Enhancing Image Quality for the Detection of Underwater Debris with Adaptive Fuzzy Filter

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ABSTRACT
The image quality improvement process plays a very important role. This is because the process can increase the clarity and accuracy of image detection. One type of image detection that exists is the detection of garbage found under the sea. One of the image quality improvement processes is related to noise removal. Noise is a sudden increase in pixel intensity in an image. This can cause various problems that occur such as in medical photos, satellites, and photography. One method used to remove noise from images is using Adaptive Fuzzy Filter (AFF). This method is carried out by first finding the average value of the mean fuzzy set and the gray level fuzzy. After that, the value comparison process is carried out. From the results of the research conducted on 689 images from the dataset obtained, there is a decrease in the amount of noise of around 96,23% of the total noise obtained previously. This can certainly provide good results in terms of changes in noise that have been made.

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1. INTRODUCTION

Waste is one of the major environmental problems faced today [1]. As the population grows and human activities increase, the amount of waste generated also rises [2]. Waste is commonly found not only on land but also underwater. According to data from CleanHub, the estimated amount of waste in the ocean is approximately 14 million tons. Indonesia is one of the largest contributors to ocean waste, ranking fifth among the top countries responsible for waste in water bodies [3]. This, of course, is not a favorable situation.

Currently, efforts have been made by the government to address this issue through the removal of waste from the ocean [4]. However, challenges remain in distinguishing what qualifies as waste and what does not during this process. One of the main problems in the differentiation process is that the captured images often contain noise. This makes it difficult to distinguish the existing waste [5]. Noise is defined as a sudden increase in pixel values in an image, which can significantly affect the detection process [6]. Therefore, the noise reduction process is important to be carried out first, before the waste detection process is carried out.

Several studies have been conducted to address noise reduction. For example, Fauzi (2022) focused on reducing noise using Gaussian and Median Filters [7][8][9]. Their study concluded that both methods were effective in noise reduction and yielded good results in preserving image details. However, this research mainly focused on the size of the image being processed. In another study by Dermawan et al. (2024), the bilateral method was used to reduce Gaussian, Salt-and-Pepper, and Speckle noise [10][11]. The results demonstrated significant noise reduction with an improvement of approximately 8.11 in signal-to-noise ratio (SNR). However, some types of noise still required adjustments to the parameters used. Halim et al. conducted another study that combined the Adaptive Fuzzy Filter (AFF) with the Fuzzy Base Enhancement Technique (FBET) to enhance image quality [6]. This study showed that the combination of the two methods effectively improved image quality. However, challenges remained in edge detection, as some noise around the edges of the image was not completely removed.

Several studies have been conducted by applying an AFF, namely Sirait et al. (2018) combined AFF with FBET, resulting in enhanced image quality for grayscale images [6]. Following this, Halim et al. (2020) combined AFF with a dark channel approach to restore blurry images and remove noise. The results indicated that the combination improved image quality [12]. Habib et al (2023) used AFF to filter impulse noise by effectively maintaining image details and edges [13]. Finally, research conducted by Aessa et al. (2024) applied AFF to remove noise from underwater sonar images, achieving the best results for speckle noise [14]. Thus, in the noise removal process this time, AFF was used to remove noise in marine images before the underwater debris detection process was carried out.

In the research conducted, improvements were made in the image detection process before noise removal. In the detection process, median filtering was applied. This process involves taking the maxing image and finding the median value. The median value is then compared to the middle value. If a difference in image intensity of 20 (the intensity threshold distinguishable by the human eye) is detected [15], the pixel is passed to the noise removal process using AFF.

2. MATERIAL AND METHOD

This section will explain the steps undertaken in this study, which focuses on analyzing image data obtained in the form of a dataset from the website [16].

2.1. Dataset Image

This study focuses on analyzing images that have been enhanced through pre-processing to remove noise. In this data collection process, a search process for image datasets that are under the sea is carried out. The data used is included in the dataset or data that has been used in previous studies. The dataset obtained comes from the Roboflow website. In the dataset [16] there are around 689 images that have the same sizes. The image consists of various types of garbage on the seabed. However, the dataset does not only focus on garbage but also marine animals.

The dataset used previously has been labeled directly on the image. This is certainly very helpful in the research being conducted. As an example of the dataset used, it can be seen in Figure 1 below:

Figure 1. Example of Dataset Image

2.2 Denoising Image

In this process, image cleaning is carried out by applying the Adaptive Fuzzy Filter (AFF) method. However, a noise detection step is first performed, followed by noise removal. The detailed steps are shown in Figure 2.

