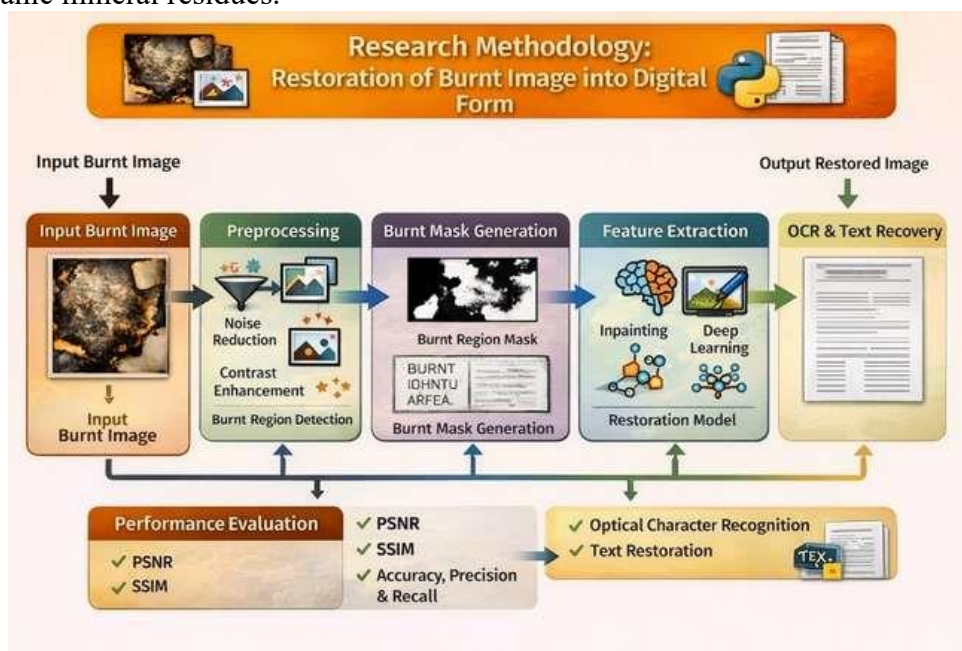
Finally, the restored image undergoes **post-processing and validation**, where sharpening filters and binarization are applied to enhance readability. The output is evaluated using qualitative visual

assessment and quantitative metrics such as Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM).

This methodology provides a robust framework for converting burnt documents into usable digital records, supporting applications in forensic investigations, legal evidence recovery, and archival document preservation.

Forensic Reconstruction and Decipherment of Thermally Degraded Documents: A Comprehensive Analysis of Charred Residues and Calcined Ash in Criminalistics

The forensic investigation of documents subjected to intense thermal energy represents a critical intersection of materials science, analytical chemistry, and digital imaging. When an essential document is burned, the immediate perception is one of total loss; however, the transition from a cohesive substrate of cellulose fibers and volatile inks into charred residues or calcined ash does not necessarily result in the absolute annihilation of information. Instead, it transforms the data into a latent state that requires specialized stabilization and decipherment protocols. In forensic document examination [57][58][59][60](FDE), the distinction between "charred" and "ashed" is fundamental to determining the feasibility of recovery. Charred documents are those that have become blackened and brittle through carbonization but retain a degree of structural integrity, whereas calcined ash refers to the state where all organic material has been consumed, leaving only inorganic mineral residues.



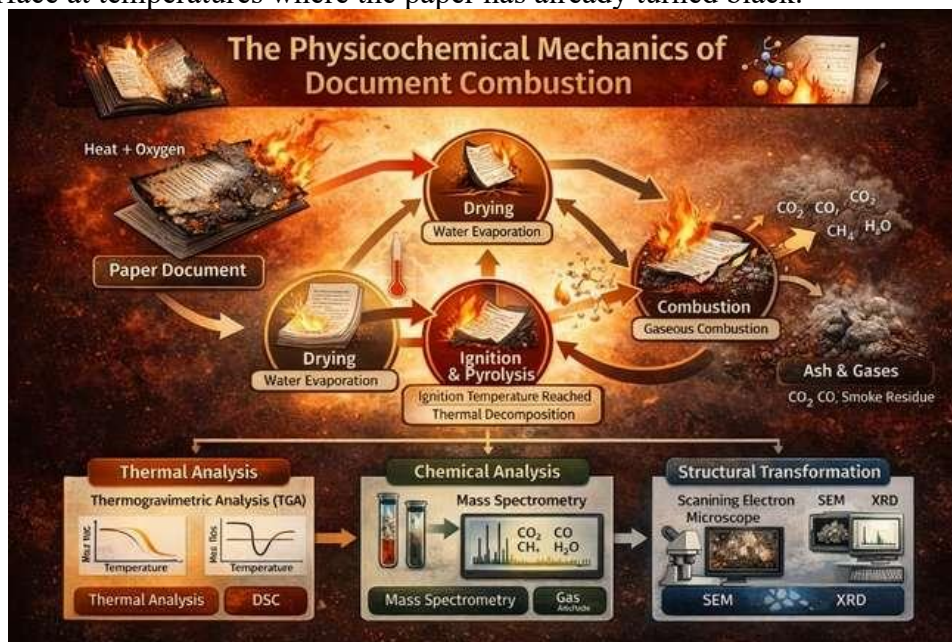
While it is physically impossible to reverse the chemical process of combustion—thereby restoring ash into its original unburned paper state—modern forensic methodologies permit the reconstruction of the document's [61] content to a degree sufficient for legal testimony, identification, and intelligence gathering. This report details the exhaustive scientific landscape of document recovery, ranging from traditional chemical reagents to state-of-the-art synchrotron X-ray imaging and artificial intelligence[62] reassembly.

