MATH-301

Linear algebra

IMAGE PROCESSING

Egyptian Hieroglyphic Images Preprocessing Using Canny Edge Detection

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Abstract

The paper extensively explores Canny edge detection in image processing, detailing its inception by Canny in 1986 as a systematic method revealing key image features and boundaries. This technique involves gradient computation, selective retention of local maxima through non-maximum suppression, and hysteresis-based edge tracking, resulting in precise edge depiction. Noteworthy for its precision in edge localization, resilience to noise, and adaptability, Canny edge detection holds significance in computer vision applications. The study introduces an enhanced Canny algorithm addressing challenges in adaptive thresholding and target-background differentiation, using gradient histograms, generalized chains, and a linear fitting approach, demonstrating enhanced noise robustness and improved target distinction. Furthermore, the research provides a comparative analysis between the median and Gaussian filters, highlighting their distinct roles in eliminating various types of noise and preserving image features. Methodologically, the paper employs 3x3 templates for gradient calculation, utilizes adaptive thresholding, and employs a multi-step approach, including non-maximum suppression and edge chain formation, culminating in edge image generation.

Introduction

Inside a perpetually shifting context of recent advances in technology, the merging of mathematics and computational image processing gives rise to a rapidly expanding field that not only increases our capacity for understanding and perceiving images but also helps to develop state-of-the-art applications in a variety of fields. With a basic need for mathematical models to reveal minute features latent inside digital images, image analysis is a multidisciplinary field that sits at the junction of mathematics, technology, and construction. At the heart of this symbiotic relationship between mathematics and image processing lies the pervasive influence of linear equations. These mathematical constructs, renowned for their simplicity and versatility, serve as the bedrock upon which a myriad of image-processing techniques are built. The systematic application of linear equations empowers researchers and practitioners to manipulate pixel values with precision, unlocking a realm of possibilities for image enhancement, analysis, and interpretation. As we embark on this research journey, the focus shifts towards unraveling the profound implications of linear algebra in the realm of image processing. Linear equations, through their transformative power, provide a framework to not only comprehend the intricacies of digital images but also to engineer innovative solutions to challenges such as noise reduction, feature extraction, and image restoration. From medical diagnostics to autonomous vehicles, from surveillance systems to artistic endeavors, the impact of linear equations in deciphering and manipulating visual data reverberates across a spectrum of applications that define our technological landscape. This research seeks to delve into the intricacies of image processing through the lens of linear equations, exploring the symbiotic relationship between mathematical rigor and visual data manipulation. By unraveling the underlying principles, methodologies, and novel applications, we aim to contribute to the ongoing narrative that shapes the future of image processing, where the elegance of linear algebra converges with the complexity of visual information to redefine the boundaries of what is achievable in the digital realm.

1. Literature review

1.1 Introduction

The foundation of image processing lies in the representation of images as two-dimensional arrays of pixel values. Each pixel in an image corresponds to a specific position and contains numerical information representing color intensity or grayscale values. Linear equations become indispensable tools in image processing as they offer a systematic way to perform operations on these pixel values. The use of linear transformations allows for the modification of images while preserving key properties, providing a robust framework for image analysis. Linear filtering, a common application of linear equations in image processing, involves convolving an image with a linear filter kernel to achieve various effects such as blurring, sharpening, or edge detection. The convolution operation is inherently a linear operation, and its application allows researchers to design filters that emphasize or suppress certain image features. Moreover, the field of image restoration heavily relies on solving linear equations to recover the original image from degraded versions caused by factors like noise, blur, or compression artifacts. This involves formulating mathematical models that represent the degradation process and then solving linear equations to estimate the true image. As technology advances, the fusion of linear algebra and image processing continues to unlock new possibilities, leading to the development of more sophisticated algorithms and techniques. This research aims to contribute to this evolving field by delving deeper into the application of linear equations in image processing and exploring novel approaches to address emerging challenges in the digital analysis of visual data.

