Assignment-1 : Edge Detection

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Objective

This assignment aims to expand our knowledge and skills by implementing cutting-edge edge detection algorithms in image processing. We are required to improve our knowledge by importing and modifying real-world photographs, using edge detection filters at different angles, building Winner-Takes-All (WTA) algorithms, and normalizing. We will also compare our methods to determine their efficacy.

Part-1

In image preprocessing, we perform three essential steps:

Grayscale Conversion: This simplifies the image by turning it into shades of gray, reducing computational complexity. We achieve this by calculating pixel values using a weighted average of color channels.

Contrast Enhancement: To improve image quality, we use histogram-based techniques like CLAHE and AHE. These methods expand the dynamic range of grayscale images while preserving local details. AHE balances the histogram for enhanced contrast, while CLAHE refines contrast in specific regions, preventing noise issues.

Gamma Correction: This technique adjusts pixel intensity, particularly useful for images with nonlinear intensity relationships. It compensates for nonlinear responses in display devices and human perception, enhancing contrast and overall visual appeal.

- These images were used for the assignment

Rocks near Ocean
640x427

Goat grazing
640x427

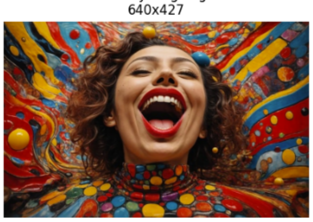
An owl in morning
640x427

A kitten playing
640x427

Small Bird
640x427

Thunderstorm over the sea
640x427

A lady laughing
640x427

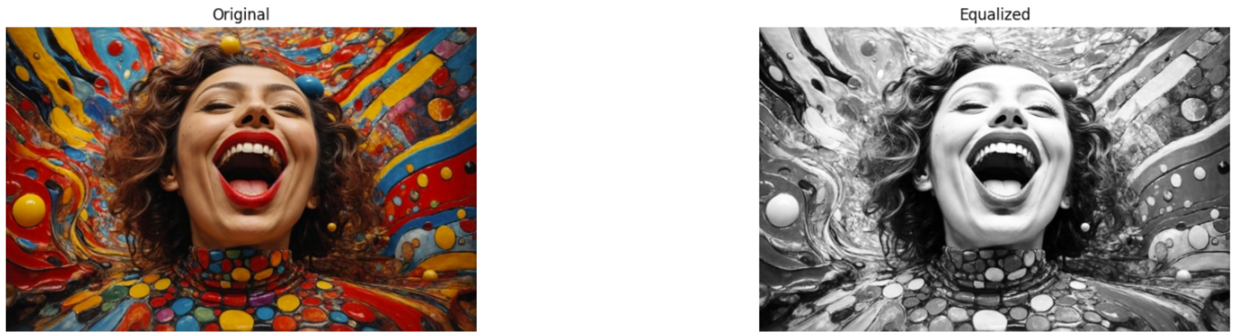


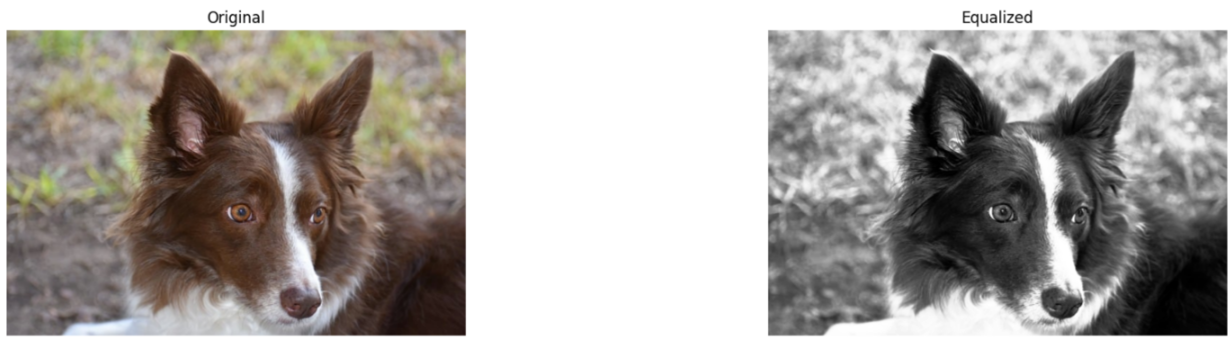
A butterfly sucking nectar
640x427

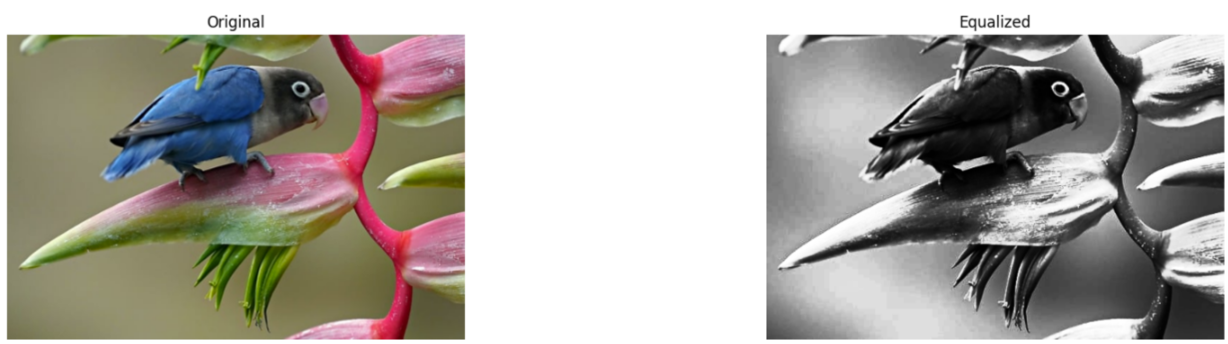
Sweet Cherries
640x427

A staring dog
640x427

- Following are the histogram equalized for some of these images -







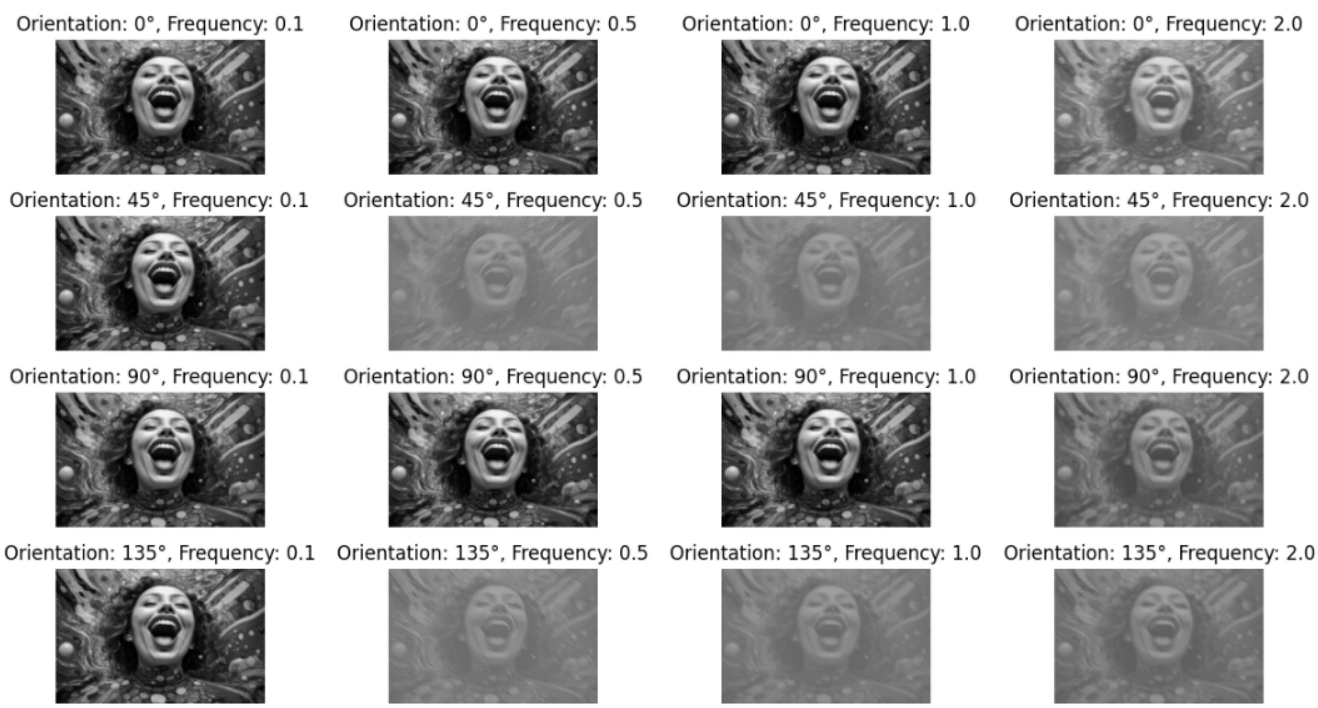
Part-2

Gaussian Smoothing: This method is crucial for reducing noise and highlighting essential structural details in an image. It uses a 2D Gaussian distribution applied through a Gaussian kernel to create a blur effect, effectively reducing high-frequency noise.

Gabor Filters: These specialized tools are designed for edge detection and texture analysis in images. Gabor filters are constructed using Gabor wavelets, which are complex sinusoidal functions modified by Gaussian distributions. By adjusting parameters like frequency, direction, and scale, Gabor filters can be customized to extract specific information