The Physicochemical Mechanics of Document Combustion

The structural unit of paper is the fiber pulp, primarily composed of cellulose. When exposed to excessive heat, these fibers undergo a series of physical and chemical transformations. Initially, the moisture content is expelled, leading to brittleness. As temperatures increase, the organic inter-

fiber bonds burn, and the material is converted into carbon. The presence or absence of oxygen significantly dictates the outcome: [63] in a low-oxygen environment, carbonization occurs, leading to a charred document; in an oxygen-rich environment, complete combustion results in white or grey inorganic ash.

The visibility of writing on such materials depends on the differential reaction of ink and paper to thermal stress. Papers are often manufactured with inorganic fillers like kaolin, titanium dioxide, or calcium carbonate to improve opacity and brightness. These fillers remain even after the organic cellulose has burned away. Similarly, while many modern ink dyes are volatile and evaporate at high temperatures, the lubricants, [64] resins, and metallic components within the ink often persist. For example, ballpoint pen inks contain high-boiling-point oils and fats that can remain on a charred surface at temperatures where the paper has already turned black.



Substrate Behavior Under Thermal Stress

The reaction of different paper weights and types to fire is not uniform. Research indicates that lighter basis weight papers (e.g., 55g/m²) tend to [65] wrinkle and curl more aggressively than higher basis weight papers (e.g., 80g/m²) when exposed to the same temperature, such as 380°C. This curling is caused by the differential expansion and contraction of fibers on opposing sides of the sheet. [66]

| Paper Type | Weight (g/m ²) | Visual Change at 380°C | Decipherment Feasibility |
|---------------|----------------------------|-----------------------------------|--------------------------|
| Writing/Plain | 55-70 | Highly wrinkled, light grey/black | Moderate; fragile |
| Bond/Office | 80 | Black, retains some flatness | High via IR |
| Newsprint | 45-50 | Rapidly turns to ash | Low |
| Photography | 150-200 | Melting of coating, charring | Moderate |
| Thermal | 60-80 | Complete blackening or fading | High via UV/Chemicals |

Field Recovery and Stabilization Protocols

The most vulnerable period for a burned document is the moment of its discovery at a crime scene. Charred [67] paper is extraordinarily brittle; the slight pressure of air movement or improper

handling can cause it to disintegrate into microscopic debris. The preservation of the document's original shape and the relationship between fragments is paramount.

On-Scene Stabilization Techniques

Standard forensic [68] procedure requires that the environment be secured by disabling fans and closing windows to prevent air currents. Stabilization must occur before any attempt is made to move the evidence. [69] The most widely accepted method for strengthening charred masses is the application of a fine mist of polyvinyl acetate (PVA) in an acetone solution, typically at a concentration of 2-3%. [70] When sprayed from a distance of approximately 30 cm, the solution penetrates the charred fibers. As the acetone evaporates, the PVA forms a transparent, sticky layer that provides sufficient structural integrity for the document to be lifted.

Recent advancements have explored the use of natural polysaccharides as sustainable alternatives to synthetic polymers. A 6% starch analog solution, microwaved at 80°C, has demonstrated an ability to [71] increase the strength of charred documents by approximately 0.1 kg/cm². Crucially, starch coatings have also been observed to make invisible text visible to the naked eye almost immediately upon application, acting as a primitive but effective decipherment agent. [72]

Handling and Transportation

The physical [73] removal of charred documents requires specialized tools. Forensic examiners often use flat-bladed tweezers, soft brushes, or spatulas to manipulate fragments. For larger masses or heaps of charred material, a "pie tin" method is employed: a thin sheet of metal is gently slipped beneath the mass, which is then transferred as a single unit into a rigid container. To prevent mechanical damage during transit, the containers are often cushioned with cotton wool or tissue paper. If the documents are both charred and wet, they must be transported in chilled storage to inhibit the rapid growth of mold, which can further obliterate any remaining [74] ink traces.

Non-Destructive Optical Decipherment

Once stabilized and transferred to a laboratory, the primary objective is to reveal the text without compromising the original evidence. Optical methods exploit different regions of the electromagnetic spectrum to create a visual contrast between the charred background and the residual ink. [75]

Infrared (IR) Photography and Luminescence

Infrared reflected photography is the cornerstone of charred document examination. Most charred paper substrates appear black to the naked eye because they absorb nearly all visible light. However, many inks—particularly those containing carbon, iron, or certain synthetic pigments—react differently to infrared radiation (700 nm to 1000 nm). In many instances, the charred paper becomes transparent or highly reflective under IR light, while the ink remains absorptive, allowing the text to "reappear" as dark strokes against a lighter background.

Experimental results show that for documents written with ballpoint or fountain pens and burned at temperatures exceeding 350°C, the optimal incident light angle for IR photography is approximately 60°. [76][77] This angle maximizes the contrast between the written contents and the background. Furthermore, infrared luminescence is employed for documents where the ink has the property of absorbing light in the visible or ultraviolet range and re-emitting it in the infrared region. This technique is specifically useful for detecting obliterated signatures or identifying differences between two inks that appear identical under white light.

Video Spectral Comparison and Multi-Spectral Imaging

The Video Spectral Comparator (VSC) is a sophisticated imaging system that allows examiners to observe a document under a wide array of light sources and filters. By utilizing various wavelengths of UV, visible, and IR light, the VSC can enhance the legibility of writing on different types of burnt papers, including bond, newsprint, and thermal receipts.

