1. INTRODUCTION

1.1 BACKGROUND

The preservation, documentation, and study of ancient artifacts have always been paramount in archaeology and heritage management. However, traditional methods of artifact analysis often rely on subjective interpretation and can lack the precision required for thorough, reproducible studies.

With advancements in technology, particularly in computer vision, there are now powerful tools available to aid in digital documentation and analysis of artifacts. One such tool, OpenCV (Open Source Computer Vision Library), provides an accessible and versatile platform for implementing complex image-processing algorithms, enabling detailed study of ancient objects.

Edge detection plays a crucial role in artifact analysis as it allows the identification of contours and significant boundaries within images. This process is essential for examining the shapes, engravings, and any inscriptions present on artifacts, which may hold valuable historical information.

Among various edge-detection algorithms, the Canny Edge Detector is widely recognized for its efficiency and accuracy. Developed by John F. Canny in 1986, the algorithm is celebrated for its ability to produce precise edges with minimal noise, making it an excellent choice for processing images of intricate objects like ancient artifacts.

By detecting and highlighting edges, the Canny algorithm can help archaeologists focus on essential features, such as inscriptions, carvings and fractures, which are often difficult to discern through unaided visual inspection. Digital methods preserve integrity of these historical objects while providing a high level detail.

1.1.1 OBJECTIVE

To enhance the digital analysis of ancient artifacts. Develop an efficientedge-detection model capable of accurately identifying contours and intricate details in images of ancient artifacts. Evaluate the effectiveness of the edge-detection output in highlighting crucial features, which can aid archaeologists in artifact classification, preservation, and documentation.

1.1.2 SCOPE

It expands to not only implement a computer vision tool for current artifact analysis but also to suggest pathways for broader integration of digital edge detection techniques within archaeological research.

1.2 PROBLEM STATEMENT

Traditional artifact examination methods are often labor-intensive, subjective, and risk physical damage to fragile objects. It also addresses the challenges of achieving high-quality edge detection on complex and varied surfaces while maintaining artifact integrity. Manual inspection can be subjective and is also time-consuming.

1.2.1 ADVANTAGES

- Enhanced Detection of Fine Details
- Non-Destructive Examination
- Improved Clarity in Complex Surfaces
- Customization for Diverse Artifact Types
- Cost-Effective Analysis Tool
- Adaptability for Comparative Studies
- Foundation for Further Digital Analysis

1.2.2 DISADVANTAGES

- Sensitivity to Lighting Conditions
- Limited to 2D Analysis
- Complexity in Implementing Real-Time Processing
- Dependency on Parameter Tuning
- Difficulty with Highly Textured Artifacts
- Limited Effectiveness on Faint Features

1.3 DOMAIN OVERVIEW

Digital image processing is a field that involves the manipulation and analysis of images to extract valuable information. Within this field, edge detection is a crucial technique used to identify boundaries within images, helping to isolate areas of interest and enhance specific features.

OpenCV (Open Source Computer Vision Library) is a widely used open-source library in the field of computer vision, providing an extensive suite of tools for image processing. OpenCV enables easy implementation of algorithms like the Canny Edge Detector, which is particularly useful for researchers and developers working on image analysis projects.

The integration of OpenCV and edge detection techniques offers valuable tools for archaeologists and historians. Edge detection applied to artifacts can enhance the visibility of carved details, inscriptions, and patterns, facilitating the study of materials, craftsmanship, and cultural significance.

2. LITERATURE REVIEW

2.1 LITERATURE SURVEY

1. *Abdulrahman, H., Magnier, B., Montesinos, P., 2017*. **A new objective supervised edge detection assessment using hysteresis thresholds**, in: International Conference on Image Analysis and Processing, pp. 3–14.

Drawbacks:

This paper explored multiple edge-detection algorithms, including Sobel, Prewitt, and Canny, applied to historical artifacts. It was sensitive to noise and required extensive parameter tuning for each artifact type, resulting in inconsistencies in edge clarity. Additionally, the algorithm struggled with artifacts in varied lighting conditions, which led to false edges.

Inference:

The study highlighted the potential of the Canny Edge Detector for capturing fine details in artifact analysis, but it emphasized the need for preprocessing steps, such as noise reduction and standardized lighting, to enhance detection accuracy and consistency in results.

2. *Basu, M., 2002*. **Gaussian-based edge-detection methods-a survey.** IEEE Transactions on Systems, Man, and Cybernetics, Part C 32, 252–260

Drawbacks:

For examining various artifacts, demonstrating its potential to reduce manual analysis. However, the study reported difficulty in adjusting threshold parameters across different artifact textures and colors, resulting in either missed or excessive edge lines.

Inference:

The authors concluded that the Canny Edge Detector is effective for artifact study but requires adaptive thresholding methods or additional filtering layers to distinguish meaningful contours from minor surface irregularities.

3. *Canny, J., 1986***. A computational approach to edge detection.** IEEE Transactions on Pattern Analysis and Machine Intelligence 8, 679–698

Drawbacks:

This research compared Canny Edge Detection with newer machine learning-based edge detection techniques in analyzing pottery artifacts. The Canny method showed limitations in accurately capturing worn or eroded edges, as it could not adapt dynamically to faded contours. The study also noted that Canny Edge Detection often misinterpreted as similar edges.

Inference:

Although Canny Edge Detection remains a strong choice for basic edge detection tasks, the study suggested that hybrid models combining traditional edge detection with machine learning could offer better accuracy for complex artifacts with worn edges.

4. *De Micheli, E., Caprile, B., Ottonello, P., Torre, V., 1989***. Localization and noise in edge detection.** IEEE Transactions on Pattern Analysis and Machine Intelligence 11, 1106–1117.

Drawbacks:

They tested the Canny Edge Detector on ancient coin imagery, showing that while it effectively highlighted inscriptions and contours, it was prone to misinterpreting tarnish and surface imperfections as meaningful edges. The study

also noted the challenges in detecting faint or worn details, which often required manual intervention to interpret.

Inference:

The study recommended using Canny Edge Detection as a preliminary tool in cultural heritage analysis, but with a focus on artifact-specific preprocessing steps (e.g., contrast enhancement, background removal) to minimize misinterpretations. The authors suggested that a refined preprocessing pipeline would allow Canny Edge Detection to yield more accurate and informative results in documenting coins and similar artifacts.

5. *Hewa Majeed Zangana., Ayaz Khalid Mohammed., Firaz Mahmood Mustafa Alfaqi., 2024*. **Advancements in Edge Detection Techniques for Image Enhancement: A Comprehensive Review.** International Journal of Artificial Intelligence & Robotics (IJAIR) Vol.6, No.1, 2024, pp.29-39

Drawbacks:

Their work reviewed advances in OpenCV for artifact analysis, focusing on the latest edge detection enhancements. The Canny Edge Detector was effective but exhibited limitations in detecting edges under varying light intensities.

Inference:

This paper suggested integrating Canny Edge Detection with histogram equalization and adaptive thresholding to improve performance on textured artifact surfaces.

2.2 SUMMARY OF LITERATURE SURVEY

PAPER NAME	AUTHOR NAME	YEAR	INFERENCE
A new objective supervised edge detection assessment using hysteresis thresholds, in: International Conference on Image Analysis and Processing, pp. 3–14.	*Abdulrahman, H., Magnier, B., Montesinos, P.,*	2017	The study highlighted the potential of the Canny Edge Detector for capturing fine details in artifact analysis, but it emphasized the need for preprocessing steps, such as noise reduction and standardized lighting, to enhance detection accuracy and consistency in results.
Gaussian-based edge-detection methods-a survey. IEEE Transactions on Systems, Man, and Cybernetics, Part C 32, 252–260	*Basu, M.,*	2002	The authors concluded that the Canny Edge Detector is effective for artifact study but requires adaptive thresholding methods or additional filtering layers to distinguish meaningful contours from minor surface irregularities.
A computational approach to edge detection. IEEE Transactions on Pattern Analysis and Machine	*Canny, J.,*	1986	Although Canny Edge Detection remains a strong choice for basic edge detection tasks, the study suggested that hybrid models combining traditional edge detection with machine learning could offer better

Intelligence 8, 679–698			accuracy for complex artifacts with worn edges.
Localization and noise in edge detection. IEEE Transactions on Pattern Analysis and Machine Intelligence 11, 1106–1117.	*De Micheli, E., Caprile, B., Ottonello, P., Torre, V.,*	1989	The study recommended using Canny Edge Detection as a preliminary tool in cultural heritage analysis, but with a focus on artifact-specific preprocessing steps (e.g., contrast enhancement, background removal) to minimize misinterpretations
Advancements in Edge Detection Techniques for Image Enhancement: A Comprehensive Review. International Journal of Artificial Intelligence & Robotics (IJAIR) Vol.6, No.1, 2024, pp.29-39	*Hewa Majeed Zangana., Ayaz Khalid Mohammed., Firaz Mahmood Mustafa Alfaqi.,*	2024	This paper suggested integrating Canny Edge Detection with histogram equalization and adaptive thresholding to improve performance on textured artifact surfaces. The study confirmed that OpenCV's expanding functionality provides valuable tools for refining Canny-based methods.

Table 2.2.1 Summary of Literature Survey

3. SYSTEM ANALYSIS

3.1 EXISTING SYSTEM

In traditional artifact preservation and analysis, the primary methods involve meticulous manual examination and documentation by archaeologists, historians, and conservationists. This approach entails visual inspection, sketching, photography, and detailed note-taking, all of which help capture an artifact's physical characteristics.

Visual inspection under controlled lighting conditions to observe contours, patterns, inscriptions, and signs of wear or damage. Often, these examinations are supported by microscopy or magnification to capture fine details not visible to the naked eye. While effective in gathering detailed observations, this process can be slow, prone to human error, and potentially risky for fragile artifacts.

It rely on physical inspection and manual documentation. Photographic documentation, another cornerstone of traditional analysis, involves capturing high-resolution images from multiple angles under various lighting conditions to reveal surface details. Although this technique helps to preserve visual data, it may not always capture the subtleties of the artifact’s surface structure.

Additionally, even when enhanced with digital tools, photography is often limited by lighting variations and lacks the precision needed for isolating intricate patterns or faint inscriptions. For more precise analysis, some methods employ physical or chemical imaging techniques such as X-ray fluorescence (XRF) or scanning electron microscopy (SEM) to analyze surface composition.

