Comparison of Filters used for Underwater Image Pre-Processing

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Abstract
Underwater image pre-processing is absolutely necessary due to the quality of images captured under water. Basically, under water images suffer from quality degradation due to transmission of limited range of light, low contrast and blurred image due to quality of light and diminishing color. When an underwater image is captured, pre-processing is necessarily done to correct and adjust the image for further study and processing. Different filtering techniques are available in the literature for pre-processing of under water images. The filters used normally improve the image quality, suppress the noise, preserves the edges in an image, enhance and smoothen the image. Therefore an attempt has been made to compare and evaluate the performance of three famous filters namely, homomorphic filter, anisotropic diffusion and wavelet denoising by average filter used for under water image pre-processing. Out of the three filters, wavelet denoising by average filter gives desirable results in terms of Mean Square Error and Peak Signal to Noise Ratio. However the elapsed time of the three filters is also studied to identify the suitable filters that process the image quickly by preserving the image quality.

Key words:
Image processing, denoising, color enhancement, homomorphic filters, SRAD filtering, wavelet denoising, Mean Square Error , Peak Signal to Noise Ratio and elapsed time

I. Introduction

Underwater instruments are used for remote sensing, because the earth is an aquatic planet and as much as 80% of its surface is covered by water. Moreover, there is a strong interest in knowing what lies in underwater. The optical sensors are used in underwater instruments to capture acoustic signal and the signals are converted into images. The images are disturbed with, the transmission of limited range of light, disturbance of lightening, low contrast and blurring of image, color diminishing during capturing. The large disturbances change the image quality and they show large temporal and spatial variations. Therefore, the image must be pre-processed before operations like segmentation or feature detection, which are the important processes in image processing. To denoise an image without affecting the image quality and edges in an image, edge preserving filters are used. The filtering methods perform several successive independent processing steps which respectively correct non-uniform illumination, suppress noise, enhance contrast and adjust colors.

Need for Pre-Processing

The pre-processing is required for underwater images due to poor captured image quality. The following reasons justify why the pre-processing is necessary for underwater images.
i. Underwater image degradation is due to specific transmission properties of light in the water like absorption and scattering.
ii. Specificity of environment like light changing, water turbidness, and blue hue is more or less predominant when vehicles move.
iii. Specificity of video captures like unknown rigid scene and unknown color or low light sensitivity due to Marine snow.
Therefore an attempt has been made to identify the suitable filter for pre processing the underwater images.
This work is organized as follows. Section.2 will describe the algorithm used for underwater pre-processing, Section.3 discusses different filtering methods, and Section.4 presents the results. Finally Section.5gives the conclusion.

2. The algorithm used for underwater pre-processing

Basically image processing steps are as follows
- a.) Image acquison
- b.) Pre-processing
- c.) Discretization/Digitization
- d.) Image Enhancement and Restoration
- e.) Image segmentation
- f.) Feature extraction
- g.) Image representation
- h.) Image interpretation

Pre-Processing is an important step in image processing technique. The algorithm used for underwater pre-processing corrects the underwater perturbation sequentially.

Manuscript received January 5, 2010
Manuscript revised January 20, 2010

Existing pre processing steps are

- Removing potential moirés effect.
- Resizing and extending symmetrically the image.
- Converting color space from RGB to YCbCr.
- Filtering
- Adjusting image intensity.
- Converting back to RGB and reverse symmetric extension.
- Equalizing color means.

Some of the famous edges preserving filtering techniques used for underwater pre-processing are
1. Homomorphic filtering
2. Anisotropic diffusion
3. Wavelet denoising by average filter

The three famous filtering techniques are taken for study and their performance is compared. The performance of the three filters is compared by the Mean Square Error (MSE) value which must be low for an image and Peak Signal to Noise (PSNR) Ratio which must be high in an image. These edge preserving filters are experimented with under water images

3. Methods of filtering

The three edge preserving filter methods taken for study are
1. Homomorphic filter
2. Anisotropic filtering
3. Wavelet denoising by average filter