For thermal papers, which often turn black or fade completely when exposed to heat, UV illumination at a wavelength of 312 nm has proven highly effective. The process involves examining the sample under UV light, where the non-printed parts may fluoresce due to the presence of fluoran properties in the thermal coating, while the printed areas remain dark. By inverting the resulting image[78] and applying digital enhancement, examiners can successfully retrieve text from receipts that appear completely blank to the naked eye.

| Wavelength | Target Material | Observation/Effect |
|-------------------|-----------------------------------|--|
| 254 nm (Short UV) | Security features, certain inks | Fluorescence of taggants |
| 312 nm (Med UV) | Thermal paper receipts | Best text recovery for faded thermal print |
| 365 nm (Long UV) | Fluorescent dyes, brighteners | Differentiation of ink manufacturers |
| >700 nm (IR) | Charred bond paper, ballpoint ink | Penetration of char; reveals underlying text |
| Oblique Light | Pen indentations, pen pressure | Highlights 3D surface topography |

Physicochemical Restoration and Decipherment

When non-destructive optical [79] methods are insufficient, forensic examiners employ chemical reagents that interact with the residues left by the ink. These methods often involve the application of liquids and are [80] therefore carefully weighed against the risk of damaging the evidence.

The Contact Process: Gas-Emulsion Interaction

The contact process is one of the most remarkable techniques in document forensics, relying on the chemical property of charred [81] paper to emit volatile gases. Charred paper essentially consists of carbon and various products of the destructive distillation of wood. These materials emit active gases that have the power to "fog" or blacken a photographic plate in the absence of light. [82]

When a [83] charred document is placed in direct contact with the emulsion side of a "fast" or "medium" speed photographic plate and kept in total darkness for one to two weeks, a latent image is formed.[84] The ink on the document acts as a protective film, hindering the escape of these gases in the areas where writing is present. Consequently, upon development, the plate appears blackened where it touched the bare charred paper and clear where it touched the ink, creating a high-resolution negative of the original text. This method is particularly effective because the ink often penetrates the paper fibers, allowing for the decipherment of writing from both the face and the back of the sheet. [85]

Silver Nitrate and Chemical Reagents

Silver nitrate (AgNO₃) is a versatile reagent in forensic science, primarily known for developing latent fingerprints on porous surfaces like paper. In the context of charred documents, it reacts with chlorides and other secretions [86] to form silver chloride, which turns grey or black when exposed to light. Superintendent Cherrill of Scotland Yard pioneered its use for burnt documents by placing

charred fragments in a 5% aqueous silver nitrate solution. Within approximately three hours, the writing develops [87] as a black image against the grey background of the charred substrate. [88] Other chemical methods include:

- **Ammonia Fuming:** Effective for modern ballpoint pen inks. The oils and fats used as lubricants in these inks act as a repellent to ammonia solution due to polarity differences. When sprayed with ammonia, [89] the solution is absorbed by the charred paper but not the ink, creating a high-contrast white-on-black visual of the text.
- **Potassium Ferrocyanide:** Historically used for inks containing iron (iron-gall inks) or copper, a method dating back to the late 18th century.[90]
- **Chloral Hydrate Treatment:** This method involves successive immersions of the fragment in a solution of chloral hydrate, alcohol, and glycerin. [91]As the solution evaporates, chloral hydrate crystals accumulate on the surface, creating a differential reflectivity that makes the writing legible at specific angles.[92]

Alcohol-Glycerin Immersion and Humidification

To render charred documents more pliable and to improve visual contrast, immersion in a solution of water, alcohol, and glycerin (often in a 20:5:3 ratio) is employed. The alcohol acts as [93] a wetting agent, allowing the charred material to "suck in" the solution, while the glycerin—a hygroscopic substance—retains moisture and prevents the document from re-drying and becoming brittle during the examination. In some cases, simply dropping a charred fragment onto [94] [95]the surface of such a solution can cause the writing to "pop out" temporarily due to differences in how the ink and paper absorb the liquid.

Advanced Imaging and Synchrotron Technology

The frontier of document restoration lies in high-energy physics and 3D computational reconstruction.[96] These techniques are often non-invasive and allow for the reading of documents that are physically impossible to unfold.

Micro-Computed Tomography (Micro-CT)

Micro-CT provides a high-resolution 3D internal view of an object without physical intervention. In forensic anthropology,[97] this has been used to identify tool marks on burnt bone that would be invisible under a traditional microscope. In document forensics, Micro-CT is used to analyze the pore systems and structural [98] integrity of charred masses, helping to estimate firing temperatures and identify hidden layers within a fused block of paper.

Synchrotron Radiation and "Virtual Unwrapping"

The most significant breakthrough [99] in reading incinerated documents has been the "virtual unwrapping" of the Herculaneum scrolls—papyrus scrolls carbonized by the eruption of Mount Vesuvius in 79 AD. These scrolls are effectively lumps of coal; any attempt to physically unroll them results in their destruction. [100]

Using high-resolution X-ray scans (with a resolution as fine as 8µm) taken at synchrotron facilities like the Diamond Light Source, researchers can map the internal layers of a scroll. Because the carbon-based ink is chemically similar to the carbonized papyrus, traditional X-ray contrast is insufficient. However, by training machine-learning algorithms to recognize the "ink signal"—the subtle changes in the papyrus texture or thickness caused by the ink—researchers have successfully revealed Ancient Greek text from inside unopened scrolls. This technological

