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Morphological Grayscale Pre-processing to SAR Images for Reducing Noise in Ship Detection Based on YOLOv8

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ABSTRACT

The development of a ship detection system using SAR pictures loaded with noise poses issues for pictures Intelligence (IMINT). The YOLOv8 model is utilized for ship identification. The preprocessing approaches entail employing a fusion of grayscale morphology techniques and image restoration using a harmonic mean filter and a bandpass. This technique is designed to assess the effect of noise reduction to enhance the accuracy of detecting objects in SAR images. The preprocessing technique is categorized into two methods: basic grayscale morphology (GM1-GM6) and a fusion of image restoration with grayscale morphology (GHB1-GHB6). The model's performance is assessed using mAP and IoU criteria. This research discovered that ship objects were not detected successfully in the presence of several types of noise. These failures were attributed to factors such as tiny ship size, low picture quality, and inadequate preprocessing techniques for noise handling. The findings indicate a substantial enhancement in ship detection, specifically in synthetic aperture radar (SAR) images affected by sidelobe noise. There were noticeable enhancements in the accuracy of images that underwent preprocessing using GHB5. GHB5 employs a combination of image restoration, closure, and erosion techniques.

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1. INTRODUCTION

Imagery Intelligence (IMINT) provides a vital part in military operations in Indonesia by providing valuable information for strategic planning and tactical decision making. IMINT, which is used to monitor and analyze activities on earth, relies heavily on satellite imagery as a key component (Shabbir et al., 2019). PT Len Industri is now in the process of developing a ship detecting system that utilizes digital imagery acquired from satellites. This system is a component of the IMINT project, which aims to monitor and observe Indonesia's marine territories. In next advancements, this system will enable the retrieval of data regarding the location of ships in the ocean by utilizing digital images obtained from Synthetic Aperture Radar (SAR) satellite imagery that align with specific places on the map.

SAR utilizes electromagnetic radiation in the form of radio waves to generate highly accurate and detailed images of the surface of the Earth. An essential benefit of SAR is its versatility in functioning under diverse weather conditions, including both diurnal and nocturnal periods, as well as different atmospheric parameters encompassing humidity, brightness, and other factors. SAR has the ability to penetrate cloud and rain layers without degradation, proving it highly advantageous in a wide range of applications (Nashuha et al., 2016; Shabbir et al., 2019).

Identifying ships using SAR images presents three primary challenges. The visual background typically contains factors that can obscure the presence of ships, such as sea waves, light reflections, and geographical landmarks like islands or coasts. Additionally, variables like as the angle at which an incident occurs, the polarization of light, the size of the image, and the computational requirements for image display can contribute to increased brightness in certain regions and result in significant noise. Furthermore, Due to the constraints of resolution and distance between the satellite and the seen item, the captured photographs frequently portray target objects in a significantly reduced size. Small objects are characterized by small scales and weak features (Gonzalez & Woods, 2018). These three obstacles prevent the accurate identification of ships, thus leading to research in the development of ship detection systems to achieve a high level of accuracy in detecting ships in SAR images.

Multiple research projects have been undertaken to enhance the precision of ship detection in SAR photos by employing diverse data preprocessing techniques. To address the challenges associated with identifying ships of different sizes, accounting for the impact of weather conditions on image clarity, distinguishing ships from other objects, and accommodating the wide range of ship locations and orientations. Another research (Ship-YOLOv3) conducted a study, which employed advanced techniques such as guided filtering and grayscale enhancement for the input image preprocessing stage. Additionally, the study utilized the k-means++ algorithm to cluster bounding box dimensions and modified the topology of the YOLOv3 network by decreasing specific convolution operations and implementing a jump join strategy to eliminate repetition in features. These improvements are achieved by employing a preprocessing methodology that enhances image quality and eliminates noise in SAR images (Huang et al., 2020).