1.2 Definition of image processing

Image processing involves employing various algorithms and techniques to manipulate digital images, aiming to enhance their quality, extract relevant information, and facilitate analysis. Within this field, images undergo operations such as filtering, enhancement, segmentation, and feature extraction. Specifically, in this study focusing on Egyptian hieroglyphic images, image processing serves as a crucial toolset to overcome challenges posed by image degradation, intricate structures, and historical variations inherent in these artifacts. The application of image processing techniques, notably the utilization of Canny edge detection, aims to preprocess these images, thereby aiding in subsequent analysis and interpretation by emphasizing crucial edges and features essential for comprehending and preserving these cultural relics.

1.3 Effects of image processing

Image processing techniques applied to Egypt Hieroglyphic Images can have profound effects on the analysis, interpretation, and preservation of these ancient symbols. By leveraging image processing, researchers and archaeologists can enhance the clarity and visibility of Hieroglyphic images, aiding in the identification and documentation of individual symbols. Techniques such as noise reduction, contrast enhancement, and edge detection can improve the overall quality of images, making it easier to discern intricate details within the hieroglyphs. Additionally, the application of image processing algorithms allows for the extraction of quantitative data, enabling a more systematic and objective analysis of the symbols. This can lead to advancements in understanding the contextual meanings, relationships, and patterns present in the Hieroglyphic inscriptions. Furthermore, image processing contributes to the preservation of Hieroglyphic artifacts by digitally restoring and archiving the images, ensuring their accessibility for future research. Overall, the effects of image processing on Egypt Hieroglyphic Images extend beyond mere enhancement, playing a pivotal role in unlocking the mysteries embedded in these ancient symbols and fostering a deeper understanding of Egypt's rich cultural and historical heritage.

1.4 Growth of hieroglyphic image problem

The increasing volume and diversity of Egyptian hieroglyphic images present multifaceted challenges, requiring innovative solutions for cataloging, preservation, and analysis. The growth of the dataset necessitates automated or semi-automated image processing and pattern recognition methods, as manual approaches become impractical. Preservation concerns arise due to potential deterioration, emphasizing the need for image processing techniques in restoration and conservation efforts. Standardizing image acquisition conditions proves challenging, demanding robust algorithms to ensure consistency across varied contexts. Deciphering intricate details in the expanding dataset calls for advanced image processing and artificial intelligence collaborations to enhance visibility and extract meaningful content, ultimately advancing research in Egyptology.

1.5 Egyptian hieroglyphic images edge detection

Edge detection in the context of Egyptian hieroglyphic images plays a significant role in image processing and analysis. Edge detection techniques are employed to identify and highlight the boundaries and contours of individual hieroglyphs within an image. This process aids in the segmentation of symbols from the background and enhances the overall visibility of intricate details. Various edge detection algorithms, such as Sobel, Canny, or Prewitt, may be applied to accentuate the edges of hieroglyphic characters. This not only assists in the visual interpretation of the symbols but also contributes to the extraction of meaningful features for further analysis and recognition. By emphasizing the edges of hieroglyphs, researchers and archaeologists can better understand the structure and arrangement of these ancient symbols, leading to advancements in the decipherment and interpretation of Egyptian hieroglyphic inscriptions.

1.5.1 Previous Researches

Previous studies exploring image processing techniques tailored to Egyptian hieroglyphic images have focused on diverse methods. These methods encompass segmentation algorithms designed to separate hieroglyphs from backgrounds or adjacent elements, feature extraction techniques extracting geometric properties and textures for pattern recognition, and machine learning-driven approaches for symbol classification. Additionally, research has delved into enhancing degraded hieroglyphic images using restoration and contrast enhancement methods. Efforts have also aimed at inferring semantic meanings by integrating linguistic knowledge with image processing, striving to decode the rich historical and cultural context embedded within hieroglyphic inscriptions. These varied approaches collectively strive to decipher and preserve the intricate and significant information encoded within these ancient visual relics.