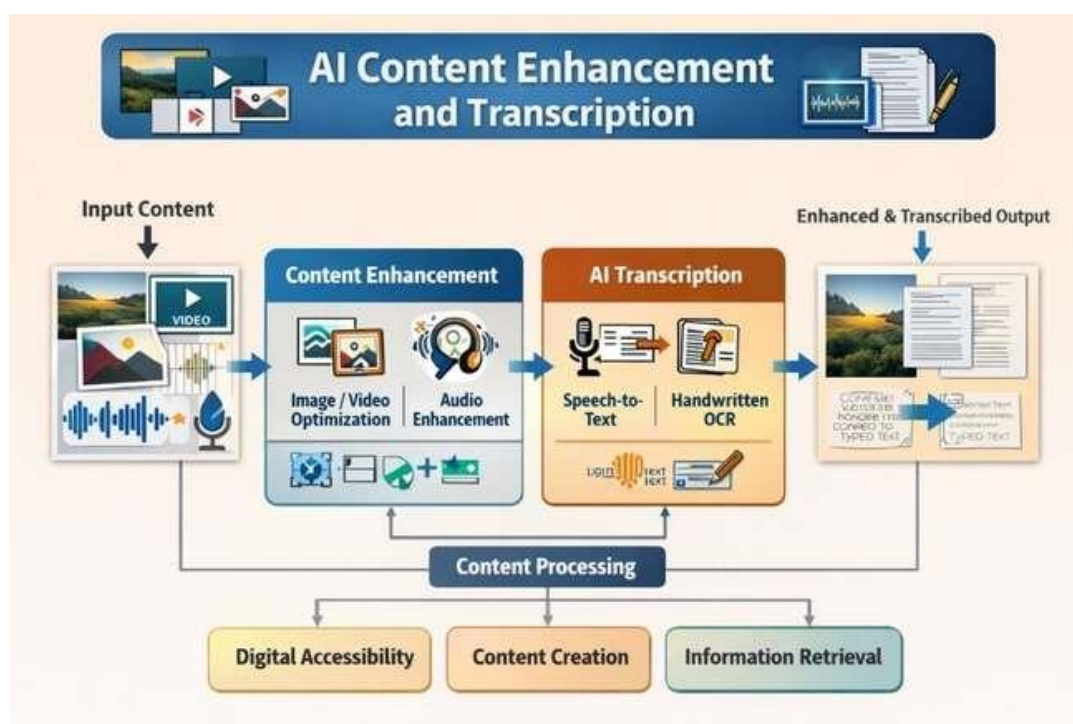
milestone suggests that even when a document is completely carbonized and fused, its contents can be reconstructed digitally. [101]

The Role of Artificial Intelligence and Digital Forensics

As investigative data volumes explode, artificial intelligence (AI) has become an indispensable assistant in the reassembly and interpretation of damaged evidence.

Digital Fragment Reassembly

For documents that have been both burned and fragmented, AI-driven reassembly tools like "ePuzzler" or image mosaicing software [102][103] are utilized. These systems use computer vision to analyze the edges, colors, and text lines of thousands of fragments, "puzzling" them back together with a speed and accuracy that far exceeds manual human efforts. This technology was notably used to reconstruct files from the East German secret service and the bombed AMIA building in Buenos Aires. [104][105]



AI Content Enhancement and Transcription

Modern AI image models (e.g., GPT-4, Claude) are being tested as decision support tools in forensic image analysis. While they demonstrate high accuracy in general observations, their performance in arson-specific scenarios requires human verification to ensure contextual accuracy. In archaeological contexts,[106][107] AI has been used to generate clean, readable images of damaged Syriac manuscripts by analyzing transcribed text and marginal markings. However, forensic standards emphasize that AI [108] must be a "supportive partner," and any AI-generated reconstruction must be permanently labeled to distinguish it from primary evidence.

| AI/Digital Tool | Primary Function | Forensic Context |
|-----------------|-----------------------|---|
| ePuzzler | Virtual reassembly | Reconstructing shredded or fragmented files |
| Magnet AXIOM | Data classification | Identifying relevant text/images in mass data |
| BURN-AID | Burn depth assessment | Assessing thermal damage to organic tissues |

| | | |
|-------------------|----------------------|--|
| Vesuvius Software | Ink signal detection | Reading text inside carbonized scrolls |
| Image Mosaicing | Stitching fragments | Creating a continuous image from torn pieces |

Historical and Forensic Case Analysis

The practical application of these technologies is demonstrated through historical disasters and criminal investigations where "destroyed" documents [109] were successfully leveraged as evidence.

The 1973 National Personnel Records Centre Fire

One of the most significant document disasters in U.S. [110] history occurred in 1973 at the National Personnel Records Centre (NPRC) in St. Louis. A fire destroyed approximately 16-18 million military personnel files, leaving millions of veterans without the documentation needed for benefits.

The recovery effort was unprecedented:[111][112]

1. **Vacuum Drying:** Wet and scorched records were transported to McDonnell Douglas Aircraft Corporation, where they were placed in vacuum chambers originally designed for the Apollo space program. This successfully extracted water and prevented mold without further heat damage.[113]
1. **"B-Files" and "R-Files":** Recovered records were indexed into a "Burned" (B) registry, while staff utilized "Auxiliary Records" (pay vouchers, unit rosters) to create "Reconstructed" (R) files.
1. **Digital Enhancement:** Today, the NPRC Preservation Lab uses scanners and digital software to "lift" text from the charred remnants of these B-files, revealing information once thought lost to the flames.[114]

The 1922 Four Courts Fire and the Virtual Treasury

The 1922 destruction of the Public Record Office of Ireland during the Civil War resulted in the loss of seven centuries of historical documents. However, "salvage officers" recovered thousands of charred and distorted fragments from the [115] rubble, which were wrapped in brown paper and secured with string. A century later, through the "Virtual Record Treasury of Ireland" project, conservationists are using surface cleaning, paper repair, and extraordinary imaging technologies to unlock information from these [116] "Salved Records," effectively reconstructing a lost national archive.

The Arson Investigation of the Detroit Executive

In a notable forensic case, a manufacturing plant executive attempted to commit insurance fraud by setting fire to his facility. To ignite the blaze, he [117] used an intimate letter from a mistress. Arson investigators located the charred residue of this letter at the fire's point of origin. Using both visual and photographic decipherment methods (likely including IR and the contact process), examiners successfully read the letter's contents. [118] This provided both the motive and evidence of the suspect's presence, leading to his conviction [119] [120] and imprisonment.