from images. Their versatility is particularly advantageous for tasks requiring comprehensive analysis across various scales and orientations, such as texture analysis and fingerprint recognition.

For the image -

Gabor Filters are applied for different orientations and frequencies-

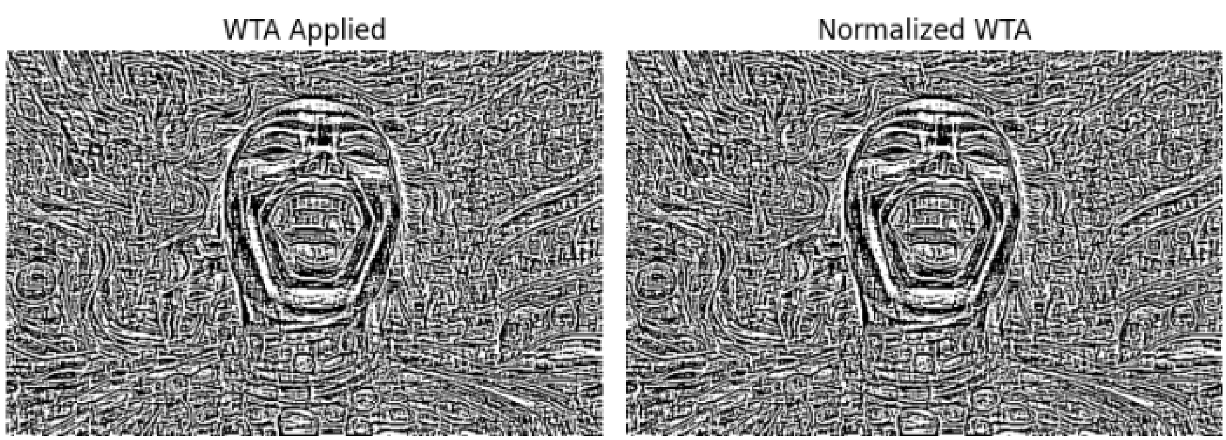


Part-3

Winner-Takes-All (WTA): WTA is a valuable approach for identifying prominent edges in images. It takes into account both orientation and magnitude data, making it robust in detecting edges of different strengths and orientations. This ensures precise edge detection, even in complex image scenarios.

Advanced Normalization Techniques (ACN and PCE): Normalization techniques serve two purposes in image processing: enhancing edges and reducing noise. Advanced methods like Perceptual Contrast Enhancement (PCE) and Adaptive Contrast Normalization (ACN) are crucial for achieving these objectives. ACN locally adjusts image contrast to enhance edges in regions with varying illumination conditions, while PCE utilizes principles of human visual perception to enhance perceptual contrast. These techniques significantly improve edge detection accuracy and noise resistance, ultimately enhancing the quality of image analysis results.