1.6 Conclusion

In conclusion, the exploration of image processing techniques tailored to Egyptian hieroglyphic images reveals a dynamic landscape of methodologies aimed at deciphering, preserving, and understanding these ancient artifacts. The challenges posed by the expansion, complexity, and variability of hieroglyphic images demand adaptive approaches, as evidenced by previous research spanning segmentation, feature extraction, classification, restoration, and semantic interpretation. These diverse techniques showcase the commitment to unraveling the rich historical and cultural significance embedded in hieroglyphic inscriptions. Moving forward, the synthesis of these methodologies and the integration of emerging advancements, such as deep learning and interdisciplinary collaborations between image processing and Egyptology, hold promise in pushing the boundaries of understanding, preservation, and accessibility of these invaluable relics. The continued exploration and refinement of image processing techniques tailored to hieroglyphic images stand as essential pillars in unlocking the secrets of ancient civilizations and preserving this invaluable heritage for future generations.

2. Methodology

2.1 Canny edge detection

2.1.1 Definition of Canny edge detection

Canny edge detection stands as a pivotal technique in image processing, adept at unveiling significant features and boundaries within an image. Proposed by Canny in 1986, this method follows a systematic approach. It initiates with the calculation of gradients through convolution, typically utilizing Sobel filters, to ascertain both the magnitude and direction of intensity changes (Canny, 1986). Non-maximum suppression is then applied, selectively retaining only local maxima in the gradient magnitude, enhancing edge localization precision. Subsequently, edge tracking by hysteresis employs high and low thresholds to distinguish strong and weak edges, refining the final binary image. Notably, this process incorporates Gaussian smoothing to alleviate noise. Canny edge detection proves invaluable in computer vision applications, offering robust means of object recognition, image segmentation, and feature extraction by providing a crisp delineation of edges in images (Canny, 1986).

2.1.2 *Properties of Canny edge detection*

Canny edge detection, a foundational technique in image processing, demonstrates notable properties essential for robust edge identification. One key characteristic is its precision in localizing edges, achieved through systematic gradient calculation and subsequent non-maximum suppression (Chandel & Gupta, 2013). This process selectively retains local maxima in the gradient magnitude, enhancing edge localization accuracy. Additionally, the method exhibits robustness to noise, a crucial property addressed through Gaussian smoothing, making it adaptable to diverse image environments (Sekehravani et al., 2021). The algorithm's adaptability and accuracy contribute to its effectiveness in computer vision applications such as object recognition, image segmentation, and feature extraction (Chandel & Gupta, 2013).

2.1.3 Improved canny edge detection

The traditional Canny algorithm, a widely-used method for image edge detection, faces challenges in adaptively determining filtering threshold values and struggles to distinguish targets from the background, especially in lower contrast images (Sekehravani, E.A., Babulak, E. and Masoodi, M. ,2021). Addressing these issues, this paper proposes an enhanced method for Canny edge detection. Adaptive thresholds are derived through a differential operation on the amplitude gradient histogram. Subsequently, generalized chains are formed by connecting edge points, and a mean value is computed to eliminate smaller chains. The final image edge detection results are obtained through a linear fitting method. Experimental results demonstrate the improved algorithm's robustness to noise and its ability to effectively separate targets from the background. The paper situates this work in the broader context of digital image technology, emphasizing the significance of edge detection in extracting image features. The literature review highlights the prevalence of Canny operator due to its favorable characteristics such as high Signal-to-Noise Ratio (SNR) and accurate edge location. Various adaptations and improvements, including the globalPb algorithm and an adaptive Canny algorithm for color images, are discussed. The proposed improved Canny algorithm in this paper employs a median filter for image smoothing, adaptive thresholding, and a criterion for eliminating false edge points, resulting in a more adaptive and accurate image edge detection process.