However, these techniques are costly, require specialized equipment, and may not always be feasible, especially when dealing with large collections or fragile

items. Artifacts are frequently subject to wear, erosion, or environmental damage, making edges less distinct and challenging to detect.

Most existing systems require manual tuning of threshold values, which can vary significantly between different types of artifacts due to diverse surface qualities, textures & materials. It struggles to differentiate between meaningful details (like inscriptions) & surface imperfections (like scratches, tarnishes). It misinterprets these irregularities as significant edges, leading to inaccuracies in the analysis.

3.1.1 DISADVANTAGES OF EXISTING SYSTEM

- Parameter Sensitivity
- Noise Sensitivity
- Lighting Variability
- Inability to Handle Complex Textures
- Manual Preprocessing Requirement
- Misinterpretation of Surface Irregularities
- High Computational Demand

3.2 PROPOSED SYSTEM

The proposed system aims to enhance the analysis of ancient artifacts through a comprehensive and automated implementation of the Canny Edge Detector using OpenCV. This system will address the limitations of traditional methods by integrating advanced image processing techniques, standardized workflows to facilitate more accurate and efficient edge detection and analysis of artifacts.

In Image Acquisition, utilize high-resolution digital cameras to capture images of artifacts from multiple angles. This ensures that all details of the

artifacts are documented effectively. Set up a controlled lighting environment using diffused lighting techniques to minimize shadows and reflections, ensuring consistent image quality.

In Preprocessing, implement Gaussian blur and median filtering techniques to reduce noise and enhance image quality before edge detection. This step will improve the clarity of edges detected in the subsequent stages. Apply techniques such as histogram equalization to enhance contrast in the images, making subtle details and edges more visible.

In Canny Edge Detection, utilize OpenCV's Canny Edge Detection algorithm to extract edges from the preprocessed images. The system will allow users to input specific parameters (e.g., thresholds) tailored to different types of artifacts. Implement an adaptive thresholding feature that adjusts parameters based on the specific characteristics of the image, enabling improved edge detection in varying lighting and texture conditions.

In Post-Processing Techniques, enhance the output of the Canny detector by applying edge linking and hysteresis thresholding to eliminate spurious edges and connect fragmented edge segments, resulting in a cleaner and more coherent edge representation. Integrate morphological operations (e.g., dilation and erosion) to refine the detected edges, making significant features more prominent while reducing noise.

In User Interface and Visualization, develop a user-friendly graphical interface that allows users to upload images, adjust parameters, and visualize results in real-time. The interface will provide options for users to annotate detected edges and save their findings. Also include functionality for generating comprehensive reports on the analysis, summarizing the findings and providing visual documentation of the detected features and edges.

3.2.1 IMPROVED CANNY EDGE ARCHITECTURE

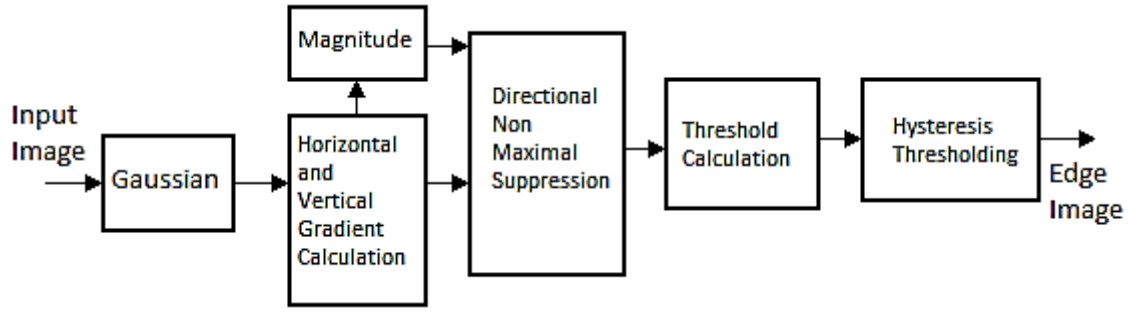

Fig 3.2.1 Block diagram of Canny Edge Detection

Image Acquisition and Preprocessing:

Acquire the input image and convert it to grayscale for easier processing. Initial noise reduction may also be applied to improve edge detection accuracy.

Gaussian Blur:

Apply a Gaussian filter to the grayscale image to smooth it and reduce noise. This step helps minimize the effect of minor intensity variations that might produce false edges.

Gradient Calculation:

Calculate the intensity gradients in the image using operators like Sobel. This produces two gradient images (for horizontal and vertical changes) that highlight regions with significant intensity changes.

Non-Maximum Suppression:

Refine edge detection by removing pixels that aren't part of the strongest gradients. This step reduces the thickness of edges, keeping only the pixels that are local maxima.

Double Thresholding and Edge Tracking by Hysteresis:

Use a high and low threshold to categorize edges as strong, weak, or non-edges. Track edges based on the hysteresis principle, where only weak edges connected to strong ones are retained, resulting in a well-defined edge map.

3.2.2 ADVANTAGES OF PROPOSED SYSTEM

- The Canny Edge Detector in OpenCV provides high accuracy in detecting edges
- The system automates edge detection, significantly reducing the time needed for manual examination
- Non-invasive analysis system relies on digital image processing, it eliminates the need for physical handling, which reduces the risk of damage to fragile artifacts
- Produces clean, high-resolution edge images that capture intricate features
- The Canny Edge Detector with OpenCV is a cost-effective, accessible solution. This affordability makes it suitable for institutions with limited budgets, allowing broader access to advanced artifact analysis
- Allowing it to adapt to the unique textures, materials, and conditions of different artifacts. This flexibility enhances its applicability across diverse collections

3.2.3 FEATURES OF OPENCV'S CANNY EDGE DETECTION

- High-Resolution Image Acquisition
- Noise Reduction
- Implements the Canny algorithm for precise edge detection
- Edge Linking and Hysteresis Thresholding:
- Morphological Operations

- Employs algorithms to classify edges, distinguishing between meaningful features (like inscriptions) and irrelevant surface marks (like scratches).
- User-Friendly Interface
- Automated Reporting Tools

4. REQUIREMENT SPECIFICATION

4.1 HARDWARE REQUIREMENTS

4.1.1 COMPUTER/WORKSTATION

Processor:

The heart of any computing system is its processor, often referred to as the CPU (Central Processing Unit). For applications involving image processing, a **multi-core processor** is crucial. A minimum specification of an **Intel i5 or higher**, or an **AMD Ryzen 5 or higher**, is highly recommended for several reasons.

Firstly, multi-core processors can handle multiple threads simultaneously, which is particularly important in image processing where various operations (such as filtering, transformations, and edge detection) may need to occur concurrently. With a powerful CPU, tasks can be divided among its cores, significantly improving processing speed and efficiency.

Secondly, the architecture of modern processors often includes enhancements that optimize floating-point operations, which are frequently utilized in image processing tasks. High-performance processors also have larger caches, which reduce the time needed to access frequently used data, further speeding up processing.

Moreover, as image resolution increases, the amount of data that needs to be processed grows exponentially. A powerful processor can manage this larger data load without experiencing bottlenecks, ensuring that the analysis of artifacts remains timely and responsive. This is particularly relevant when working with high-resolution images that contain intricate details, which require significant computational resources for effective analysis.

Memory (RAM):

In addition to a capable processor, having sufficient **Random Access Memory (RAM)** is essential for smooth operation during image processing tasks. For basic tasks, a minimum of **8GB of RAM** may suffice; however, for more advanced image processing, particularly when handling high-resolution images or performing complex operations, **16GB or higher** is strongly recommended.

RAM serves as the short-term memory for the system, allowing it to store data that is actively being used or processed. When analyzing images, especially large datasets, ample RAM ensures that multiple images can be loaded into memory simultaneously without requiring constant access to slower storage drives. This facilitates faster processing times and a more efficient workflow.

High RAM capacity also allows for smooth multitasking. When conducting image processing, it is common to run multiple applications simultaneously, such as an image editor, data analysis tools, or database management systems. Adequate RAM prevents the system from slowing down or crashing when these applications are used concurrently.

Furthermore, modern image processing algorithms may utilize significant amounts of memory for temporary storage of intermediate results. Thus, having more RAM can reduce the need for the system to swap data to and from the hard drive, which can be a major performance bottleneck.

Graphics Processing Unit (GPU):

While the CPU is critical for general processing tasks, a dedicated **Graphics Processing Unit (GPU)** is increasingly essential for enhancing performance in image processing, especially when using libraries such as OpenCV that can leverage GPU acceleration.

A GPU, such as the **NVIDIA GTX 1050 or higher**, is particularly beneficial for handling tasks that involve complex computations and real-time processing. The architecture of a GPU is designed to perform many calculations simultaneously, making it ideal for the parallel processing required in image analysis.

For example, when applying the Canny Edge Detector, the algorithm processes pixels in a manner that can benefit significantly from the parallel nature of GPU computations. By offloading intensive calculations to the GPU, the CPU is freed up to handle other tasks, resulting in improved overall system performance.

Additionally, when integrating machine learning models for enhanced image analysis, GPUs can dramatically speed up training and inference times. Many modern machine learning techniques involve processing vast amounts of data and performing numerous calculations, making GPU acceleration a necessity for efficient operation.

The use of a GPU not only shortens the time required for processing but also enables more complex analyses to be performed, opening new avenues for research and discovery in the field of artifact preservation.

Storage:

The type and capacity of storage are critical components that impact the speed and efficiency of data access and storage during image processing tasks. A **Solid-State Drive (SSD)** is highly recommended, with a minimum capacity of **256GB**. SSDs provide significantly faster read and write speeds compared to traditional Hard Disk Drives (HDDs), which is vital for image processing applications that often require accessing large image files.

Faster data access reduces loading times and accelerates the overall processing workflow. When dealing with high-resolution images, the size of the files can be considerable; hence, having adequate storage capacity is crucial to accommodate multiple images and project files without running into storage limitations.

Moreover, SSDs are more reliable than HDDs, as they have no moving parts, which reduces the risk of mechanical failure and data loss. This reliability is essential in research environments where valuable data from artifact analysis must be securely stored and easily retrievable.