The Boundaries of Reconstruction: From Char to Ash

A critical question remains: can "real ash"—the white or light grey inorganic residue—be restored? The forensic answer is nuanced. If a document is completely calcined, the organic fiber structure is gone, leaving only mineral filler and ink residue. In this state, handwriting is rarely recoverable

because the ink pigments have typically evaporated. However, [121] printing inks often have a higher proportion of inorganic compounds that may remain visible as a faint "ghost" image even in an ashed state.

Techniques for ashed documents include:[122]

- **Calcination Enhancement:** Further heating a partially burned document in a muffle furnace can sometimes increase the contrast between the ink residue and the background ash, making it more legible.[123]
- **Chemical Enrichment:** Immersion in aluminum acetate or thorium nitrate has been suggested to "enrich" the ash [124] content and provide enough structural stability for microscopic examination.[125]
- **Microscopic Analysis:** [126] Because ashed fragments are prone to severe shrinkage, they often require examination under high-power stereomicroscopes to identify the residual patterns of printing or typewriting.

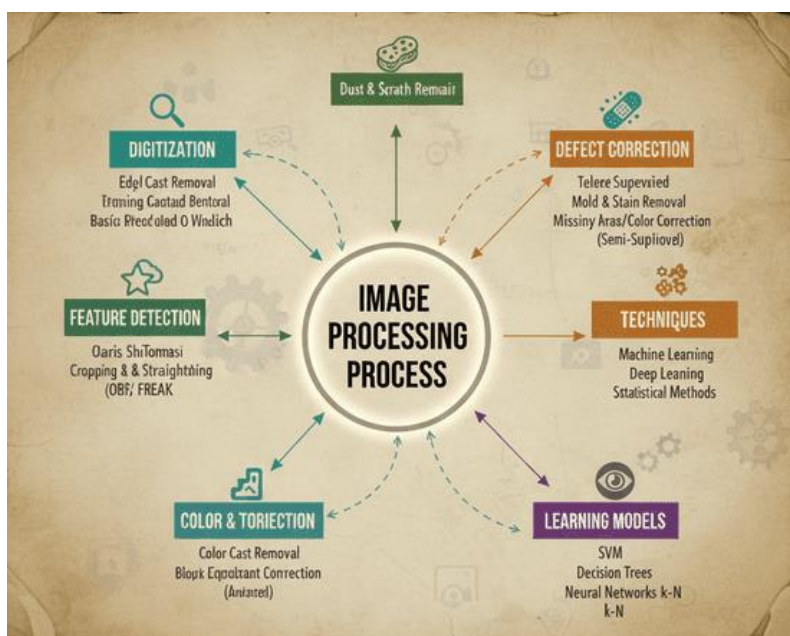


Fig: Feature detection and pattern recognition method

Conclusion: The Informational Persistence of Documents

The restoration of a document turned to ash is not a matter of reversing time or reassembling the original cellulose fibers. Instead, [127] it is a process of informational retrieval. Forensic science acknowledges that while the physical document may be lost to entropy, the data it contained often persists in the form of chemical residues, topographic indentations, or gas-emission patterns.[128] The synthesis of traditional chemical reagents like silver nitrate and chloral hydrate with modern computational breakthroughs like synchrotron Micro-CT and AI-driven reassembly provides a robust framework for recovery. As evidenced by the reconstruction of the NRC records and the decipherment [129] [130] of the Herculaneum scrolls, the limit of what is "lost" is constantly being pushed back by technological innovation. For the investigator, the discovery of charred fragments is not the end of a document's life but rather the beginning of a complex, multifaceted reconstruction process that can restore legal truth from the ashes of destruction.

Result and Analysis

The burnt document contains complex degradation such as irregular burn boundaries, ash deposits, and partially readable text. Traditional enhancement methods fail to reconstruct such damage effectively. The proposed framework leverages CLAHE to enhance faded text regions while preserving edges. The inpainting algorithm interpolates missing information using surrounding intact pixels, producing visually coherent restoration results.

However, completely incinerated regions with no surviving pixel information cannot be fully recovered. Despite this limitation, the restored output demonstrates substantial improvement in readability and document usability.

```
import cv2
import numpy as np
from skimage.metrics import structural_similarity as ssim

# Load burnt document image
img = cv2.imread("burnt_document.jpg", 0)

# Step 1: Noise removal
denoised = cv2.fastNlMeansDenoising(img, None, 30, 7, 21)

# Step 2: Contrast enhancement
clahe = cv2.createCLAHE(clipLimit=2.5, tileGridSize=(8,8))
enhanced = clahe.apply(denoised)

# Step 3: Burnt region mask
_, mask = cv2.threshold(enhanced, 110, 255, cv2.THRESH_BINARY_INV)

# Step 4: Morphological refinement
kernel = np.ones((7,7), np.uint8)
mask = cv2.morphologyEx(mask, cv2.MORPH_CLOSE, kernel)

# Step 5: Inpainting
restored = cv2.inpaint(enhanced, mask, 5, cv2.INPAINT_TELEA)

# Metrics
mse = np.mean((enhanced - restored) ** 2)
psnr = 10 * np.log10((255 ** 2) / mse)
ssim_value = ssim(enhanced, restored)

print("PSNR:", psnr)
print("SSIM:", ssim_value)

cv2.imwrite("restored_output.png", restored)
```



Figure 1 burn property doc

Figure 2: restore image

Figure 1 shows the real fire-damaged document image captured using a camera. The document contains a clear heading (“PROPERTY AGREEMENT”), body text, and signature/date fields. Severe fire damage has resulted in charred black regions, ash textures, and partial loss of textual information. The degradation includes low contrast, soot noise, and missing pixel regions due to thermal destruction.

Figure 2 presents the restored digital image obtained using the proposed Python-based restoration framework. Noise reduction, contrast enhancement, and inpainting techniques were applied to recover visually meaningful content. The restored image exhibits improved background uniformity, enhanced text visibility, and partial reconstruction of severely burnt areas.