In Figure 2, the noise removal process is explained, starting with the input of the image. Afterward, the input image is converted into a set of data (array). The array is then divided into three types: Red, Green, and Blue. This is because creating a color image requires a combination of these three values. The result of this conversion into an array can be seen in the matrix below:

0	0	10
0	0	10
255	255	0

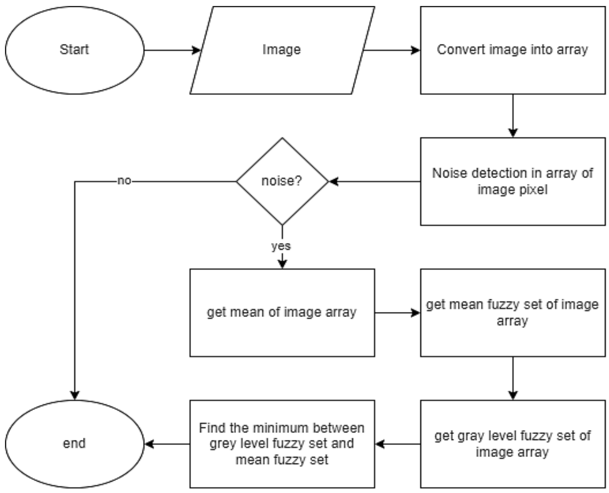

Figure 2. Noise Cleaning Stages

The array is obtained from the edge pixels of the image. However, the edge values (column 1 and row 1) are derived by mirroring the directly adjacent pixels. Thus, the resulting array is obtained. After the pixel values are converted into an array, a detection process is carried out using the Median Filter [17] [18]. This process is performed to ensure that the processed pixel contains noise. The formula used to determine whether the pixel is noise or not can be seen in formula 1.

$$f' = \underset{(s,t) \in S_{xy}}{median} \{g(s,t)\} \quad (1)$$

The function will compare each value directly neighboring the pixel being processed. The direct neighbors refer to the pixels located to the left, right, top, and bottom, as well as the left and right edges. Once the values are obtained, the process continues to determine the median value from the given data. After the median value is determined, it is compared to the pixel being processed. If the difference exceeds 30 (the pixel intensity value distinguishable by the human eye), the pixel is classified as noise and proceeds to the next process. This stage is a further stage that focuses on getting the average value of the masking contained in the image. First, all the values in the masking are added up. After getting the summation result, it is continued to the division process. The resulting value obtained will later be used again in the process of determining the minimum value of the final stage.

This stage has almost the same stages as the previous stage. At this stage, previously the search for the sum of all intensities was carried out, first, the process of determining the membership function using a trapezium was carried out. After the results were obtained, the addition process was carried out and divided by the number 9 according to the amount of data in the array. After the process of finding the mean of the Fuzzy Set is carried out, it is continued by changing the value in the masking into a membership function using a trapezium that is divided evenly into 15 pieces. This aims to find a value that is close to the result value.

After getting the results from the mean fuzzy set and gray level fuzzy set, a comparison process is carried out with the average value that has been obtained previously. This aims to find a value that is close to the expected final result value.

In general, the noise removal process using the AFF method has proven to be effective and efficient. This is because the process within this method applies an adaptive concept and is based on Fuzzy logic, which helps preserve the details of the processed image. For instance, a study conducted by Mallat in 2021 applied AFF to medical images to remove noise from Computed Tomography Scan (CT) and Magnetic Resonance Imaging (MRI) images [19]. The results showed an improvement in the Peak Signal-to-noise ratio (PSNR) value of the processed images.

3. RESULTS AND ANALYSIS

Before explaining the obtained results, the noise reduction process using the concept of Adaptive Fuzzy Filter is described first. The image to be processed is first input into the method, as shown in Figure 3.

Figure 3. Input Image

After the image is input, the process continues with converting the pixel values of the image into an array (Red, Green, Blue) as previously explained in Figure 3. Following this step, additional pixels are added to the edges. This aims to clean the edges of the processed image. Once the edge pixel addition is completed, the process continues with calculating the median value of the neighboring pixels obtained. The details of the calculation process are as follows: 0, 0, 0, 0, 10, 10, 255, 255. From the list of eight pixel values, the median value is calculated as (0 + 10) / 2 = 5. This value is then compared to the pixel value being tested. The difference between the values is calculated as 5 - 0 = 5. Therefore, the pixel is not classified as noise.

Another example obtained from the array can be seen in the matrix below:

209	60	174
148	248	102
129	164	62

From the set of values, the median value is determined as follows: 60, 62, 102, 129, 148, 164, 174, 209, with the median calculated as (129 + 148) / 2 = 138.5 ≈ 139. When compared to the tested value, 248 - 139 = 110, which exceeds the threshold of 30, it is classified as noise. Therefore, the process proceeds to the next step.

After obtaining the average value, the next step is to compute the average value of the fuzzy set. The type of fuzzy membership used to find the average value is the trapezoidal type, as shown in the following Figure 4:

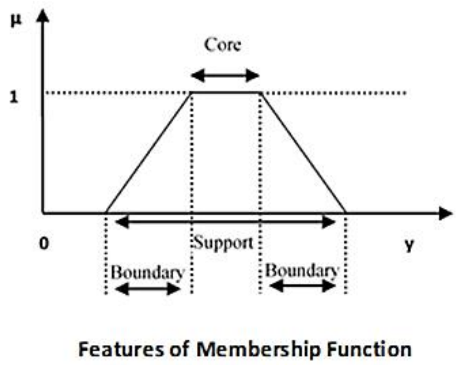

Figure 4. Membership Function Trapezoid [20]

Each value in the array undergoes a transformation according to the membership function used. The boundary value applied is 3, based on the research that has been conducted. After obtaining these values, the next step is the gray-level fuzzy set process. The membership function used for this process is the one shown in the following Figure 5.