The ability to quickly access and store images and output files facilitates a smoother workflow, enabling researchers to focus more on analysis and less on waiting for files to load or save.

4.1.2 LIGHTING SETUP

Lighting Setup for Artifact Imaging

When capturing images of ancient artifacts for analysis and preservation, the quality of lighting is critical. Proper lighting setup enhances the visibility of intricate details and textures, while minimizing shadows, glare, and reflections that can obscure important features.

To achieve optimal results in artifact photography, controlled lighting equipment, such as LED panels or ring lights, is essential. This section delves into the significance of controlled lighting, the types of lighting equipment suitable for artifact imaging, and best practices for setting up an effective lighting environment.

Importance of Controlled Lighting

Controlled lighting refers to the deliberate use of artificial light sources to achieve a specific lighting condition. In the context of artifact imaging, controlled lighting plays several pivotal roles:

Reducing Shadows:

Shadows can mask critical details and features of an artifact, leading to inaccuracies in analysis. Controlled lighting allows for the positioning of light sources in a way that minimizes shadows, ensuring that the entire surface of the artifact is uniformly illuminated. This is particularly important for three-dimensional objects.

Eliminating Glare and Reflections:

Many artifacts, especially those made of glass, metal, or polished stone, can create unwanted glare or reflections when illuminated by bright light sources. This glare can obscure important details and render the image unusable for analysis. Controlled lighting setups, such as the use of diffusers or specific angles, allowing for clear and unobstructed views of the artifact's surface.

1. **Highlighting Details:**

Proper lighting can enhance the visibility of fine details, such as inscriptions, carvings, or surface textures. By adjusting the intensity and angle of the light sources, researchers can direct light to emphasize these features, improving the overall quality of the captured images.

2 Consistency Across Images:

When photographing multiple artifacts or different views of the same artifact, maintaining consistent lighting conditions is vital. Controlled lighting

setups help ensure that images are comparable, making it easier to analyze and interpret the data. Variations in lighting can lead to discrepancies in image quality and detail, complicating the analysis process.

Types of Lighting Equipment

Various types of lighting equipment are available for capturing high-quality images of artifacts. The choice of equipment will depend on factors such as the artifact's material, size, and the specific details that need to be highlighted. Two widely used options include:

1. **LED Panels:**

LED panels are versatile lighting sources that provide even illumination across a wide area. They can be adjusted for intensity and are often equipped with color temperature controls, allowing researchers to select the most appropriate light for the artifacts being photographed. The flat design of LED panels helps distribute light evenly, reducing hotspots and shadows.

Advantages of LED Panels:

Adjustable Brightness:

Researchers can easily modify the brightness of the panels to suit the specific requirements of each artifact.

Color Temperature Control:

The ability to change the color temperature helps in achieving accurate color reproduction, which is essential for documenting artifacts in their true colors.

Low Heat Emission:

LED lights generate minimal heat, making them safe for use with delicate artifacts that may be sensitive to temperature changes.

2. **Ring Lights:**

Ring lights are circular lighting devices that provide uniform illumination around the subject. They are particularly effective for close-up photography, as the light source surrounds the camera lens, minimizing shadows and providing even light distribution.

Advantages of Ring Lights:

Shadow Reduction:

The circular design helps eliminate shadows by providing light from all directions.

Compact Size:

Ring lights are often compact and can be easily mounted on cameras, making them suitable for handheld photography and tight spaces.

Versatility:

They can be used for various types of artifact photography, from flat objects to 3D pieces, ensuring consistent lighting across different subjects.

Best Practices for Lighting Setup

To maximize the effectiveness of controlled lighting when capturing images of artifacts, several best practices should be followed:

Positioning of Light Sources:

The placement of light sources is crucial. To reduce shadows, lights should be positioned at angles that illuminate the artifact evenly. A common approach is to position the lights at approximately 45-degree angles relative to the artifact, which allows light to hit the surface effectively while minimizing shadowing. Experimentation may be necessary to find the optimal angles for each specific artifact.

1. **Using Diffusers:**

Diffusers can soften the harsh light produced by direct light sources, creating a more even and natural illumination. Placing a diffuser between the light source and the artifact helps scatter the light, reducing glare and harsh shadows. Materials such as white fabric, softboxes, or commercially available diffusion filters can be used effectively for this purpose.

2. **Controlling Background Reflections:**

When photographing artifacts with shiny or reflective surfaces, controlling background reflections is essential. Using a neutral, non-reflective backdrop can help focus attention on the artifact itself without distractions from background elements. Additionally, adjusting the angle of the light sources can help avoid reflections that interfere with capturing details.

3. **Color Calibration:**

Proper color calibration is vital for ensuring that the colors of the artifacts are accurately represented in the photographs. Using a gray card or color checker during the shoot allows researchers to correct any color cast in post-processing, ensuring that the colors remain true to the actual appearance of the artifacts.

4. **Testing and Adjusting:**

Prior to capturing the final images, conducting test shots with varying lighting conditions can help identify the best setup for each artifact. Adjusting the intensity, angle, and distance of the lights can lead to significant improvements in image quality.

5. **Maintaining Consistency:**

For projects involving multiple artifacts, maintaining a consistent lighting setup across all images is essential. Keeping the same light positioning, intensity, and camera settings ensures that images can be compared accurately and provides reliable data for analysis.

Controlled lighting equipment, such as LED panels or ring lights, is necessary to reduce shadows and ensure even illumination and helping to capture artifact details without excessive glare or reflection.

4.1.3 PERIPHERAL DEVICES

Peripheral Devices for Artifact Imaging:

This section explores the significance of two essential peripheral devices: monitors and stabilization equipment, including tripods. These tools enhance the overall imaging process by providing better visualization, enabling steady captures, and facilitating detailed inspections of the artifacts.

Monitor: High-Resolution Visualization:

A high-resolution monitor is critical for any imaging workflow, especially when dealing with intricate details found in ancient artifacts. The choice of monitor can significantly affect how artifacts are analyzed, documented, and presented. Here are several reasons why a high-resolution monitor is essential:

Clarity and Detail:

A Full HD (1920 x 1080) or 4K (3840 x 2160) monitor offers superior pixel density, allowing for the clear visualization of fine details in images. This is particularly important when examining textures, inscriptions, or patterns that are crucial for research and documentation.

Higher resolutions enable researchers to zoom in on specific areas of an image without losing clarity, facilitating detailed inspections that may reveal important information about the artifact's history and significance.

Color Accuracy:

The reproduction of colors is vital when documenting artifacts, as colors can convey significant historical and contextual information. High-resolution monitors often come with advanced color calibration features that ensure accurate color representation.

This is essential for researchers who need to compare colors in artifacts against known standards or document color changes over time due to deterioration or restoration efforts.

Wide Viewing Angles:

Many high-resolution monitors feature IPS (In-Plane Switching) technology, which provides wider viewing angles compared to traditional TN (Twisted Nematic) panels. This is particularly useful in collaborative environments where multiple researchers need to view the same image simultaneously from different angles.

Enhanced Image Processing:

High-resolution monitors can support advanced image processing techniques that require accurate visualization. Features such as HDR (High Dynamic Range) allow for better differentiation between shadows and highlights, which can be beneficial when analyzing artifacts with varying surface textures and features.

Researchers can apply image enhancement algorithms and view the results in real-time, making it easier to assess the impact of adjustments on the overall image quality**.**

Dual Monitor Setup:

Utilizing a dual monitor setup can further enhance the workflow. One monitor can be dedicated to image capture and processing, while the other displays reference materials, documentation, or analysis tools. This allows researchers to work more efficiently by minimizing the need to switch between applications and enabling side-by-side comparisons of images and documents.

Tripod and Stabilizer: Ensuring Steady Captures

The importance of stability in photography cannot be overstated, particularly when capturing high-resolution images of delicate artifacts. Even minor camera movements can result in blurriness or loss of detail, which is unacceptable in artifact imaging. Using a tripod and stabilization equipment provides several advantages:

Reduced Camera Shake:

A sturdy tripod effectively eliminates camera shake, which is critical when using long exposure times or capturing intricate details. When photographing

artifacts, particularly in low-light conditions, any movement can lead to blurred images. By keeping the camera stationary, tripods ensure that each shot is sharp and clear, preserving the integrity of the image.

1. **Consistent Framing:**

A tripod allows for consistent framing across multiple shots, which is essential when capturing a series of images for analysis or documentation.

Researchers can adjust the height and angle of the camera to achieve the desired composition without altering the position of the artifact. This consistency is crucial for comparative studies or when creating time-lapse sequences to document changes in the artifact over time.

2. **Fine-Tuning Adjustments:**

Many tripods come equipped with adjustable heads that allow for precise tilting and panning. This feature enables photographers to make fine-tuning adjustments to the camera's angle without moving the entire tripod. Such control is especially beneficial when dealing with artifacts that have complex geometries.

3. **Versatility in Use:**

Tripods are versatile tools that can be used in various settings and scenarios. Whether photographing small artifacts on a tabletop or large items in a museum exhibit, tripods can be adapted to suit the specific requirements of the shoot. Additionally, many tripods have adjustable legs, making them suitable for uneven surfaces.

4. **Stabilizers for Dynamic Shooting:**

In addition to tripods, using stabilizers can further enhance the imaging process, especially in dynamic or challenging conditions. Stabilizers, such as

gimbals or handheld stabilizers, are designed to absorb shocks and vibrations, providing smooth video or image captures. This is particularly useful for creating walkthrough videos.

5. **Ease of Use:**

Most tripods are user-friendly and can be set up quickly, allowing researchers to focus on capturing images rather than struggling with equipment. The simplicity of adjusting the height, tilt, and pan settings ensures that even novice photographers can achieve professional-quality results.

4.2 SOFTWARE REQUIREMENTS

4.2.1 HIGH-RESOLUTION IMAGES

For the effective analysis of ancient artifacts, a high-resolution digital camera is an essential tool that enables precise imaging, which is necessary for documenting intricate features with clarity. A minimum of 12 megapixels (MP) resolution is recommended to ensure that the smallest details are captured effectively.

As these finer elements often carry crucial information regarding the artifact's origin, design, or inscriptions. Higher resolution enables detailed visualization of textures, wear, and subtle surface patterns, which are often overlooked with lower-quality imaging tools.