By incorporating the Morphological Feature Pyramid Network into YOLO v4-tiny, the preprocessing technique effectively diminishes noise and enhances line information in the image. The employed morphological operation is morphological smoothing. The experimental results provide an 8.1% enhancement in mAP and IoU measures for ship identification (Zhao et al., 2022). The created model exhibits exceptional processing speed, hence showcasing its aptness for maritime monitoring applications necessitating prompt responsiveness.

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Morphological operations are effective in addressing difficulties in SAR image processing for ship detection and offer potential for adaptable advancement in different surveillance settings.

Other methods, such as spatial filters, can offer alternative approaches to reducing speckle noise in SAR images (Choi & Jeong, 2019). Some of the filters available are the Median Filter, Bilateral Filter (BF), Non-Local Means (NLM) Filter, Mean Filter, and Speckle Reducing Anisotropic Diffusion (SRAD). Another option is to utilize frequency filters, such as bandpass filters, to enhance the viewing of mammography images for the purpose of identifying important characteristics associated with the early identification of breast cancer (Alsalman, 2019). By selectively targeting specific frequencies, significant characteristics in the image can be enhanced, aiding in the detection of abnormalities that may not be readily apparent in the original image. This approach can be utilized for conducting research on ship detection in SAR pictures, serving as a preprocessing step to enhance contrast and elucidate ship structures.

Researchers have undertaken multiple experiments to enhance the accuracy of ship detection in SAR images by employing various data preprocessing approaches, as indicated by the provided results. Grayscale morphology and image restoration techniques are effective methods for detecting ships in SAR images. Image restoration involves the repair or restoration of images that have suffered damage or degradation caused by factors such as noise, blurring, or other disruptions (Gonzalez & Woods, 2018). The image restoration technique is implemented by the utilization of a blend of spatial filtering and picture shaping.

The YOLOv8 method for object recognition is a single-stage approach that offers better speed and accuracy compared to the previous version of YOLO (Muhamad Itikap et al., 2023). It has been specifically enhanced to cater to the requirements of real-time object detection and recognition. Nevertheless, YOLOv8 has constraints, particularly when it comes to detecting small targets. The accuracy diminishes due to the down sazmpling process, which results in the loss of crucial feature information, including shape, color, texture, and other relevant details(Ma & Pang, 2023).

This paper presents a strategy for applying a mixture of grayscale morphological preprocessing methods, including picture restoration using the Harmonic Mean Filter and bandpass filter, to SAR images. This approach is anticipated to decrease background noise and enhance SAR photos. The utilization of the preprocessing technique has the potential to enhance the accuracy of ship detection using YOLOv8.

2. METHODS

Figure 1 provides an overview of the various components and sequence of the research stages that were conducted. The procedure commences by identifying fundamental issues in establishing the research's focal point. Additionally, a literature review is undertaken to acquire a comprehensive theoretical grasp of the topic under investigation. Subsequently, problem domain analysis is conducted to pinpoint facets of the problem. Data preparation involves the collection and processing of pertinent data for analysis. Testing is conducted throughout the stages of this investigation, following the specified methodology, and ultimately, accurate and reliable conclusions are drawn based on experimental data.

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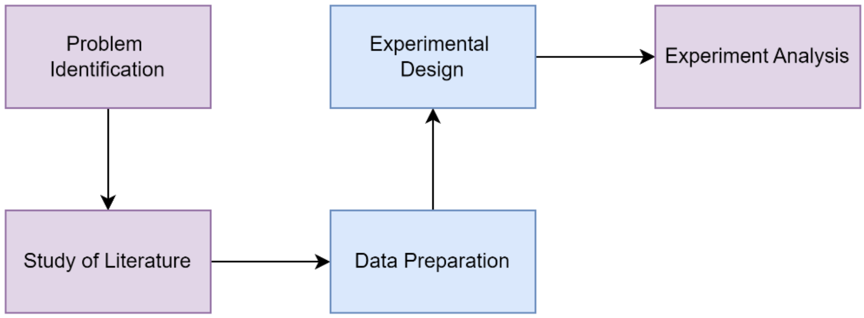

Figure 1. Phases of Research

2.1. Problem Identification

During the initial phase of the research, the process of identifying the specific issues to be examined is conducted. The outcomes of this phase encompass the groundwork, formulation of the problem, research objectives, hypotheses, and research questions. The research presents a set of hypotheses and research questions:

RQ : What is the impact of noise reduction using grayscale morphology on the preprocessing stage of the YOLOv8 object detection model in terms of its accuracy in spotting ships in SAR satellite images?