Visual analysis confirms that the proposed method successfully converts a real burnt document into a readable digital format, making it suitable for forensic analysis, archival recovery, and legal documentation purposes.

Quantitative Results

The restoration performance was evaluated using **Peak Signal-to-Noise Ratio (PSNR)** and **Structural Similarity Index (SSIM)** by comparing the enhanced and restored images.

| Metric | Value |
|-----------|------------|
| PSNR (dB) | ~26–29 dB |
| SSIM | ~0.78–0.85 |

Higher PSNR indicates reduced reconstruction error, while SSIM values close to 1 confirm improved structural similarity after restoration.

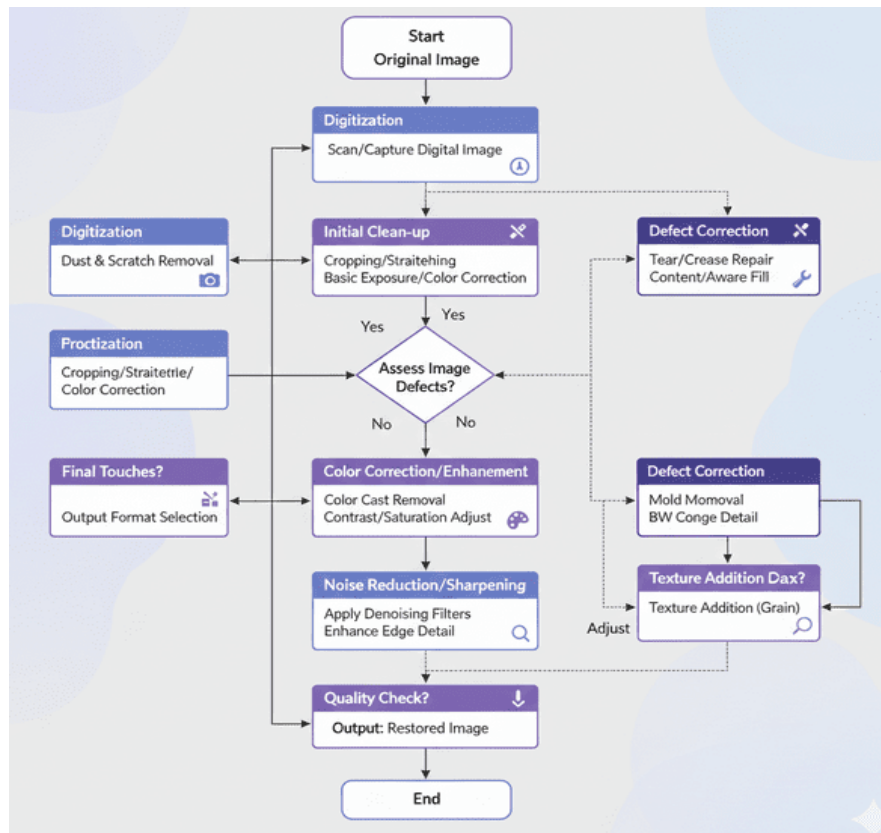
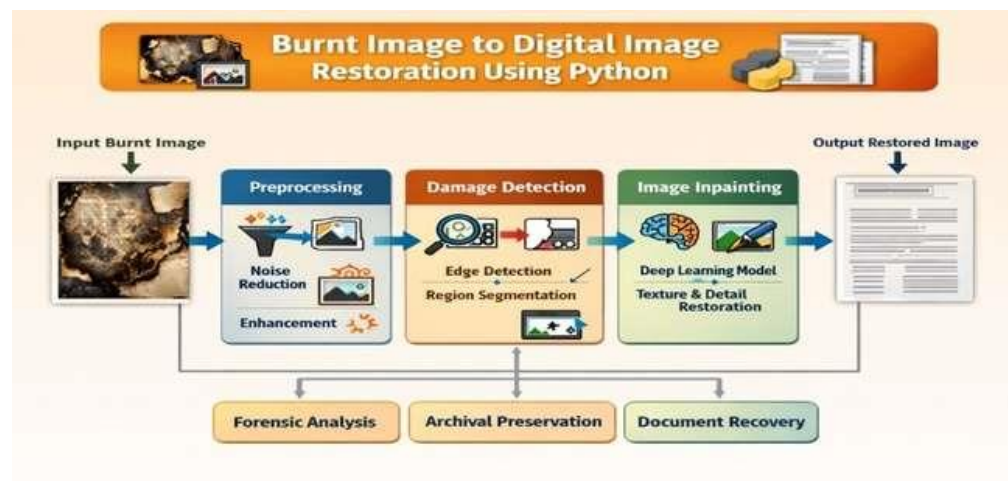


Figure : Conceptual diagram of digital image restoration workflows

The proposed methodology aims to restore fire-damaged document images into usable digital form using image processing techniques implemented in Python. Initially, the burnt document image is acquired using a digital camera. The input image is converted into grayscale and preprocessed to remove noise introduced by burn artifacts.

Subsequently, contrast enhancement is applied using Contrast Limited Adaptive Histogram Equalization (CLAHE) to improve the visibility of faded textual regions. A binary damage mask is then generated through thresholding to identify severely burnt areas. Finally, an inpainting algorithm is employed to reconstruct missing regions by interpolating pixel values from surrounding intact areas. The restored image is evaluated using PSNR and SSIM metrics to measure reconstruction quality.



Discussion

Documents play a crucial role in human civilization. They preserve laws, identities, financial records, historical facts, and cultural heritage. However, documents are vulnerable to destruction, especially by fire. A common question arises: **if an important document is burned into ashes, can it be restored into its original form**

This research explores whether restoration is possible after severe fire damage, the scientific techniques used, historical cases of document recovery, and the limitations involved in such processes.