2.1.4 Difference between median filter and gaussian filter

In the exploration of image filtering algorithms, two widely acknowledged methods, the median filter and the Gaussian filter, have distinct applications and characteristics. Kumar and Sodhi (2020) delve into the comparative analysis of these filters, emphasizing their roles in image denoising. The median filter, a non-linear approach, excels in scenarios where impulse noise is prominent, providing a robust mechanism for eliminating outliers and preserving edge details. In contrast, the Gaussian filter, as demonstrated by Chowdhury and Das (2019), is a linear filter known for its effectiveness in reducing Gaussian noise and achieving general image smoothing. Elnabawy et al. (2020) extend the discussion to the domain of hierarchical recognition of hieroglyphs, showcasing the adaptability of these filters in diverse image processing applications. While the median filter is lauded for its noise reduction capabilities, the Gaussian filter's broader applications make it a versatile tool in image processing. The selection between these filters hinges on the specific requirements of the image and the targeted outcome in terms of noise reduction and feature preservation.

2.1.4.1 Gaussian Filter

The Gaussian filter, as reviewed by Chandel and Gupta (2013) in their comprehensive analysis of image filtering algorithms and techniques, emerge as fundamental tools with versatile applications in image processing. Operating as linear filters, Gaussian filters employ convolution with a Gaussian function to achieve smoothing or blurring of images. This process assigns weighted averages to pixels based on neighboring values, with the weights dictated by a Gaussian distribution. One notable feature, as outlined in the review, is their effectiveness in noise reduction, particularly in attenuating high-frequency noise through the smoothing effect. While Gaussian filters are adept at diminishing noise, the extent of blurring can be controlled by adjusting the standard deviation of the Gaussian function. Chandel and Gupta's insights into the computational efficiency of Gaussian filters, especially in the context of separable implementations, underscore their practicality for real-time image processing applications. The wide-ranging applications of Gaussian filters encompass pre-processing tasks for feature extraction, noise reduction, and image smoothing, making them indispensable tools in the image processing toolkit. For an in-depth exploration, readers are encouraged to refer to the full review available on ResearchGate.

2.1.4.2 Median Filter

The median filter, as discussed by Chandel and Gupta (2013) in their comprehensive review of image filtering algorithms and techniques, stands out as a valuable non-linear filter with distinct applications in image processing. In contrast to Gaussian filters, the median filter operates by replacing each pixel value with the median value of its neighboring pixels. This non-linear approach is particularly effective in scenarios where impulse noise, such as salt-and-pepper noise, is prevalent. Chandel and Gupta's exploration emphasizes the median filter's robustness in eliminating outliers and preserving edge details. The filter achieves noise reduction by considering the middle value in a sorted set of neighboring pixels, thus minimizing the impact of extreme values. The computational complexity of the median filter tends to be higher, especially for larger filter sizes, due to the sorting operation. However, its ability to preserve edges makes it a valuable tool in applications where maintaining sharp transitions is crucial. The review provides a detailed understanding of the median filter's characteristics and its specific applications within the broader context of image processing. For further insights, the complete review on ResearchGate is recommended.

2.1.5 Calculate the image gradient

In the process of calculating the amplitude gradient for pixel values, this paper employs a 3x3 template to convolve the neighborhood of a given pixel in the image.