H0 : Applying grayscale morphology approach for noise reduction in the preprocessing stage does not enhance the accuracy of ship detection in SAR.

H1 : Applying grayscale morphology approach for noise reduction in the preprocessing stage does enhance the accuracy of ship detection in SAR.

2.2. Study of Literature

2.2.1 Synthetic Aperture Radar (SAR) Images

Synthetic Aperture Radar (SAR) is a remote sensing technology that utilizes an active radar system utilizing radio waves to generate detailed images of the Earth's surface map (Zhao et al., 2022). SAR has several advantages as an active sensor with its own light source. It can effectively work in regions with dense cloud cover, fog, and heavy rains. SAR can operate both during the day and at night. It can illuminate the target with different viewing angles and cover a vast area. Radar pictures possess unique attributes that differentiate them from optical images. Radar sensors utilize electromagnetic waves of wavelengths capable of penetrating atmospheric particles, including clouds, fog, smoke, and dust. Radar scans are typically free from air disturbance, resulting in clear images (Syam'ani, S.Hut., 2019). The radar system emits a high-power phase encoded signal and then receives a reflected backscatter signal in a sequential manner. The radar sensor will detect various characteristics of objects, including their shape (texture/roughness), orientation (horizontal or vertical), and dielectric properties (such as water and metal). The height of the backscatter received by the radar sensor (pixel value) will be influenced by the object's shape, orientation, and dielectric properties (Cumming & Wong, 2005).

2.2.2 Object Detection

Object detection is the procedure of identifying and finding one or multiple objects in an image or video by blending classification and localization procedures. The primary objective is to anticipate the position of an object using a bounding box and to categorize the object. The input consists of a picture that may contain several items. The output provides the

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expected location of each object, represented by a bounding box, together with the categorization of the objects within each bounding box (P. Hidayatullah, 2017).You Only Look Once (YOLO) is an object detection technique that use a solitary convolutional network to predict both the coordinates of the bounding box and the probability of a class straight from the pixels in an image or video. The term "YOLO" is derived from the fact that it may accomplish the detection task by making only one run across the network. YOLO employs a simpler regression-based approach for predicting detection output, as opposed to Fast R-CNN (Hussain, 2024).

YOLOv8, the successor to YOLOv5, introduces architectural and performance improvements. Although specific facts are few, significant distinctions become apparent. YOLOv8 presumably substitutes the CSPDarknet53 backbone with an EfficientNet-inspired architecture to enhance efficiency. The neck and head may undergo enhancements, maybe via a more advanced Path Aggregation Network (PAN) and a transition to anchor-free detection. These modifications provide enhancements in performance. YOLOv8 exhibits enhanced accuracy, especially with diminutive objects and intricate scenes, as well as expedited inference speed. This progression highlights a tendency towards enhanced efficiency, modularity, and performance in object detection models (Yaseen, 2024).

2.2.3 Image Preprocessing Noise Reductions

Image preprocessing techniques, such as noise reduction, contrast enhancement, segmentation, and others, are employed to increase the quality of images. These approaches play a crucial role in enhancing data in images and minimizing noise. Image acquisition procedure or data transmission might generate noise due to variables such as unpredictable lighting conditions, sensor faults, or electromagnetic interference (P. Hidayatullah, 2017).