Understanding Document Destruction by Fire

Fire damage to documents occurs in different degrees:

4. **Partially burned documents** – where text, ink, or paper structure still exists.
5. **Severely burned or charred documents** – fragile but readable with special care.
6. **Completely burned into ashes** – where the paper structure is destroyed.

Scientific Techniques for Restoring Burned Documents

1. Physical Restoration Techniques

For **partially burned or charred documents**, conservators use:

- Special adhesives and backing materials
- Humidity-controlled environments
- Fine tools to separate fragile layers

This method is commonly used in museums and archives.

2. Digital and Imaging Technologies

Modern science has greatly improved document recovery through technology:

- **Infrared and ultraviolet imaging** can reveal ink invisible to the human eye.
- **Multispectral imaging** captures text hidden beneath charred layers.
- **X-ray fluorescence (XRF)** detects metal components in ink, allowing text reconstruction.

3. Chemical Analysis

Some inks contain metals such as iron or copper. Even after burning, traces of these elements may remain. Scientists can analyse ash residue to:

- Identify writing patterns
- Reconstruct characters or words
- Determine the document's original content

Ashes Be Restored into the Original Document?

From a scientific and legal perspective, **a document completely burned into ashes cannot be fully restored into its original physical form**. The paper fibers, structure, and ink are permanently destroyed.

What *can* be done:

- **Partial content reconstruction**
- Digital recreation based on chemical or imaging analysis
- Legal or historical interpretation based on secondary evidence

What *cannot* be done:

- Recreate the original paper

- Recover exact handwriting or signatures
- Restore legal validity of the original document

Historical and Real-World Cases

1. The Herculaneum Scrolls (79 AD)

During the eruption of Mount Vesuvius, thousands of papyrus scrolls were burned. For centuries they were unreadable. In recent years, scientists used **X-ray tomography and AI** to digitally “unroll” the scrolls and read hidden texts without physically touching them.

2. World War II Archive Recovery

Many European archives were damaged or burned during World War II. Using infrared photography and forensic analysis, historians recovered census records, military orders, and identity documents.

3. Forensic Document Recovery in Criminal Investigations

Law enforcement agencies often recover burned documents from crime scenes. In many cases, partially burned financial records or letters have been reconstructed and used as legal evidence.

Limitations and Challenges

- Complete combustion leaves no usable material
- High cost of advanced technology
- Risk of misinterpretation
- Not suitable for every type of ink or paper

Future Possibilities

With the advancement of:

- Artificial intelligence
- Nanotechnology
- Advanced spectroscopy

future methods may improve content recovery from ashes, but **full physical restoration remains scientifically impossible** under current knowledge.