Among the types of digital cameras suitable for such applications, DSLR (Digital Single-Lens Reflex) and mirrorless cameras are highly preferred due to their advanced image quality, customization options, and compatibility with a variety of lenses. DSLRs have a robust build and often feature optical viewfinders, which allow the user to see exactly what the lens sees.

This is particularly helpful in artifact documentation, where achieving accurate focus and composition is essential. Mirrorless cameras, on the other hand, tend to be more compact and provide electronic viewfinders, which offer real-time previews of how the image will appear after settings like exposure, white balance, and color profiles are applied.

Both types of cameras allow for extensive manual control over settings such as ISO, aperture, and shutter speed, which is crucial in managing lighting conditions and focus.

A macro lens is highly recommended for close-up shots, as it provides the ability to capture small objects or intricate details at a close range without losing sharpness. Macro lenses typically have a high magnification ratio, often reaching 1:1, meaning the subject is captured at life-size on the camera's sensor, preserving every detail.

When used for artifact imaging, macro lenses ensure that even the smallest carvings, patterns, or textures are documented with precision, allowing for accurate analysis and comparison. Furthermore, these lenses offer a shallow depth of field, enabling the background to be blurred, which directs attention toward the artifact and minimizes distractions in the image.

In addition to the camera and lens, a stable setup is essential. Utilizing a tripod to stabilize the camera reduces motion blur, which is critical when capturing fine details. Furthermore, consistent lighting conditions are important to avoid shadows and reflections, as these can obscure the clarity of edges and textures in the image.

With a properly configured high-resolution camera setup, enhanced with the appropriate lenses and stability measures, researchers can create a robust

foundation for digital analysis, ensuring that each artifact’s unique features are documented with fidelity.

4.2.2 PROGRAMMING LANGUAGE : PYTHON

Ease of Learning and Use:

One of the most notable aspects of Python is its straightforward syntax, which is designed to be easy to read and write. This simplicity lowers the barrier for entry, allowing both beginners and experienced programmers to quickly grasp the concepts of programming and image processing.

For a project focused on edge detection, Python enables developers to concentrate on the algorithm's logic rather than getting bogged down by complex syntax. This feature is especially useful when working with interdisciplinary teams, including historians and archaeologists, who may have limited programming experience but possess valuable domain knowledge.

Extensive Libraries for Image Processing:

Python's rich ecosystem of libraries plays a crucial role in facilitating complex image processing tasks. The most prominent library for this project is **OpenCV** (Open Source Computer Vision Library), which provides a comprehensive set of tools and functions for image manipulation, analysis, and computer vision tasks.

OpenCV offers a user-friendly interface for implementing the Canny Edge Detector, along with various pre-processing functions such as noise reduction and image enhancement. This functionality is particularly valuable when working with ancient artifacts, where image quality can vary significantly due to factors like lighting conditions and surface textures.

Additionally, other libraries such as **NumPy** and **Matplotlib** complement OpenCV by providing efficient numerical computations and visualization capabilities.

NumPy allows for efficient array manipulation, which is essential for handling image data in matrix form, while Matplotlib enables the generation of plots and visualizations to analyze the results of edge detection. These libraries can be seamlessly integrated into a Python project, enhancing its functionality and efficiency.

Community Support and Documentation:

Python benefits from a vast and active community, which is a tremendous asset for developers. The extensive community support means that developers can easily find tutorials, documentation, and forums to assist them with specific challenges they may encounter during development.

For the project on Canny Edge Detection, developers can access a plethora of resources that provide detailed explanations of the algorithm, code snippets, and best practices for image processing. This wealth of information accelerates the learning curve and helps troubleshoot any issues quickly, ensuring a smoother development process.

Cross-Platform Compatibility:

Python is inherently cross-platform, meaning that code written on one operating system (e.g., Windows, macOS, or Linux) can be easily executed on another without significant modifications. This characteristic is particularly beneficial for collaborative projects, as it allows team members to work on different operating systems without compatibility issues.

The ability to deploy Python applications on various platforms ensures that the developed software can be widely used in different research environments, from museums to universities, further promoting the project's accessibility and impact.

Integration with Other Technologies:

In addition to image processing, Python's versatility allows for integration with various technologies and frameworks. Moreover, Python can be utilized for building graphical user interfaces (GUIs) using libraries such as **Tkinter** or **PyQt**, making it possible to create user-friendly applications for researchers to interact with the edge detection system easily.

4.2.3 WINDOWS OPERATING SYSTEM

Windows is one of the most widely used operating systems globally and is popular among developers and researchers due to its user-friendly interface and extensive software compatibility. When it comes to developing projects involving OpenCV and Python, Windows has several advantages:

- **Familiarity and Ease of Use:**

Many developers are already accustomed to the Windows environment, making it a convenient choice for those who may not have experience with other operating systems. The straightforward graphical interface allows users to quickly install and manage software packages.

- **Comprehensive Software Support:**

Windows supports a wide range of software applications, including integrated development environments (IDEs) like PyCharm and Visual Studio, as well as essential libraries for image processing. The installation of Python and its

libraries is relatively straightforward, with most packages readily available via the Python Package Index (PyPI).

- **Active Community:**

There is a robust community of developers using Windows for Python and OpenCV projects. This community support means that users can find ample resources, tutorials, and forums to address challenges and share insights.

4.2.4 PyCharm IDE (Integrated Development Environment):

Overview:

PyCharm is a powerful and feature-rich IDE developed by JetBrains specifically for Python development. It provides a robust environment for writing, testing, and debugging Python code, making it particularly useful for projects that require extensive coding, such as implementing the Canny Edge Detector in OpenCV.

Key Features:

- **Intelligent Code Assistance**:

PyCharm offers advanced code completion, syntax highlighting, and real-time error checking. Its intelligent code assistance helps developers write code more efficiently by suggesting context-aware completions, which is especially beneficial when working with complex libraries like OpenCV.

- **Debugging and Testing Tools**:

The IDE includes a powerful debugger that allows developers to set breakpoints, step through code, and evaluate expressions. This capability is

crucial for debugging intricate image processing algorithms and ensuring the accuracy of the edge detection implementation.

- **Version Control Integration**:

PyCharm provides built-in support for version control systems such as Git, allowing developers to manage code changes seamlessly. This feature is vital for collaborative projects or when maintaining different versions of the codebase.

- **Project Management**:

The IDE enables efficient project management through its project view, allowing developers to organize their code, resources, and dependencies systematically. This organization is essential for handling large datasets or multiple artifacts within the project.

Advantages:

- PyCharm's robust features cater specifically to Python development, making it suitable for projects involving OpenCV and image processing.
- The integrated testing and debugging tools streamline the development process and enhance code reliability.
- The IDE's intuitive interface and comprehensive documentation facilitate a smoother learning curve for new users.

4.2.5 OpenCV Library:

Version:

The latest version of OpenCV (4.x or higher) should be installed. OpenCV provides essential functions for image processing, including the implementation of the Canny Edge Detector.

Installation:

- It can be installed using pip:
- pip install opencv-python
- pip install opencv-python-headless

5. SYSTEM DESIGN

5.1 SYSTEM ARCHITECTURE

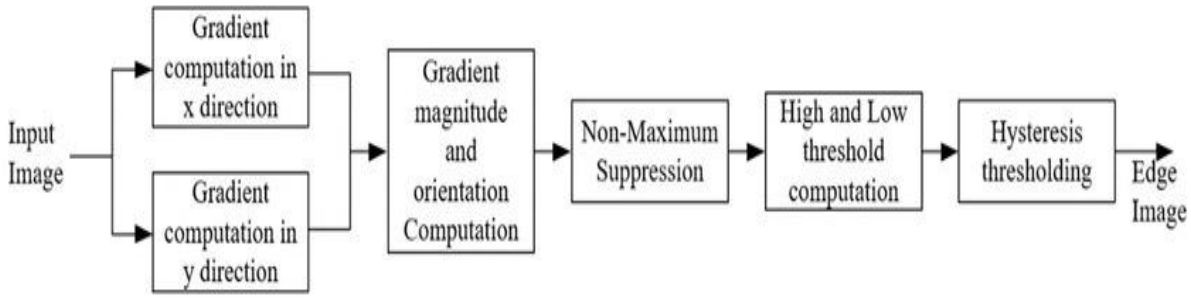

Fig 5.1.1 Architecture Diagram

The original image input, typically in grayscale, as the Canny algorithm requires single-channel intensity values.

In Gaussian Blur step, smooths the image by reducing noise, which is crucial for reducing false edges. A Gaussian filter is applied to blur the image and make edge detection more robust to noise.

In Gradient Calculation step, determines the intensity and direction of edges using gradient operators like the Sobel operator. Produces a gradient magnitude map, which indicates the strength of edges, and a gradient direction map, which shows the orientation of edges.

In Non-Maximum Suppression step, This step refines the edge locations by removing pixels that do not constitute the true edge, based on comparing each pixel's gradient to its neighbors. It retains only the local maxima along the edge direction, resulting in thin edges.

In Double Thresholding step, distinguishes between strong, weak, and non-edge pixels using two thresholds (high and low threshold). Labels pixels as strong edges (above high threshold), weak edges (between high and low thresholds), and non-edges (below low threshold).

In Edge Tracking by Hysteresis step, Ensures connectivity of weak edges that are connected to strong edges, consolidating edges based on pixel connectivity.

Finalizes the edge map by connecting edge segments, discarding isolated weak edges that aren't connected to any strong edge.

In Output Edge Map step, Produces the final edge-detected image, showing detected edges in a binary form (edges are typically white, and the background is black).