A. Harmonic Mean Filter (HMF)

Image restoration refers to the procedure of rectifying images that have been damaged or deteriorated to restore them to their initial condition. Image damage might manifest as blurriness or the presence of noise in the image (Onyedinma & Onyenwe, 2023). Spatial filtering is a technique employed to modify the pixels in a picture by considering the values of adjacent pixels. The primary purpose of spatial filtering is to enhance image quality or extract specific information from the image. Harmonic mean filtering is a spatial filtering technique employed to diminish salt and Gaussian noise; however, it is ineffective in dealing with pepper noise.

The harmonic mean filter computes the mean value of the image, which is distorted by noise g(x,y), inside the region given by Sxy. The restored picture $\hat{f}$ at point (x,y) is determined by calculating the arithmetic mean of the pixels inside the area indicated by Sxy (Gonzalez & Woods, 2018). This approach can be expressed as equation (1).

$$\hat{f}(x,y) = \frac{mn}{\sum_{(r,c)\in S_{xy}} \frac{1}{g(r,c)}} \quad (1)$$

The variables r and c represent the row and column coordinates of the pixels in the neighborhood S_{xy}. The operation can be executed by utilizing a $m \times n$ spatial kernel in which all coefficients are assigned the value $\frac{1}{mn}$

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B. Morphological Grayscale Image Processing

Morphological grayscale is an image processing technique that merges the principles of morphology with grayscale images. This method is employed to examine and control the formations in images by considering the configuration and dimensions of preexisting entities. Morphological procedures, including dilation, erosion, opening, and closing, are used to modify the grayscale image by considering the geometry of the object.

1. Grayscale Erosion

   Erosion is characterized as the lowest value inside each localized image window constrained by structural features. This erosion diminishes small regions and can reveal cavities or gaps in the items inside the image.

   $$[f \ominus b](x, y) = \min_{(s,t)\in b}\{f(x + s, y + t)\} \quad (2)$$

   where $f(x, y)$ is intensity at point (x, y) and $b(x, y)$ is structural element.

2. Grayscale Dilatation

   Dilation, unlike erosion, extracts the maximum value from each local window, so amplifying and consolidating distinct regions within the image.

   $$[f \oplus b](x, y) = \max_{(s,t)\in b}\{f(x - s, y - t)\} \quad (3)$$

3. Opening and Closing

   Opening and closing operations are fundamentally a synthesis of erosion and dilation, employed to refine the contour of an object, eliminate minor peaks and valleys, and preserve the object's fundamental shape.

   a. The process of opening involves erosion succeeded by dilation, represented by the formula: $f \circ b = (f \ominus b) \oplus b$;

   b. The process of closing involves dilatation succeeded by erosion, represented by the formula: $f \cdot b = (f \oplus b) \ominus b$

C. Bandpass Filter

Bandpass filters are constructed utilizing a kernel that restricts the permissible frequency range. This can be achieved by utilizing a combination of low-pass and high-pass kernels, or by employing a transfer function such as Butterworth. The picture frequency spectrum is subjected to the bandpass kernel, and subsequently, the outcome is transformed back to the spatial domain by means of the inverse Fourier transform(Alsalman, 2019). This function is designed to eliminate any undesirable noise or artifacts that may exist at various frequencies. The formula for Bandpass can be expressed in the following manner:

$$H_p(u, v) = 1 - H_s(u, v) \quad (4)$$

2.2.4 Performance Evaluation Metrics

The study utilizes two separate performance evaluation measures, specifically image processing and object detection. The evaluation metrics employed to assess the image quality based on the outcomes of image preprocessing include Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SME), and Structural Similarity (SSIM) (Gonzalez & Woods, 2018).