Implementation of WTA and it’s normalization



Part-4

Image quality assessment relies on the **Structural Similarity Index (SSIM)**, which ranges from -1 to 1, with 1 denoting perfect similarity. SSIM considers luminance, contrast, and structural similarities between images. Its versatility allows it to handle local and global variations, making it valuable for algorithm performance evaluation and overall perceptual image quality assessment.

Edge detection accuracy is measured by the Edge F1-score, which combines accuracy and recall, considering false positives and false negatives while minimizing spurious results.

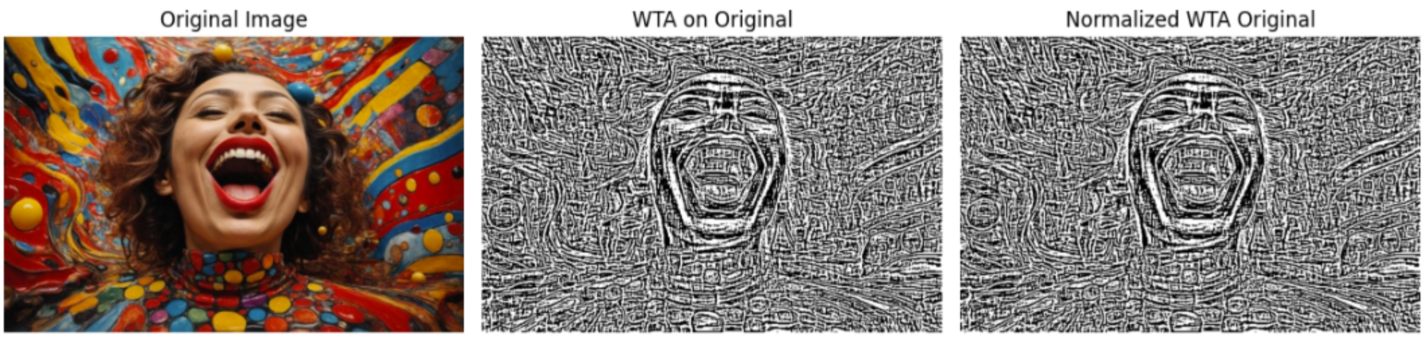
In image manipulation, we have two useful functions:

Adding Gaussian Noise: This function enhances an image by introducing Gaussian noise with controllable variance and mean parameters. Gaussian noise simulates random pixel value changes, often reducing image quality and increasing graininess. It's useful for testing algorithm resilience against real-world noise sources.

Simulating Motion Blur: This function mimics camera or object motion during image capture by adding motion blur. The "size" parameter controls the blur's size and direction, creating a sense of objects being blurred in the direction of motion. This effect is common in images taken with moving cameras or during long exposures.

For edge detection, the FIND_EDGES filter from Pillow, a Python Imaging Library, is used on various image variations: the original grayscale image, an image with added Gaussian noise, and an image with motion blur. This filter highlights edges and contours by emphasizing intensity changes between regions, resulting in binary edge images (1 for edges, 0 for non-edges). This simplifies tasks like feature extraction and object segmentation, facilitating edge processing and analysis.

A pipeline to apply all these methods for edge detection was develop and was to compare original and noisy images (motion blur and gaussian noise) with ssm and f-1 score

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SSIM Score (gaussian noise): 0.1862
Edge F1 Score (gaussian noise): 0.5929
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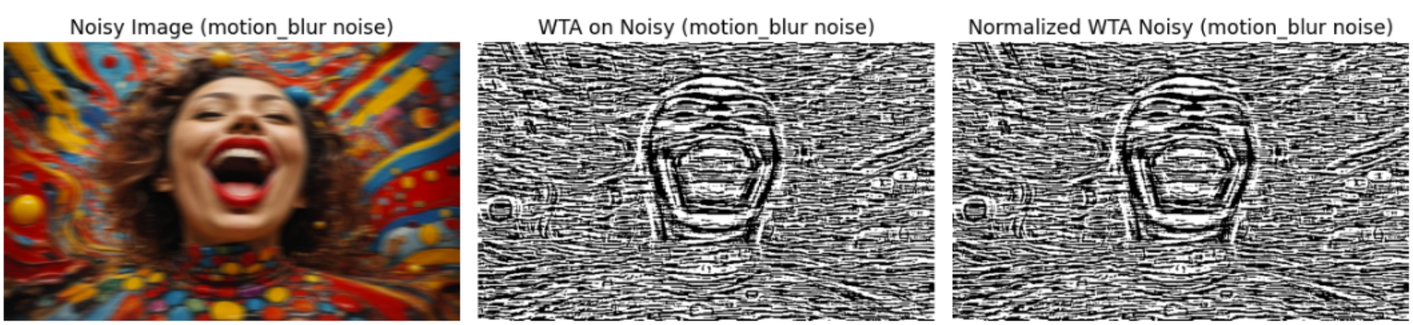
SSIM Score : 0.1862 Edge F1 Score : 0.5929