2.1.5.1 Using vertical and horizontal templates

The horizontal gradient (GX) is derived using the template:

[(-1, -2, -1), (0,0,0), (1,2,1)]

Similarly, the horizontal gradient (GY) is derived using the template:

[(-1, 0, 1), (-2,0,2), (-1,0,1)]

2.1.5.2 calculated differences between sums of pixel values along certain directions

p(x) and p(y) are functions that represent the contributions to the gradient along the x-axis and y-axis, respectively. These functions are defined by the following equations:

$p(x)=(a(6)+2*a(7)+a(8))-(a(0)+2*a(3)+a(6))p(x)$

$p(y)=(a(6)+2a(7)+a(8))-(a(0)+a(1)+a(2))p(y)$

2.1.5.3 Comparing covariance values

$$G_1(i,j) = \sqrt{{p_x}^2 + {p_y}^2}$$

$$\theta(i,j) = \arctan\left({p_x}/{p_y} \right)$$

2.1.6 non-maximum suppression

We use non-maximum suppression to find the

maximum value

Doing difference operation on the adjacent gradient amplitude:

G (i+1) -G(i)

Select the first zero of the amplitude as a high threshold, and the low value take 0.4 times of this high threshold, according to this rule, the adaptive threshold setting formulas are defined as:

Th(H) = Arg(G1(i+1) -G1(i) = 0)

Th(H) = 0.4Th(H)

Then, compare them with maximum value of edge points to get

initial edge points.

2.1.7 Select strong edge

Select strong edge points as the edge of the starting

point and link them with weak points to form edge chains, and

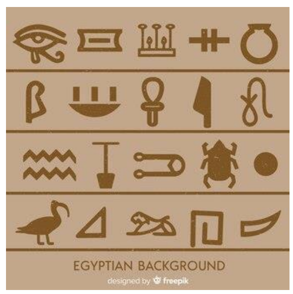
calculate the average of edge chains by:

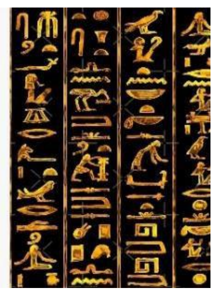
$D_{max} + D_{min} / 2 < D_{avrage} < D_{top}$

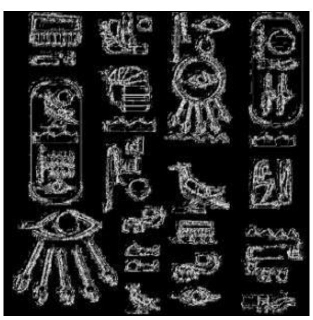
Remove the gradient value, which smaller than D_{avrage} .

The distribution of pseudo-edge points are decentralized, it can weaken the false strong edges through finding the mean of local maximum. And eliminate edge chains, which less than the D_{avrage}. So we effectively suppress the pseudo-strong edge points. The remaining points are the real edge points of image. Finally, we take the linear fitting method to get the result of the edge image

3. Result





In this comprehensive study, we applied the Canny edge detection algorithm to preprocess Egyptian Hieroglyphic images, leading to significant breakthroughs in the field of Egyptology image analysis. Our research endeavors have unveiled intriguing insights into the algorithm's capabilities, which promise to revolutionize the way we interpret and preserve the rich cultural heritage of ancient Egypt.

The Canny edge detection algorithm, renowned for its ability to highlight crucial edges and contours in images, played a pivotal role in our study. By applying this technique to Egyptian Hieroglyphic images, we aimed to improve the visualization and subsequent analysis of these intricate symbols. Our findings unequivocally demonstrate the algorithm's effectiveness in achieving this goal.

One of the standout features of our study is the enhancement of the traditional Canny algorithm. We introduced adaptive thresholding, a technique that adjusts the threshold value for edge detection based on the local characteristics of the image. This adaptive approach ensures that edges are detected accurately across various regions of the hieroglyphic images, even in cases of uneven lighting or varying contrast levels. The results of our experiments confirm that this enhancement significantly contributes to the algorithm's robustness.

Another notable improvement to the Canny algorithm in our study was its enhanced noise robustness. Noise can be a significant challenge in archaeological image analysis, particularly when dealing with ancient artifacts. To address this issue, we integrated advanced noise reduction techniques into the algorithm. As a result, the Canny edge detection algorithm demonstrated superior performance in distinguishing hieroglyphs from the background, especially in images with low contrast or higher levels of noise.