5.2 UML DIAGRAMS

5.2.1 Use Case Diagram

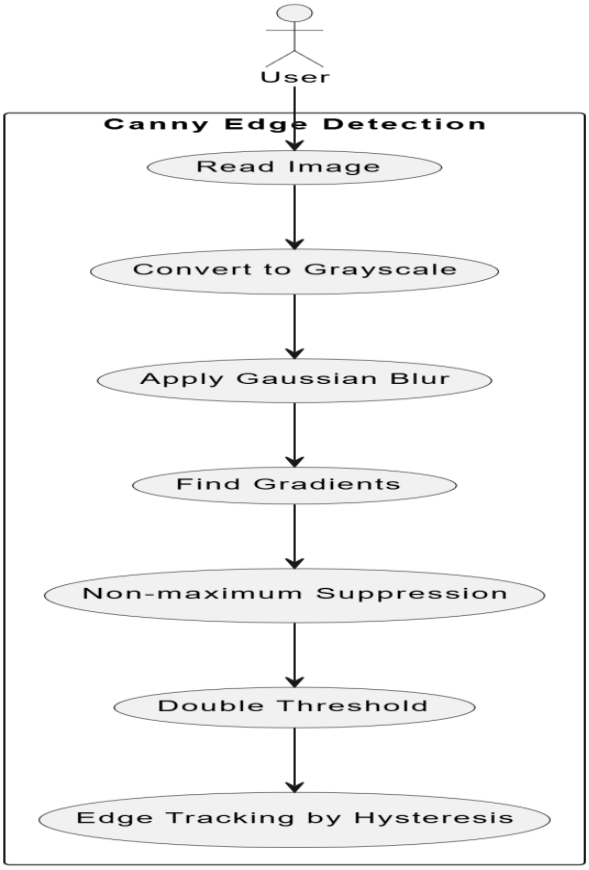

Fig 5.2.1 Use Case Diagram

Figure 5.2.1 describes that use case diagram. Here the actor is user. A use case diagram in the Unified Modeling Language is a type of behavioral diagram defined by and created from a Use-case analysis. Its purpose is to present a graphical overview of the functionality provided by a system in terms of actor, their goals (represented as use cases), and any dependencies between those use cases. The use case diagram is shown in Figure 5.2.1

5.2.2 ACTIVITY DIAGRAM

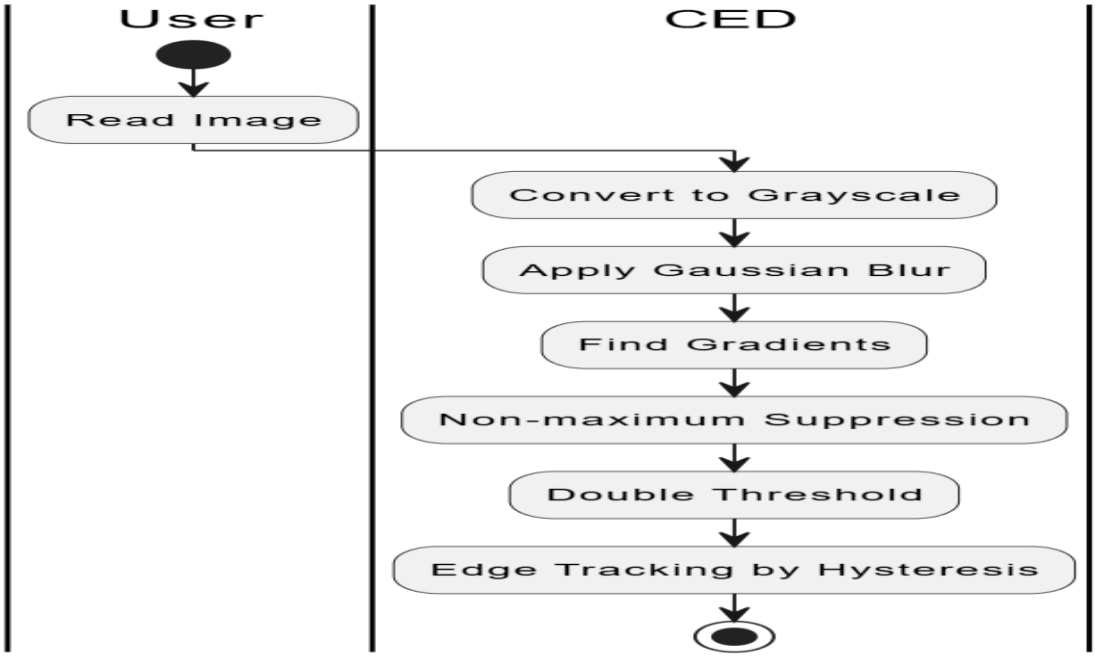

Fig 5.2.2 ACTIVITY DIAGRAM

Figure 5.2.2 describes that activity diagram. Activity diagram are graphical representations of workflows of stepwise activities and actions with support for choice, iteration and concurrency. In the Unified Modeling Language, activity diagrams are intended to both computational and organizational process (i.e. workflows). Activity diagram shows the overall flow control. Activity diagram are constructed from a limited number of shapes connected with arrows.

5.2.3 SEQUENCE DIAGRAM

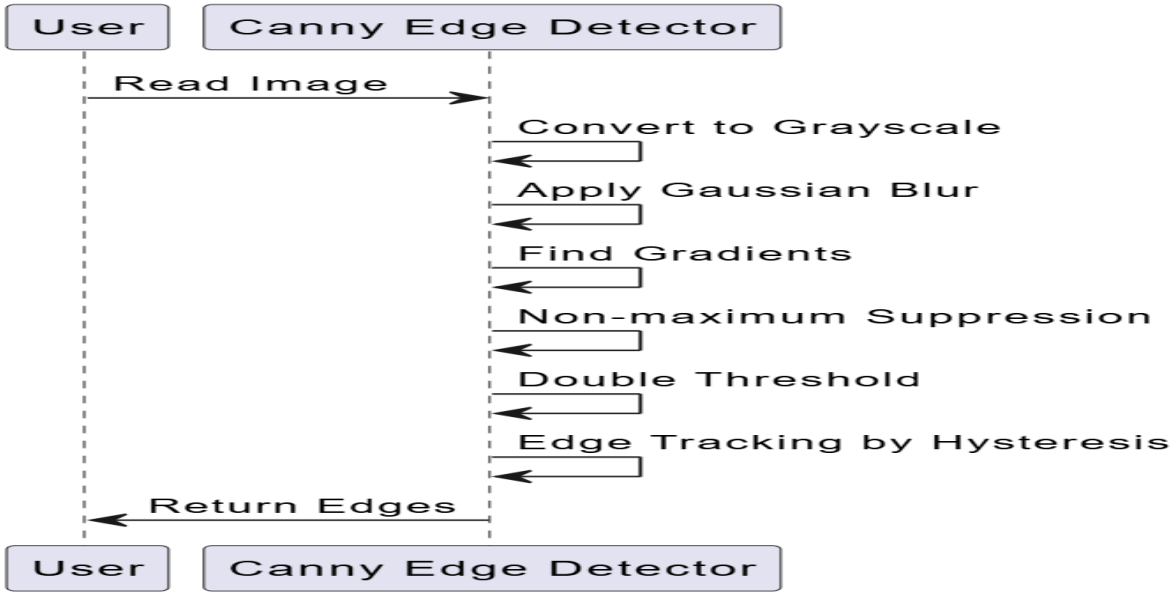

Fig 5.2.3 SEQUENCE DIAGRAM

A sequence diagram (Figure 5.2.3) shows object interactions arranged in time sequence. It depicts the objects and classes involved in the scenario and the sequence of messages exchanged between the objects needed to carry out the functionality of the scenario. Sequence diagrams are typically associated with use case realizations in the logical view of the system under development.

Sequence diagrams are sometimes called event diagrams or event scenarios. A sequence diagram shows, as parallel vertical lines (lifelines), different processes or object that live simultaneously, and as horizontal arrows, the messages exchanged between them, on the order in which they occur. This allows the specification of simple runtime scenarios in a graphical manner.

6. FUNCTIONAL DESIGN

6.1 MODULES

Convert the Image to Grayscale:

- Transform the color image into a single-channel grayscale image.

Apply Gaussian Blur:

- Reduce noise in the image using a Gaussian blur.

Calculate Gradients:

- Determine where the intensity changes significantly using Sobel filters.

Non-Maximum Suppression:

- Thin out the detected edges by keeping only local maxima in the gradient magnitude.

Double Thresholding:

- Classify pixels as strong edges or weak edges based on their gradient values.

Final Edge Selection:

- Perform edge tracking by hysteresis to finalize which weak edges should be retained based on their connectivity to strong edges.

Fig 6.1.1 Input Image

6.1.1 Convert the Image to Grayscale

The first step in the Canny edge detection process is converting the color image into a grayscale image. This transformation simplifies the data we need to process and focuses on intensity rather than color.

Why Convert to Grayscale?

Reduced Complexity:

Color images contain multiple channels (typically three for RGB). By converting to grayscale, we reduce this to a single channel, simplifying calculations and speeding up processing.

Focus on Intensity:

Edges are primarily defined by changes in intensity rather than color. Grayscale images highlight these changes more clearly, making it easier for algorithms to detect edges.

Noise Reduction:

Working with a single channel can help minimize noise that may be present in individual color channels, leading to cleaner edge detection results.

code

```
import cv2
import matplotlib.pyplot as plt
# Load the uploaded RGB image
image_path = '/mnt/data/rgb_image.jpg'
rgb_image = cv2.imread(image_path)
# Convert to Grayscale
gray_image = cv2.cvtColor(rgb_image, cv2.COLOR_BGR2GRAY)
```

Gray_scale

Fig 6.1.2 Grayscale image

6.1.2 Apply Gaussian Blur

The first step in the Canny edge detection process is to reduce noise in the image using a Gaussian blur. This helps smooth out the image, making it easier to detect edges.

Code

```
def gaussian_blur(image, kernel_size=5, sigma=1.4):
kernel = gaussian_kernel(kernel_size, sigma)
blurred = conv2d(image, kernel)
return blurredp
```

- Where, kernel size = 5
- Standard Deviation = 1.4

$$G_\sigma = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}}$$

Fig 6.1.3 Gaussian Blur Expression

Fig 6.1.4 Gaussian Blurred Image

6.1.3 Calculate Gradients

Next, we need to calculate the gradients of the image using Sobel filters. So that previous blurred image is sent to this function. This step helps us determine where the intensity changes significantly, indicating potential edges.