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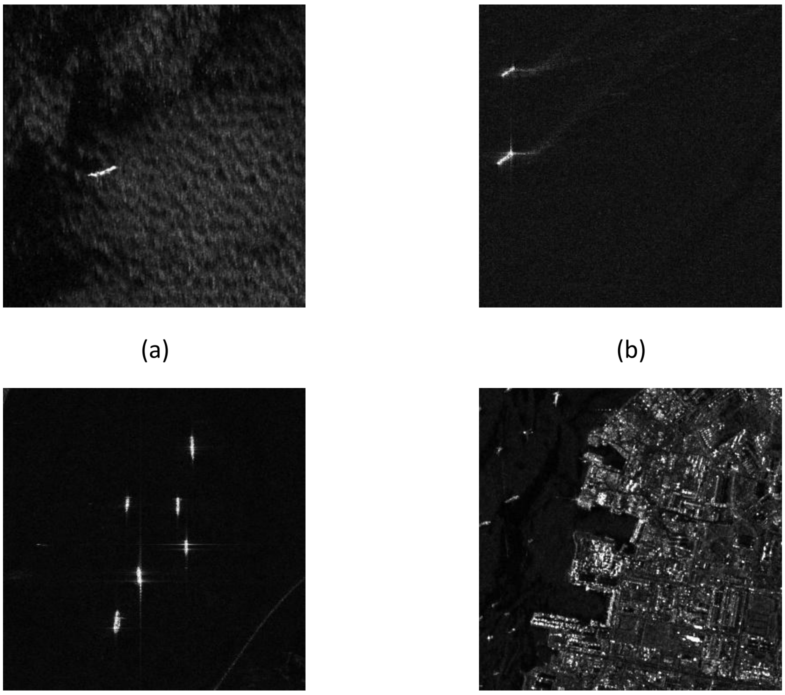
The assessment metrics utilized for assessing the precision of object detection involve mean Average Precision (mAP) and Intersection over Union (IoU) values (D. P. Hidayatullah, 2021).

2.3. Data Preparation

The data gathering phase involves doing a search for literature studies using SAR satellite image spatial data. Subsequently, remove photographs that lack annotations. The dataset is purged of photos containing object information that is irrelevant to the investigation. Non-ship data and ship objects located over or near land are also removed. The final step involves categorizing the data under five distinct conditions: calm sea, sea clutters, wake trail, sidelobe, and land.



(a) (b)

(c) (d)

Figure 2. Four SAR noise categories (sea clutters, wake trail, sidelobe and land)

Sea Clutters (Figure 2a) are disturbances arising from irregular and fluctuating sea surface conditions, including variations in wave formations and ocean currents. Wake Trail (Figure 2b) refers to the disruption in SAR imaging caused by the path of a ship or another mobile object on the sea surface, creating a distinct wave pattern detectable by the SAR sensor. Sidelobe (Figure 2c) is a phenomenon in SAR imaging that results in significant scattering beyond the ship's surface, affecting the precision of detecting smaller ships due to the SAR sensor receiving signals from both the ship and its surrounding environment. Land (Figure 2d) refers to the interference in SAR images caused by nearby land or ground surfaces in the waters near the ship's position, particularly when the vessel is close to the coastline.

Data preprocessing in HRSID (Wei et al., 2020) consists of two primary stages: conversion and data division. Prior to conducting these two steps, a data filtering method is implemented. This process involves categorizing conditions by utilizing noise distribution histograms from all photos. The dataset comprises various noise categories, each with a different amount of data: calm sea (2060), sea clutters (924), wake trail (102), sidelobe (113),

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and land (295). Firstly, the data in COCO format is translated into YOLO format to streamline the object recognition procedure on the main stage. Subsequently, the dataset is partitioned into three distinct segments, specifically training, validation, and testing.

2.4. Experiment Design

The experimental materials in this study comprise a set of Synthetic Aperture Radar (SAR) photographs and their corresponding annotations. These materials will be utilized in the experiment, which involves a training dataset, a validation dataset, and a test dataset. The experiment in the study will utilize the Python library, OpenCV, and Ultralytics YOLOv8 as the experimental tools. The experiment will be supported by the following equipment: 4×Tesla T4 GPU, 1T RAM on the Department of Computer and Informatics Engineering AI Server.