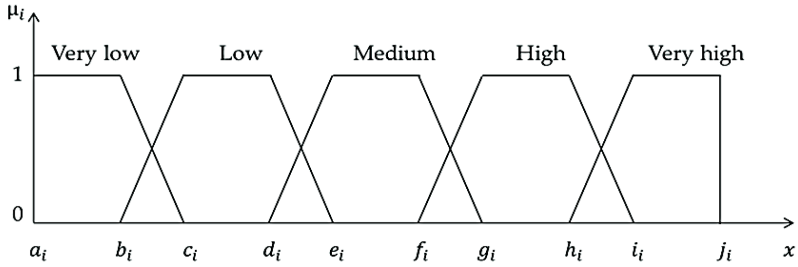

Figure 5. Membership Function for Gray Level Fuzzy Set [21]

From the array values obtained previously, the next step is to find the average value of the gray-level fuzzy set using the function shown in figure 7. After obtaining this value, the gray-level fuzzy set is compared with the previous mean fuzzy set. A comparison of the minimum values corresponding to the tested pixels is performed. This process will be carried out for all the pixels in the image. The result of the image enhancement process can be seen in the following Figure 6:

Figure 6. Result Image

Based on the test results, there were 7461 noise points in the initial image. After the process, the remaining noise was 1056 points. Thus, the denoising process successfully removed 6405 noise points or 85% of the initial noise. This proves that the denoising process was successful for the tested image.

3.1. Result

The process described previously was also applied to 689 images with a size of 640 x 640 pixels. Since the images tested are categorized as colored images, a multiplication process with a value of 3 (red, green, blue channel) was performed. As a result, the total number of pixels became 1,228,800 pixels. The initial amount of noise for each image processed can be seen in the following table 1.

Table 1. List of Images with Percent of Noise

Image	Noise	Percent Noise
1	47340	3.85%
2	21033	1.71%
3	50271	4.09%
4	52338	4.26%
5	44115	3.59%

After the process of checking each image related to the amount of noise in the image, it is continued to the noise removal process by applying the AFF method. The results of the cleaning process that has been carried out are as table 2.

Table 2. Summary of Image Denoising

Image	Noise	Percent Noise	Noise After Process	Percent Noise After Process
1	47340	3.85%	36690	2.99%
2	21033	1.71%	10641	0.87%
3	50271	4.09%	40092	3.26%
4	52338	4.26%	42237	3.44%
5	44115	3.59%	34230	2.79%

In Table 2, the results of the noise removal analysis for several sample images using the AFF method are presented. The results show a reduction in the amount of noise for each processed image. This can be seen in the first image, where the initial noise count of 47,340 pixels was reduced to 36,690 pixels or a decrease of about 22.5%. This percentage decrease is also evident for each image when compared to the previous process. The best result was achieved for image number 4, with a noise reduction of 3.44%.

3.2. Analysis

After processing all the images in the dataset used, the results obtained were an increase in the images obtained. The results of the increase in all images in the dataset can be seen in the following Table 3:

Table 3. Result of All Image Process

Status	Noise Change (%)	Total of Image
Succeed	96,23%	663
Failed	3,48%	24
Not Change	0,29%	2

From Table 3, the analysis results show that the noise removal process using the AFF method successfully reduced noise by 96.23% for the 689 images tested. After that, there were also failure cases with a 3.84% change in noise. This process was considered a failure because there was an increase in the amount of noise compared to the initial noise. Additionally, two images showed no change in noise at all. Based on these results, the success rate of noise removal was found to be 96.23%, meaning that the noise removal process was mostly successful.

3.2. Discussion

From the results of the research that has been done, there is a discussion section that discusses the results obtained in this study. The discussion that was carried out was that AFF has an advantage in terms of a success rate of 96.23%, which reflects the strength of the AFF method in handling existing noise. This result was obtained because the majority of the images used were included in the images that received the appropriate light, so the noise removal process was successful. However, there were also 3.48% of images that failed. This is because some of these images have low light intensity levels. Therefore, further analysis of the image is needed. The process in question is to increase the increase in light in the process. This further testing process can be focused on refining the parameters used or developing the AFF method applied. Seeing the high success rate, the AFF method has great potential for future applications, such as underwater debris detection.

4. CONCLUSION

From the results of the research that was conducted on 689 images from the dataset obtained, there is a decrease in the amount of noise, around 96,23% of the total noise obtained previously. This can certainly provide good results in terms of changes in noise that have been made. So, this method is worthy to be continued to the next process in the form of garbage detection or other processes. However, this method also experienced a failure rate of 3.48%, which necessitates additional processes such as readjusting the parameter values used, increasing the image resolution, and considering the type of noise applied. This way, the method can proceed to the next detection process.

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