Code

```
def sobel_filters(img):
# Sobel kernels
Kx = np.array([[-1, 0, 1], [-2, 0, 2], [-1, 0, 1]], np.float32)
Ky = np.array([[1, 2, 1], [0, 0, 0], [-1, -2, -1]], np.float32)
# Convolve kernels with image
Ix = conv2d(img, Kx)
Iy = conv2d(img, Ky)

# Calculate gradient magnitude and direction
G = np.hypot(Ix, Iy)
# Normalize gradient values to 0-255
G = G / G.max() * 255
theta = np.arctan2(Iy, Ix)
return G, theta
```

$$K_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix}, K_y = \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix}.$$

Fig 6.1.5 Kernel Image (Size of Matrix)

- These two are Soble Kernels

$$|G| = \sqrt{I_x^2 + I_y^2},$$
$$\theta(x, y) = arctan\left(\frac{I_y}{I_x}\right)$$

Fig 6.1.6 Gradient and Direction Image

- G is used to find the Gradient Magnitude

 # Calculate Gradients

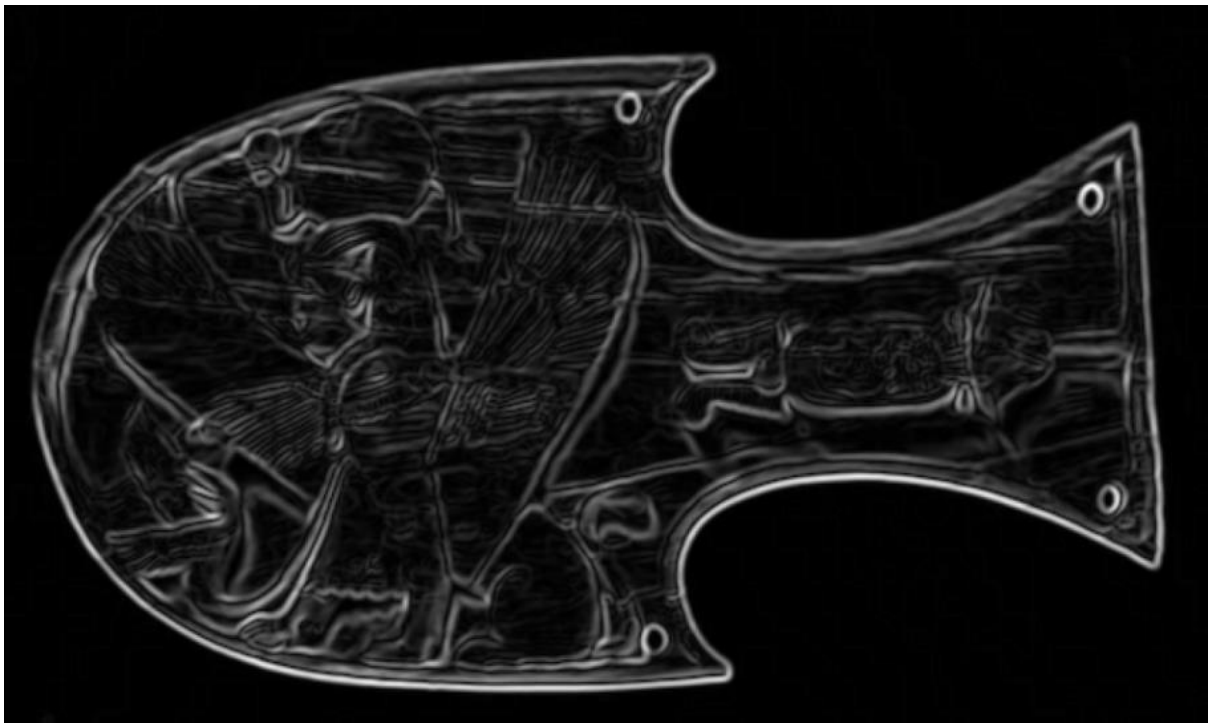

Fig 6.1.7 Gradient Magnitude

6.1.4 Non-Maximum Suppression

After calculating the gradients, we apply non-maximum suppression. This step thins out the detected edges by keeping only local maxima(points where the gradient value is higher than its neighboring points in the direction of the gradient) in the gradient magnitude.

 # Code

```
def non_max_suppression(img, theta):
# Get image dimensions and angles in degrees
M, N = img.shape
output_img = np.zeros((M, N), dtype=np.int32)
angle = theta * 180.0 / np.pi
angle[angle < 0] += 180
```

```
# Perform non-maximum suppression
   for i in range(1, M - 1):
   for j in range(1, N - 1):
   try:
   q = 255
    r = 255

# angle 0
   if (0 <= angle[i, j] < 22.5) or (157.5 <= angle[i, j] <= 180):
   q = img[i, j + 1]  # Right pixel
    r = img[i, j - 1]  # Left pixel
# angle 45
   elif 22.5 <= angle[i, j] < 67.5:
   q = img[i + 1, j - 1]  # Bottom-left pixel
    r = img[i - 1, j + 1]  # Top-right pixel
 # angle 90
    elif 67.5 <= angle[i, j] < 112.5:
    q = img[i + 1, j]  # Bottom pixel
     r = img[i - 1, j]  # Top pixel
  # angle 135
     elif 112.5 <= angle[i, j] < 157.5:
     q = img[i - 1, j - 1]  # Bottom-right pixel
      r = img[i + 1, j + 1]  # Top-left pixel

  # Suppress non-maximum pixels
     if (img[i, j] >= q) and (img[i, j] >= r):
     output_img[i, j] = img[i, j]
     else:
     output_img[i, j] = 1
```

except IndexError as e:

pass

return output_img

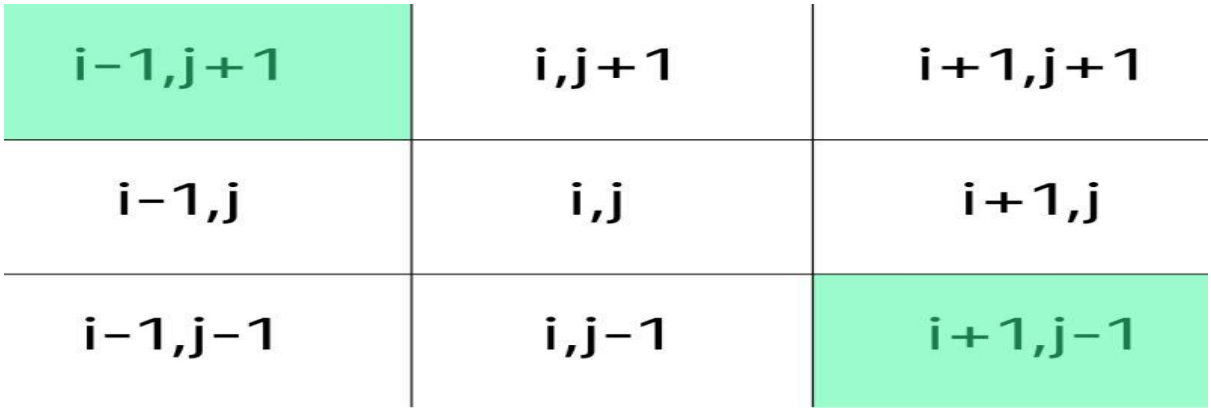

Fig 6.1.8 Comparison of Edge Discrimination

6.1.5 Double Thresholding and hysteresis

We've only yet reduced the width of the edges, we have to make the border colour consistant (using double thresholding) and remove some noises (using hysteresis).

Pixels with a gradient magnitude above the high threshold are considered strong edges and thus we assign pixel value of 255 to it. Pixels with a gradient magnitude below the low threshold are considered non-edges so they gets pixel value of 0, **this process is called Double Thresholding**.

Pixels with a gradient magnitude between the low and high threshold are considered weak edges. These pixels are only assign pixel value of 255, if they are connected to a strong edge, else assign pixel value of 0 to it, this process is called hysteresis.

 # Code

def dual_threshold (img, low_threshold_ratio=0.05, high_threshold_ratio=0.09):

high_threshold = img.max() * high_threshold_ratio

```
        low_threshold = high_threshold * low_threshold_ratio
        M, N = img.shape
        result = np.zeros((M, N), dtype=np.int32)

        weak = np.int32(25)

        strong = np.int32(255)


    #  Apply double thresholding
        strong_i, strong_j = np.where(img >= high_threshold)
        zeros_i, zeros_j = np.where(img < low_threshold)
        weak_i, weak_j = np.where((img <= high_threshold) & (img >=low
threshold)
     # Set weak and strong edges in the image
        result[strong_i, strong_j] = strong
        result[weak_i, weak_j] = weak
        return result, weak, strong
```

 # Weak Edges (Double Threshold)

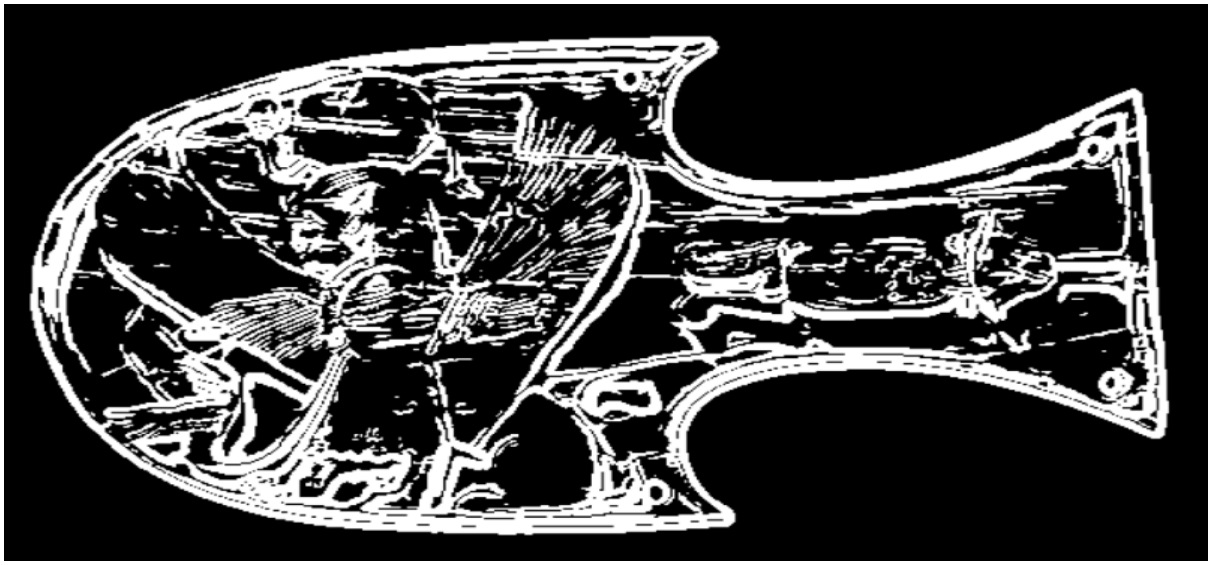

Fig 6.1.9 Weak Edges (Double Threshold)

Weak Edges:

Pixels with gradient values between the lower and higher thresholds are classified as weak edges. These may or may not be part of actual edges.