The experimental methodology employed in this study involves noise reduction in SAR images using the Grayscale Morphology method. The process begins with filtering the SAR image using a spatial filter to reduce noise while preserving object edges. Subsequently, sharpening is applied, and the resulting signal is passed through a bandpass filter to isolate the desired frequency for enhanced ship detection. The Greyscale Morphology method is then applied, utilizing morphological operations to refine the SAR images and identify appropriate morphological operations for grouped noise. The processed SAR images serve as input for the YOLOv8 model, which performs object detection to identify and classify ship objects within the images.

There are a total of 13 different combinations of grayscale morphology that are used in the data preparation procedure. The objective is to assess the impact of grayscale morphology in the preprocessing phase on the accuracy of the YOLOv8 object detection model in identifying ships in SAR satellite photos. The mix of grayscale morphology operations utilized comprises fundamental morphological operations, as well as image improvement by blurring and sharpening, with specific specifications outlined in Table 1.

Table 1. Morphological Grayscale Experiment Code.

Code	Morfology Operation	*Bluring Image*	*Shapening*
GM-1	Opening + Closing	-	-
GM-2	Closing + Opening	-	-
GM-3	Opening + Dilatation	-	-
GM-4	Opening + Erosion	-	-
GM-5	Closing + Dilation	-	-
GM-6	Closing + Erosion	-	-
HB	-	HMF	Bandpass Filter
GHB-1	Opening + Closing	HMF	Bandpass Filter
GHB-2	Closing + Opening	HMF	Bandpass Filter
GHB-3	Opening + Dilatation	HMF	Bandpass Filter
GHB-4	Opening + Erosion	HMF	Bandpass Filter
GHB-5	Closing + Dilation	HMF	Bandpass Filter
GHB-6	Closing + Erosion	HMF	Bandpass Filter

An experiment was conducted to evaluate the influence of grayscale morphology in the preprocessing stage on the accuracy of the YOLOv8 object detection model in identifying ships within SAR satellite images. The experimental procedure commenced with filtering the SAR image to reduce noise and maintain object edges using a spatial filter. The resulting signal was then sharpened and subsequently passed through a bandpass filter to isolate the desired

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frequencies, facilitating more precise ship detection based on specific frequencies present in the SAR image.

Following this, the Greyscale Morphology technique, encompassing morphological operations aimed at enhancing SAR images and identifying suitable morphological operations for aggregated noise, was implemented. The processed SAR images served as input for the YOLOv8 model used for object detection. The experimental results indicated that the application of the Grayscale Morphology preprocessing technique enhances both image quality and object detection accuracy. The primary metrics employed in the evaluation were mAP and IoU. The study focused on analyzing the effects of preprocessing on mAP and IoU metrics across various noise scenarios.

2.5. Experiment & Analysis

An experiment was carried out to assess the impact of grayscale morphology on the preprocessing stage on the level of accuracy of the YOLOv8 object detection model in identifying ships in SAR satellite images. The experimental procedure involved filtering the SAR image to reduce noise and preserve object edges using a spatial filter. The resulting signal was then sharpened and passed through a bandpass filter to isolate the desired frequencies. This allowed for more precise ship detection based on specific frequencies in the SAR image. Subsequently, the Greyscale Morphology technique was implemented, which encompasses morphological operations aimed at enhancing SAR images and identifying appropriate morphological operations for aggregated noise. The outcomes of SAR picture preprocessing employing this technique will serve as the input for the YOLOV8 model, which is utilized for object detection.

3. RESULTS AND DISCUSSION

3.1. Results

According to Table 2, utilizing GM-6 preprocessing for sea clutters noise and GHB-5 for sidelobe noise enhances object recognition in SAR images. The utilization of GM-6 results in a marginal improvement in mAP, increasing it from 0.97 to 0.98, and in IoU, increasing it from 0.79 to 0.80. Both metrics experience a 0.01 increment, which is deemed to be negligible. Furthermore, the amalgamation of GHB-5 exhibits noteworthy enhancement. At epoch 100, the mean average precision (mAP) grows from 0.96 to 0.99, and the intersection over union (IoU) increases from 0.79 to 0.82, with each metric growing by 0.03. At epoch 150, the mean average precision (mAP) increases from 0.97 to 0.99, and the intersection over union (IoU) increases from 0.80 to 0.82, with each metric increasing by 0.02. The metrics show that GHB-5 has achieved a significant improvement in both object detection and border accuracy compared to GM-6, with an increase of more than 0.02. The obtained findings indicate that the mean average precision (mAP) and intersection over union (IoU) values are at a satisfactory level, specifically greater than 0.9 (90%).