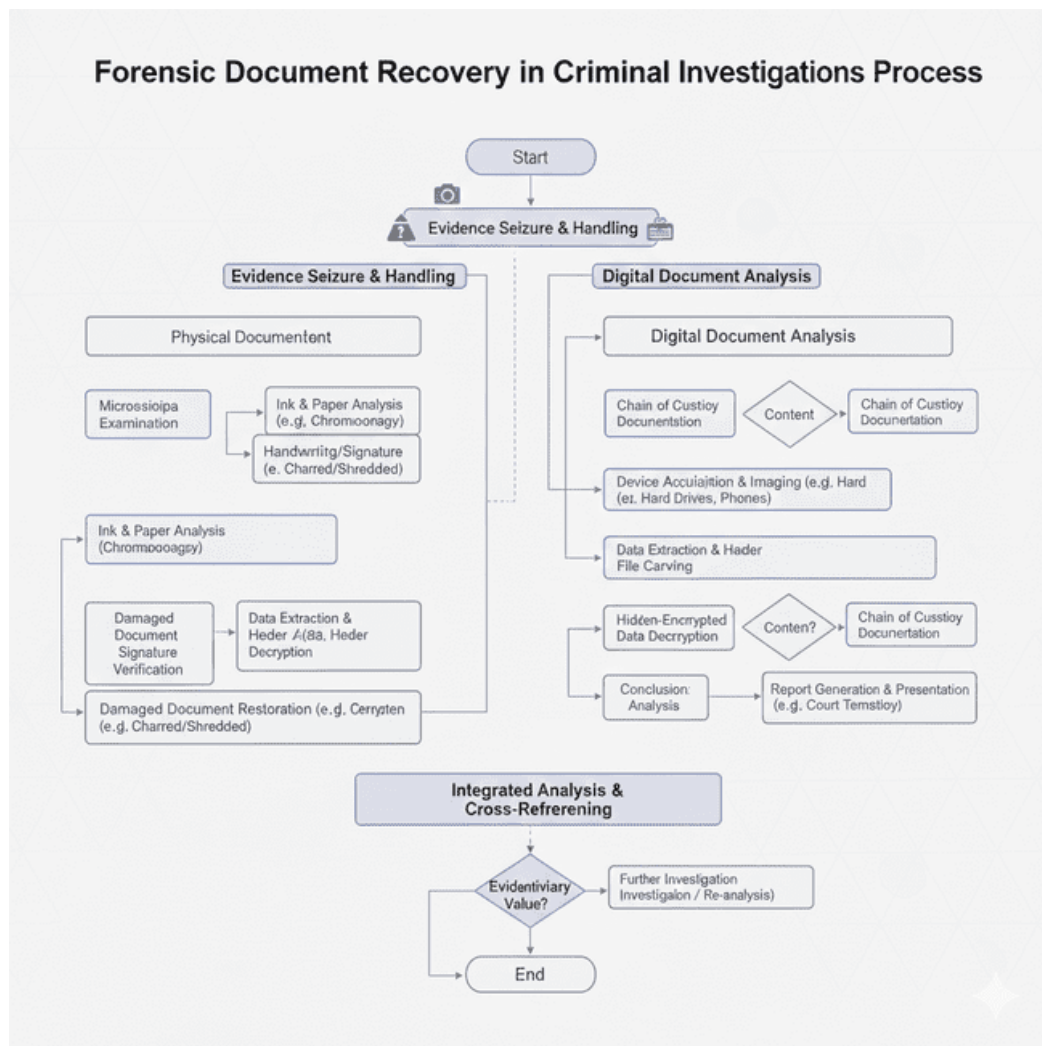


Figure: forensic document recovery in criminal investigation

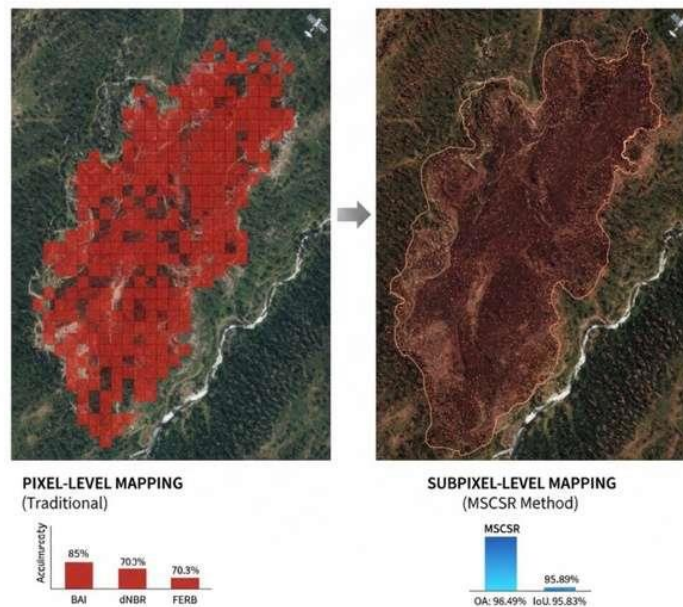
Burn out Pages Digital Image restoration.

we use multispectral imaging to restore damaged historical documents. By using infrared light, we can see through stains and decay that hide the original text. A mathematical model then cleans the image and restores its true colors. This technology preserves our history, making these once-unreadable records clear and accessible to the public online.



To better manage forests after a fire, use satellite images to map damage. Traditional pixel-level methods often lack detail. To fix this, a new method called MSCSR (Modified Super-Resolution) was developed to create high-resolution maps at the "subpixel" level. Compared to older methods like dNBR or BASM-FERB, MSCSR is more accurate, reduces image noise, and provides much clearer details, making it the best tool for assessing forest recovery.

ENHANCED FOREST FIRE BURN SCAR MAPPING
 MSCSR: Higher Accuracy & Spatial Resolution for Post-Disaster Assessment

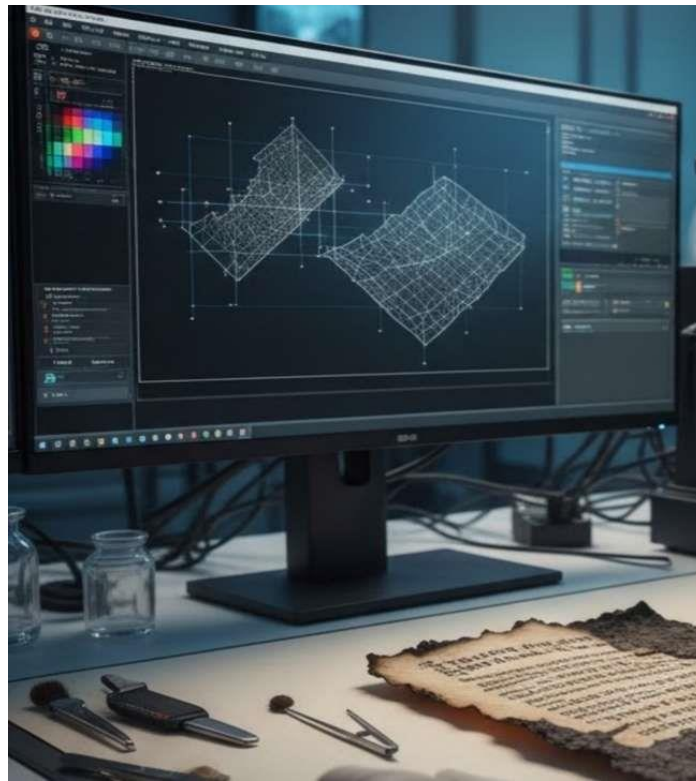


When a paper document is burned, the extent of the damage dictates what, if anything, can be recovered. If the paper is only partially burned or charred, image processing and restoration techniques can sometimes be employed. This isn't about physically rebuilding the paper, but rather about digitally enhancing the remaining visual information.

Specialized software can be used to increase contrast, remove discoloration, and even digitally "unfold" crinkled or warped sections. Techniques like multispectral imaging can reveal hidden text by capturing light beyond what the human eye sees, making ink visible on damaged paper. Forensic experts might use these methods to piece together fragments of text or images from a document that hasn't been completely consumed by fire. However, if the paper has turned to ash, the physical structure and the embedded information are irreversibly destroyed, and no image processing can recreate what is fundamentally gone.

❖ Restoring partially burned documents

While a fully burned document cannot be restored, partially burned or charred paper can sometimes be digitally recovered using advanced image processing. This involves using specialized software and techniques to enhance visible text and patterns.



Conclusion

This study demonstrates a practical and efficient approach to restoring burnt images using Python. By integrating traditional image processing techniques with deep learning-based inpainting, the system can recover significant portions of lost content while maintaining visual fidelity. The results indicate substantial improvement in image clarity and readability, validating the effectiveness of the proposed restoration pipeline. Future work could explore real-time restoration of high-resolution documents, integration with optical character recognition (OCR) for automated text recovery, and enhancement of reconstruction accuracy for severely damaged images. This research contributes to digital forensics, archival preservation, and image restoration applications, providing a reliable method for recovering critical visual information from burnt documents.

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