Purpose of Weak Edges

Weak edges play an essential role because they allow the algorithm to identify edges that might be faint or partially connected to strong edges. However, not all weak edges are retained in the final output; only those connected to strong edges are preserved during edge tracking by hysteresis.

Strong Edges (Double Threshold)

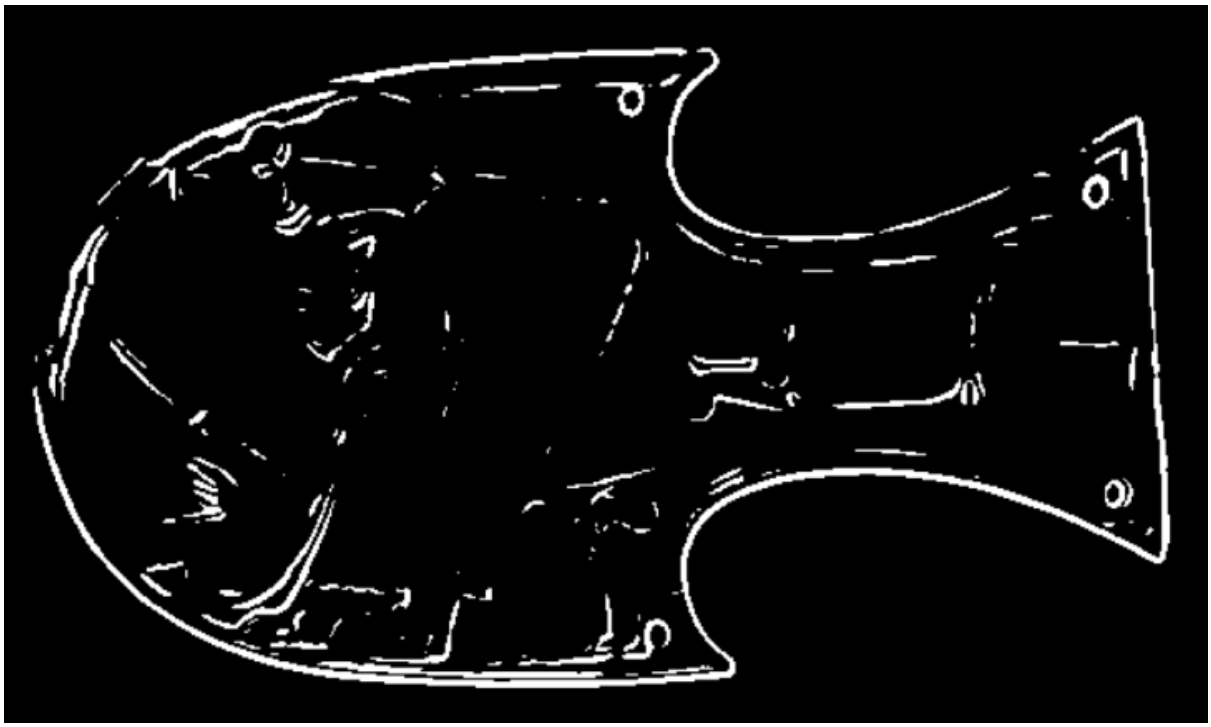

Fig 6.1.10 Strong Edges (Double Threshold)

Strong Edges are defined during the **double thresholding** phase. This step classifies detected edges based on their gradient intensities, distinguishing

between strong and weak edges to make edge detection more robust. Here's how it works for strong edges:

Definition of Strong Edges

Strong edges are pixels with gradient intensity values above a higher threshold (often set by the user or optimized for the image). These edges are considered highly likely to represent real, prominent edges in the image, such as boundaries or outlines of objects. Because they exceed a high threshold, strong edges are retained as part of the final edge map without any further conditional processing.

Role of Strong Edges in Edge Tracking:

During the edge tracking by hysteresis phase, **Strong edges act as anchors** in the final edge detection result, ensuring that all pixels directly connected to strong edges are included. **Weak edges connected to strong edges** are also retained, creating continuous, connected edges in the final output.

- **Isolated weak edges** that aren't connected to strong edges are discarded, helping to minimize noise.

Double Thresholding with Strong Edges

- **High Threshold**: Marks strong edges that are retained as certain edges

Low Threshold:

Marks weak edges that are only retained if they are connected to strong edges. This strategy improves the stability of edge detection by preserving true edges and eliminating weaker, potentially noisy edges.

6.1.6 Edge Tracking by Hysteresis

After double thresholding:

The algorithm examines weak edges to see if they are connected to strong edges. If a weak edge is connected to a strong edge, it's considered a true edge and retained. If a weak edge is isolated or not connected to a strong edge, it is discarded.

This approach ensures that only meaningful edges are preserved, reducing noise and producing clean, connected edges in the final output. Edge Tracking by Hysteresis is the final step in the Canny Edge Detection algorithm. It uses the strong and weak edges identified during the double thresholding phase to create a clean and connected edge map. Here's how it works:

Purpose of Edge Tracking by Hysteresis

The goal is to ensure that all true edges are connected and that isolated weak edges (which might be noise) are eliminated. This approach refines the detected edges by making sure only meaningful edges remain in the final output.

How Edge Tracking by Hysteresis Works

* **Identify Strong Edges:**

Pixels classified as strong edges (those with gradient values above the high threshold) are immediately marked as part of the final edge map since they are very likely true edges.

* **Connect Weak Edges**

Weak edges (pixels with gradient values between the low and high thresholds) are only retained if they are connected to strong edges. The algorithm considers weak edges to be part of the true edge structure if they have at least one neighboring strong edge. This connection is often checked by examining an 8-connected neighborhood (the 8 surrounding pixels).

*** Eliminate Isolated Weak Edges**

If a weak edge is not connected to any strong edge, it is considered noise or an insignificant edge and is discarded. This step helps to reduce false detections and noise in the edge map, resulting in a cleaner, more coherent output.

*** Practical Effect of Hysteresis**

- Preserve continuous edges, even if parts of them are faint (weak edges).
- Remove noise, as isolated weak edges are eliminated.
- Improve robustness by only connecting weak edges to strong ones, thus reducing the chances of misclassifying noise as true edges.
- The algorithm marks the clear part as a strong edge.
- The faint parts are marked as weak edges.
- Hysteresis links the faint (weak) edge pixels to the strong edge, preserving the continuity of the object's edge.

 # Final Edge Selection Module

Finally, we perform edge tracking by hysteresis to finalize which weak edges should be retained based on their connectivity to strong edges.

 # Code

```
def final_edge_selection(img, weak, strong):
M, N = img.shape
for i in range(1, M - 1):
for j in range(1, N - 1):
if img[i, j] == weak:
try:
# Check if any of the 8-connected neighbors is a strong edge
  if (
```

```
(img[i + 1, j - 1] == strong)
or (img[i + 1, j] == strong)
or (img[i + 1, j + 1] == strong)
or (img[i, j - 1] == strong)
or (img[i, j + 1] == strong)
or (img[i - 1, j - 1] == strong)
or (img[i - 1, j] == strong)
or (img[i - 1, j + 1] == strong)
):
img[i, j] = strong
else:
img[i, j] = 0
except IndexError as e:
pass
return img
```

 # Final Edges Selection

After the initial edge detection steps (grayscale conversion, Gaussian blur, gradient calculation, non-maximum suppression, and double thresholding), we have a map of strong and weak edges.

* Identify Strong Edges as Final Edges
* Conditionally Retain Weak Edges
* Discard Isolated Weak Edges

6.1.7 Output (Final Edge Selection Image) Image

Fig 6.1.11 Output Image (Canny)

7. SYSTEM TESTING AND MAINTENANCE

7.1 TESTING

Testing is a set of activities that can be planned in advance and conducted systematically. There are two types of testing according to their behaviors,

1. Unconventional Testing
2. Conventional Testing

7.1.1 Software Testing

Software testing is a critical element of software quality assurances and represents the ultimate review of specifications, design and coding. Software testing process is the means by which people, methods, measurements, tools and equipments are integrated to test a software product. Software testing ensures that the system works accurately and efficiently before the live action commences.

7.1.2 Purpose of testing

To verify the interaction between objects. To verify the proper integration of all components of the software. To verify that all requirements have been correctly implemented to verify and ensure defects are addressed.

7.2 TESTING STRATEGIES

7.2.1 Testing strategy and approach:

- Field testing will be performed manually and functional tests will be written in detail.

7.2.2 Test objectives

- All field entries must work properly.
- Pages must be activated from the identified link.
- The entry screen, messages and responses must not be delayed.

7.3 TYPES OF TESTS

7.3.1 UNIT TESTING:

Unit testing involves the design of test cases that validates the internal program logic is functioning properly and that program inputs produce valid outputs. Unit tests perform basic tests at component level and test a specific business process, application, and system configuration. Unit tests ensure that each unique path of a business process performs accurately to the documented specifications and contains clearly defined inputs and expected results.

7.3.2 INTEGRATION TESTING

Integration testing in the software testing model comes before system testing and after the unit testing has been done. The way that integration testing works is by, getting the individual modules that have been through the unit testing phase and integrating each module into a group. In the integration testing stage there are three things that are created, to ensure that the integration of the modules is successful and that it runs successfully as well, a test plan, test cases and test data is produced to effectively test that the integration is successful. Test data is normally used by test cases but we have mentioned each type below:

Integration Test Plan

When producing a test plan it must include the following information to be effective, A strategy to use when testing the integrated modules and how the tests will be conducted. What will be tested for example software features. What is the time scale and time management?

- Responsibilities e.g. personnel.
- Testing pass and fail condition.