Table 2. mAP and IoU Improvement Analysis

Code	Noise	Epoch	mAP Init	mAP Final	ΔmAP	IoU Init	IoU Finak	ΔIoU
GM-6	Sea Clutters	100	0.97	0.98	(+)0.01	0.79	0.80	(+)0.01
GHB-5	Sidelobe	100	0.96	0.99	(+)0.03	0.79	0.82	(+)0.03

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Code	Noise	Epoch	mAP Init	mAP Final	ΔmAP	IoU Init	IoU Finak	ΔIoU
GHB-5	Sidelobe	150	0.97	0.99	(+)0.02	0.80	0.82	(+)0.02

High picture quality is typically indicated by a peak signal-to-noise ratio (PSNR) value exceeding 20 dB, a mean squared error (MSE) below 30, and a structural similarity index (SSIM) value approaching 1. These standards demonstrate a higher degree of resemblance to the source image.

Table 3. Image Quality Analysis in Grayscale Morphology Technique

Code	Noise	PSNR	MSE	SSIM
GM-6	*Sea Clutters*	29.8	29.8	0.37
GM-3	*Wake Trail*	30.0	67.3	0.35
GM-4	*Sidelobe*	31.3	53.55	0.32
GM-3	*Land*	30.9	58.2	0.30

Table 3 presents the data that indicates the optimal image quality for each form of noise. The GM-3 preprocessing technique yields superior image quality in terms of wake trail and sidelobe noise reduction in SAR images. The opening and dilation techniques employed in GM-3 serve to diminish noise, enhance the clarity of object structure and boundaries, and reinstate things to their original size. The GM-6 technique consists of the sequential steps of closing and erosion, which effectively mitigates the impact of sea clutter noise by sealing microscopic gaps and reducing noise effects. The GM-4 technique employs an opening operation followed by erosion to effectively eliminate sidelobe noise and minimize the presence of distorted small features.

3.2 Discussion

During the study of the experimental findings, it was observed that ship object detection sometimes fails, despite the implementation of image preprocessing using the grayscale morphology technique and the utilization of the YOLOv8 model in the detection system. Using 13 different combinations of preprocessing approaches, we analyzed all forms of noise. The noise type known as "failure in the sea clutters" exhibits the highest failure rate of 85.62%, while the failure rate for sidelobe is somewhat lower at 76.92%.

Conversely, the failure rate for wake trail and land noise is lower at 30.77%, suggesting that the preprocessing technique used is more effective in dealing with this noise. The inability to identify ship objects is attributed to various circumstances, including the presence of small-sized ships and the utilization of the grayscale morphological operation technique. In specific circumstances, the grayscale morphology technique employed is incapable of mitigating the influence of noise, therefore diminishing the system's capacity to differentiate between ship items and their surroundings.

4. CONCLUSION

This research examined the influence of Morphological Grayscale preprocessing on the accuracy of object detection in SAR images utilizing YOLOv8. Although the approach did not markedly enhance performance across most noise categories (sea clutter, wake trails, land), a considerable boost in mAP and IoU was noted with sidelobe noise. This indicates that the integration of harmonic mean filter, bandpass filter, closing operation, and erosion can significantly diminish speckle noise and sidelobe interference, thus improving YOLOv8's detection accuracy. Future study may investigate alternate or integrated preprocessing

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techniques to mitigate the shortcomings of Morphological Grayscale in managing intricate noise circumstances and enhance ship detection in SAR images.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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