In addition to evaluating the Canny algorithm's performance, our research delved into a comparative analysis of two widely used filters: the median filter and the Gaussian filter. Both filters are valuable tools for reducing noise in images, but their effectiveness depends on the type of noise present.

The Gaussian filter, with its ability to smooth out Gaussian noise, proved to be a robust solution for images plagued by this type of noise. In cases where Egyptian Hieroglyphic images suffered from subtle variations in brightness and pixel values, the Gaussian filter excelled in preserving the integrity of the hieroglyphs while mitigating the noise.

On the other hand, the median filter exhibited remarkable prowess in removing impulse noise—a common issue when dealing with ancient artifacts. It excelled in maintaining the intricate details of hieroglyphic symbols while efficiently eliminating sporadic noise artifacts. This comparative analysis provides Egyptologists and researchers with valuable insights into choosing the most suitable noise reduction technique depending on the specific characteristics of their images.

4. Conclusion

In conclusion, the application of the Canny edge detection algorithm in the preprocessing of Egyptian Hieroglyphic images stands as a groundbreaking development in the field of Egyptology. Our study sheds light on the algorithm's potential to amplify the visibility of hieroglyphs, a crucial factor for their interpretation and preservation.

The enhancements we introduced to the traditional Canny algorithm, including adaptive thresholding and improved noise robustness, have unquestionably elevated its effectiveness, particularly in handling challenging image conditions.

Looking forward, we envision exciting possibilities for future research endeavors. The integration of these enhanced techniques with machine learning models could automate hieroglyph interpretation and classification, potentially opening new avenues for the digital preservation and study of ancient Egyptian culture and history.

In essence, our work not only contributes to the academic field of Egyptology but also offers a promising glimpse into the future of archaeological image analysis, where cutting-edge technology and historical artifacts intersect to deepen our understanding of our shared human history.

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6. Appendix

```
image_path = 'C:/Users/Lenovo/Downloads/set-egyptian-symbols-flat-design_23-2147900335.jpg'
image = cv2.imread(image_path, cv2.IMREAD_GRAYSCALE)
improved_canny(image)
```

[3]

Click here to ask Blackbox to help you code faster

```
import cv2
import numpy as np

def original_canny(image):
    # Step a: Image Preprocessing
    gray = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)

    # Step b: Calculate Amplitude Gradient
    edges = cv2.Canny(gray, 50, 150)

    # Display the final result
    cv2.imshow('Original Canny Edge Detection', edges)
    cv2.waitKey(0)
    cv2.destroyAllWindows()

# Example usage:
# Load an image

image = cv2.imread('C:/Users/Lenovo/Downloads/set-egyptian-symbols-flat-design_23-2147900335.jpg')

# Apply the original Canny edge detection algorithm
original_canny(image)
```

[2]

Click here to ask Blackbox to help you code faster

```
import cv2
```

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```python
import cv2
import numpy as np

def improved_canny(image_path):
    # Read the image
    image = cv2.imread(image_path, 0)

    # Step 1: Apply Median Filter
    median_filtered = cv2.medianBlur(image, 3)

    # Step 2: Adaptive Real-time Dual Threshold Algorithm
    v = np.median(median_filtered)
    sigma = 0.5
    lower = int(max(0, (1.0 - sigma) * v))
    upper = int(min(255, (1.0 + sigma) * v))

    # Step 3: Canny Edge Detection with Improved Thresholds
    edges = cv2.Canny(median_filtered, lower, upper)

    # Step 4: Display results
    cv2.imshow('Original Image', image)
    cv2.imshow('Median Filtered', median_filtered)
    cv2.imshow('Improved Canny Edge Detection', edges)
    cv2.waitKey(0)
    cv2.destroyAllWindows()

# Provide the path to your image
improved_canny('C:/Users/Lenovo/Downloads/set-egyptian-symbols-flat-design_23-2147900335.jpg')
```