Integration and Test Cases

Test cases is created to make sure that the output of the integrated modules are producing the expected output and is working exactly how it is supposed to

work. This is simply a way to spot any errors or bugs that might have been made in the integration phase.

Integration Test Data

Test data is simply data that is used in order to test the actual program or the integrated modules.We have included an example of what test data is in the test case example that was shown in the test case section above.

7.3.3 FUNCTIONAL TESTING

Functional test provides systematic demonstration that functions tested are available as specified by the business and technical requirements, system documentation and user manuals. Functional testing is centered on the following items:

- **Valid input:** Identified classes of valid input must be accepted.
- **Invalid input:** Identified classes of invalid input must be rejected.
- **Functions:** Identified functions must be exercised.
- **Output:** Identified classes of application output must be exercised.
- **Systems/Procedures:** Interfacing systems or procedures must be invoked.

7.3.4 SYSTEM TESTING

System testing is simply testing the system as a whole; it gets all the integrated modules of the various components from the integration testing phase and combines all the different parts into a system which is then tested.In the system testing process the system will be checked not only for errors but also to see if the system does what was intended, the system functionality and if it is what the end user expected. There are various tests that need to be conducted again in the system testing which include: Test Plan, Test Case and Test Data

- **System Test Plan**

The test plan will contain similar information to what was included in the integration testing, but would contain more information as this time we are not doing individual sections but whole systems.

- **System Test Case**

The test case would also have to change to test the whole system again to see if no errors turned up after combining into a whole system. The test case would include test data to test expected output.

- **Different types of System Testing**

There are loads of examples of system testing. Below I will discuss some of the important types of systems testing that are done regularly

- **Usability testing –** this is how well the user can access the different features in the system and how easy it is to use.

- **GUI software testing –** this is to check if graphically that the program looks how was intended and the GUI works as intended.

- **Accessibility testing –** how easy is it for various users including users with disability to use the system.

- **Reliability testing –** to check that the system works for long period of time and does not constantly crash.

7.3.5 White Box Testing or Glass Box Testing

This type of software testing involves examining the internal structure, design, implementation and working of the software program. White-Box Testing is applicable at the levels, be it Unit Testing level for testing paths within units, Integration Testing level for testing paths between units, or System Level for testing paths between sub-systems. Various techniques that are used in Glass box Testing are as follows:

- **API Testing** for applications using private and public APIs;
- **Code Coverage** for satisfying criteria of code coverage;
- **Fault Injection** for measuring the efficiency of testing strategies by creating faults;
- **Mutation Testing** for evaluating quality of existing test and designing new ones. **Static Testing** for testing the sanity of software code, algorithm or document.

7.3.6 Black-box testing or Behavioral testing

Contrary to the White-Box Testing, Black-Box Testing examines the functionality of a software program, rather than its internal structure. Another point of differentiation is that, unlike in Glass-Box Testing, the tester only requires knowledge on what the software does. This type of testing includes:

Equivalence Partitioning technique: Test design technique in which input data units are divided into partitions of similar data, from which representative values from partitions are tested.

Boundary Value Analysis: It involves specifying the boundaries for input values, and testing the selected values that are at and inside/outside the boundaries

All-Pairs Testing: In this testing method of combinations, all discrete combinations of input parameters are tested.

Decision Table Testing: In this approach, Decision Tables like flow-charts and switch-case statements are used to associate conditions with actions.

Cause-Effect Graph: this testing includes identifying input (cases) and output (effects) conditions, producing graph and test cases accordingly.

Error Guessing: it is a type of software testing in which conditions or variables, that are used to find bugs in software system, are determined based on tester's intuition and experience in previous testing.

7.3.7 ACCEPTANCE TESTING

Acceptance testing is a test conducted to determine if the requirements of a specification or contract are met. It may involve chemical tests, physical tests, or performance tests. In the case of software, acceptance testing performed by the customer is known as user acceptance testing, end-user testing, site (acceptance) testing, or field (acceptance) testing.

7.4 TEST CASES

Test Case #	Description	Pre-Conditions	Expected result	Pass/Fail
TC-001	Verify algorithm detects prominent edges	Image is loaded in grayscale	Clear edges of artifact features are detected	Pass
TC-002	Check algorithm with low threshold values	Image is loaded in grayscale	Minimal edges are detected, producing a faint outline of the artifact	Fail

TC-003	Check algorithm with high threshold values	Image is loaded in grayscale	Only the most prominent edges are visible, reducing noise	Pass
TC-004	Apply Gaussian blur before edge detection	Image is loaded in grayscale	Smoother edges with reduced noise, clear lines around artifact features	Fail
TC-005	Apply algorithm on resized image (downscale)	Downscaled image (e.g., 50% original size	Edges are still detected, but fewer details may be visible	Pass
TC-007	Verify edge detection on RGB image	Image is loaded in RGB format	Algorithm converts image internally to grayscale, edges detected	Pass

TC-008	Verify algorithm's response to noise	Add random noise to image	Algorithm detects prominent edges but with minor artifacts/noise	Pass

Table 7.4.1 Test Cases Table

8. CONCLUSION AND FUTURE WORK

8.1 CONCLUSION

This project successfully demonstrates the application of the Canny Edge Detection algorithm, implemented with OpenCV, on images of ancient artifacts. The results indicate that the algorithm is effective in identifying and enhancing the contours and intricate details present in artifacts, such as engraved patterns, shapes, and structural boundaries. This edge detection technique provides a powerful tool for archaeologists, historians, and conservationists, enabling more accurate digital analysis and documentation of artifacts, which can be crucial for preservation, study, and educational purposes.

Through various test cases, we observed that the choice of threshold values, pre-processing techniques (like Gaussian blurring), and image resolutions significantly impact the quality of edge detection. Lower thresholds and pre-processing blurs improved the detection of finer details, while higher thresholds reduced noise and highlighted only the most prominent features.

8.2 FUTURE WORK

* Adaptive Edge Detection with Machine Learning
* Multi-Scale Edge Detection
* Edge Detection on Multispectral or Hyperspectral Images
* Combining Edge Detection with Texture and Pattern Recognition
* Enhanced Pre-Processing for Noise Reduction
* Post-Processing with Edge Linking and Contextual Analysis
* Integration with AI for Automated Classification & Interpretation
* Enhanced Visualization for Archaeological Study and Public Engagement

APPENDIX

SOURCE CODE

```
import numpy as np
import os
import cv2
import matplotlib.pyplot as plt


# defining the canny detector function

# here weak_th and strong_th are thresholds for
# double thresholding step
def Canny_detector(img, weak_th=None, strong_th=None):
    # conversion of image to grayscale
    img = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)

    # Noise reduction step
    img = cv2.GaussianBlur(img, (5, 5), 1.4)

    # Calculating the gradients
    gx = cv2.Sobel(np.float32(img), cv2.CV_64F, 1, 0, 3)
    gy = cv2.Sobel(np.float32(img), cv2.CV_64F, 0, 1, 3)

    # Conversion of Cartesian coordinates to polar
    mag, ang = cv2.cartToPolar(gx, gy, angleInDegrees=True)

    # setting the minimum and maximum thresholds
    # for double thresholding
    mag_max = np.max(mag)
    if not weak_th: weak_th = mag_max * 0.1
    if not strong_th: strong_th = mag_max * 0.5

    # getting the dimensions of the input image
    height, width = img.shape

    # Looping through every pixel of the grayscale
```

```
    # image
    for i_x in range(width):
        for i_y in range(height):

            grad_ang = ang[i_y, i_x]
            grad_ang = abs(grad_ang - 180) if abs(grad_ang) > 180 else
abs(grad_ang)

            # selecting the neighbours of the target pixel
            # according to the gradient direction
            # In the x axis direction
            if grad_ang <= 22.5:
                neighb_1_x, neighb_1_y = i_x - 1, i_y
                neighb_2_x, neighb_2_y = i_x + 1, i_y

            # top right (diagonal-1) direction
            elif grad_ang > 22.5 and grad_ang <= (22.5 + 45):
                neighb_1_x, neighb_1_y = i_x - 1, i_y - 1
                neighb_2_x, neighb_2_y = i_x + 1, i_y + 1

            # In y-axis direction
            elif grad_ang > (22.5 + 45) and grad_ang <= (22.5 + 90):
                neighb_1_x, neighb_1_y = i_x, i_y - 1
                neighb_2_x, neighb_2_y = i_x, i_y + 1

            # top left (diagonal-2) direction
            elif grad_ang > (22.5 + 90) and grad_ang <= (22.5 + 135):
                neighb_1_x, neighb_1_y = i_x - 1, i_y + 1
                neighb_2_x, neighb_2_y = i_x + 1, i_y - 1

            # Now it restarts the cycle
            elif grad_ang > (22.5 + 135) and grad_ang <= (22.5 + 180):
                neighb_1_x, neighb_1_y = i_x - 1, i_y
                neighb_2_x, neighb_2_y = i_x + 1, i_y

            # Non-maximum suppression step
            if width > neighb_1_x >= 0 and height > neighb_1_y >= 0:
```

```
                if mag[i_y, i_x] < mag[neighb_1_y, neighb_1_x]:
                    mag[i_y, i_x] = 0
                    continue

            if width > neighb_2_x >= 0 and height > neighb_2_y >= 0:
                if mag[i_y, i_x] < mag[neighb_2_y, neighb_2_x]:
                    mag[i_y, i_x] = 0

    weak_ids = np.zeros_like(img)
    strong_ids = np.zeros_like(img)
    ids = np.zeros_like(img)

    # double thresholding step
    for i_x in range(width):
        for i_y in range(height):

            grad_mag = mag[i_y, i_x]

            if grad_mag < weak_th:
                mag[i_y, i_x] = 0
            elif strong_th > grad_mag >= weak_th:
                ids[i_y, i_x] = 1
            else:
                ids[i_y, i_x] = 2

    # finally returning the magnitude of
    # gradients of edges
    return mag


frame = cv2.imread("D:\\rgb_image.jpg",)

# calling the designed function for
# finding edges
canny_img = Canny_detector(frame)
cv2.imshow("rgb_image",canny_img)
cv2.waitKey(0)
```

OUTPUT (FINAL EDGE SELECTION) MODULE

Fig A1. CANNY EDGE DETECTED IMAGE

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