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SSIM Score (motion_blur noise): 0.2929
Edge F1 Score (motion_blur noise): 0.6621
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```

SSIM Score : 0.2929 Edge F1 Score : 0.6621

Colab file can be referred for results for all other images.

In summary, this edge detection technique enhances the visibility of image edges, making it valuable for computer vision and image processing applications where extracting structural information from images is essential.

Our observations revealed a higher structural similarity between the original image and the blurred image compared to the original image and the noised image. Additionally, the F1 score for edge detection was consistently higher in the case of the blurry image compared to the noisy image in all scenarios. It's important to note that specific outcomes may vary based on the extent of blur and noise applied to the image.

Advantages:

Effective Complex Edge Capture: Gabor filters excel at capturing intricate edge patterns and can adapt to variations in orientation and scale.

Distinguishing Edges in Textured Backgrounds: They are proficient at distinguishing edges from textured backgrounds, enhancing edge detection in challenging scenarios.

Limitations:

Computational Intensity: Applying Gabor filters across various orientations and scales can be computationally intensive, which may pose challenges in real-time or large-scale applications.

Parameter Selection Complexity: Selecting optimal parameters, such as scale and orientation, can be a complex task requiring extensive experimentation.

Part-5

In image processing, two valuable techniques for visualizing results and features are overlaying edge detection results onto original images and generating gradient magnitude and orientation maps. Each method serves specific purposes and has its advantages and disadvantages.

Overlaying Edge-Detection Results on Original Images:

Advantages:

- Maintains context by preserving the original image.
- Presents edges in a natural visual context.
- Facilitates qualitative assessment and visual interpretation.

Disadvantages:

- Limited scope for quantitative analysis.
- Potential clutter if not properly adjusted.

Creating Gradient Magnitude and Orientation Maps:

Advantages:

- Offers clear feature localization by highlighting intensity variations.
- Yields quantifiable data for numerical analysis.
- Customizable options for visualization.

Disadvantages:

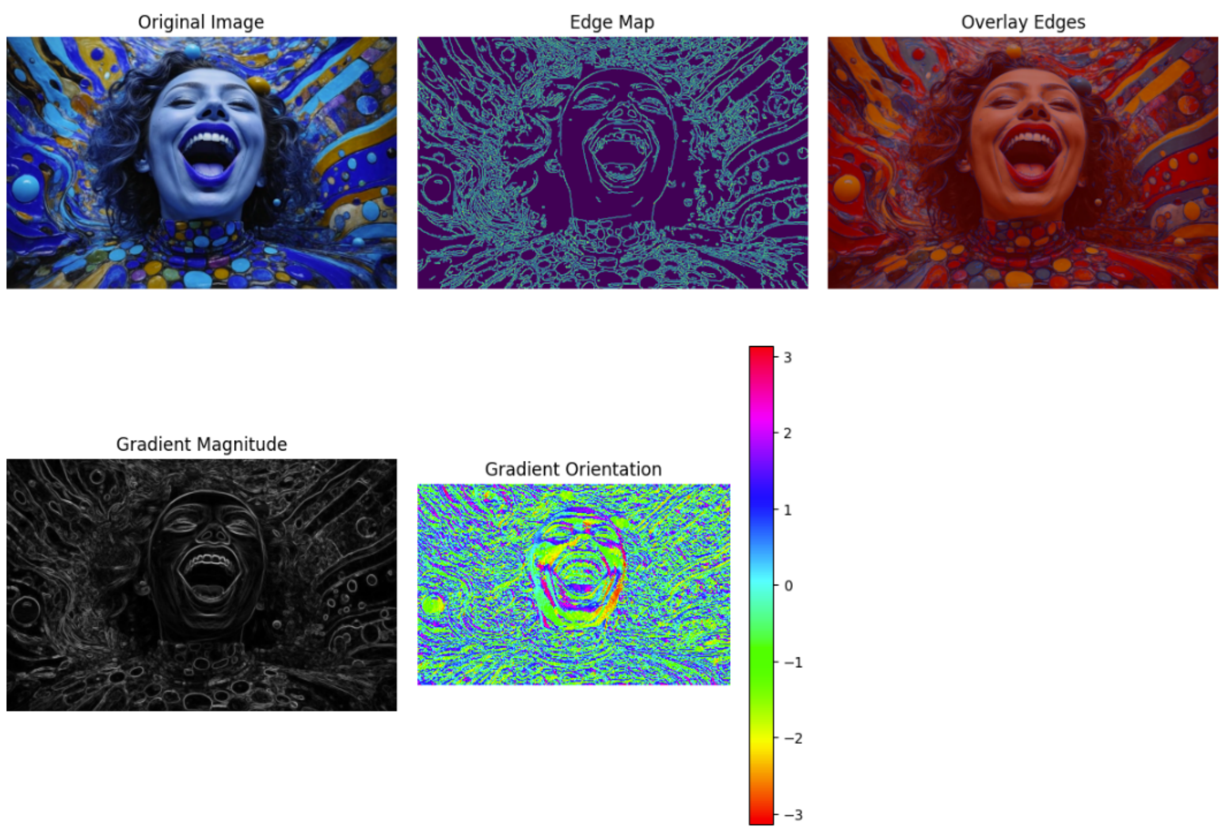
- May result in contextual information loss since it focuses on gradients.
- Requires knowledge of image processing principles for interpretation.

The choice between these visualization techniques depends on the specific goals of the analysis:

For quick evaluations, presentations, and qualitative assessments, overlaying edge detection results onto original images is often more suitable. It helps maintain context and aids in visual interpretation.

In-depth quantitative studies where precise numerical data is crucial favor gradient maps. These maps provide detailed insights into feature attributes and enable quantitative analysis.

These techniques can also complement each other effectively. Gradient maps offer detailed feature information, while overlaying provides essential context for visual interpretation. The choice ultimately depends on the analysis objectives and the balance between qualitative and quantitative insights required.



Conclusion

In conclusion, our exploration of edge detection strategies, specifically the Gabor-based method and Winner-Takes-All (WTA), has highlighted several key insights:

1. **Image Preprocessing's Significance:** Image preprocessing, including techniques like contrast enhancement, plays a pivotal role in shaping final outcomes. The application (or omission) of these techniques can significantly impact results.
2. **WTA System's Effectiveness:** The WTA system demonstrated its effectiveness by enhancing feature visibility while preserving contextual connections. It illustrated the benefits of consolidating outcomes from various filters.
3. **Metrics for Evaluation:** Metrics like SSIM are valuable tools for assessing and providing feedback on image processing results. They enable us to compare and analyze outcomes across a range of diverse images.
4. **Diverse Visualization Approaches:** Our experimentation encompassed various visualization techniques, including gradient magnitude and orientation maps, which deepened our understanding of identified features.
5. **Real-World Application:** This assignment provided practical experience in applying image processing techniques to real-world photographs. Such exposure is valuable for future endeavors in fields like computer vision and medical imaging.
6. **Algorithm Selection's Importance:** The assignment emphasized the critical role of algorithm selection in achieving various tasks. A solid understanding of each method's strengths and weaknesses is essential for dependable results.
7. **Enhanced Data Understanding:** Effective visualization techniques enhance our comprehension of data. Incorporating methods like gradient magnitude and orientation maps significantly improved our ability to understand and convey the characteristics under scrutiny.