3.1. Homomorphic filtering

The homomorphic filtering is used to correct non-uniform illumination to enhance contrast in the image. It is a frequency filtering method. Compared to other filtering techniques, it corrects non-uniform lighting and sharpens the image.
In the Illumination-reflectance model, where image is defined as a intensity illumination and the reflectance function as follows:

$$F(x,y)=i(x,y)*r(x,y) \text{ -------------(Eq.1)}$$

Where F(x,y) is the image sensed by instrument, i(x,y) the illumination and r(x,y) the reflectance function. On contrary, reflectance is associated with high frequency components. By multiplying these components a high-pass filter can be suppress the low frequencies, i.e the non uniform illumination in the image can suppressed. The algorithm is described as follows:

1.) The illumination and reflectance components by taking the logarithm of the image give (Eq.2).

$$G(x, y) = \ln (f(x, y)) = \ln (i(x, y).r(x, y) = \ln (i(x, y))+ \ln (r(x, y)) \text{ -------(Eq.2)}$$

2.) Computation of the Fourier transform of the log-image gives (Eq.3)

$$G (wx, wy) = I (wx, wy) + R(wx,wy) \text{ -----------(Eq.3)}$$

3.) High-pass filtering. The filter applied to the Fourier transform decreases the contribution of low frequencies (illumination) and also amplifies the contribution of mid and high frequencies (reflectance), sharpening the edges of the objects in the image given in (Eq.5)

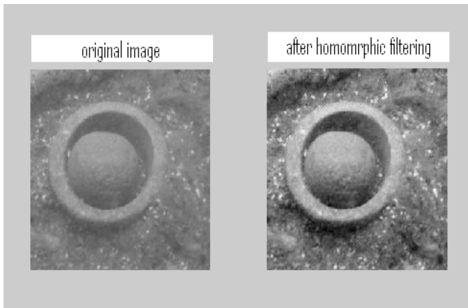
$$S(wx,wy)=H(wx,wy).I(wx,wy)+H(wx,wy)*R(wx,wy) \text{ --Eq.4)}$$

With,

$$H (wx, wy) = (rH - rL). (1 - \exp (- (w2x+ w2y2/2w))) + rL$$

where $rH = 2.5$ and $rL = 0.5$ are the maximum and minimum coefficients homomorphic filtering factors these two are selected empirically.

4.) Computation of the inverse Fourier transforms is taken to reconstruct the original image. The resultant filtered image is obtained.



a) Original b) Filtered image
Fig –1Application of homomorphic filtering original

Figure 1 gives the original image and the resultant image after applying homomorphic filter.

3.2 Anisotropic filtering

Anisotropic filtering simplifies image features to improve image segmentation. This filter smoothes the image in homogeneous area but preserves edges and enhances them. It is used to smooth textures and reduce artifacts by deleting small edges amplified by homomorphic filtering.

The filter used here is a speckle reduction using anisotropic filtering method (SRAD) by Yongjian Yu [1]The Probality Density Equation PDE-based speckle removal approach [1] allows the generation of an image scale space (a set of filtered images that vary from fine to coarse) without bias due to filter window size and shape. Speckle Reduction by Anisotropic Diffusion (SRAD) not only preserves edges but also enhances edges by inhibiting diffusion across edges and allowing diffusion on either side of the edge. SRAD is adaptive and does not utilize hard thresholds to alter performance in homogeneous regions or in regions near edges as well as small features. The new diffusion technique is based on the same minimum mean square error (MMSE) approach to filtering as the Lee [8] (Kuan) and Frost filters. In fact, it can be shown that the SRAD can be related directly to the Lee and Frost window-based filters. So, SRAD is the edge sensitive extension of conventional adaptive speckle filter. Perona and Malik[1] anisotropic diffusion is the edge sensitive extension of the average filter. Anisotropic diffusion can be applied to radar and medical ultrasound images. Spatially correlated multiplicative noise is present in such images.
The above filter is used for reducing multiplicative noise. The filtered image I is calculated as

$$I = SRAD(A,T)$$

The function should be written in above format where I denote the output of the filter, A is the input images, T is the threshold value. The quality of an image depends upon the threshold value and noise which is added to an image. The results are shown in the following figure 2


a) Original image


b) noisy image

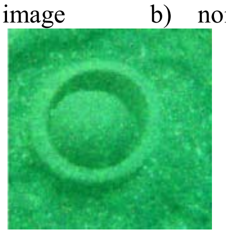

c) After filtering

Fig-2 Original image and image after applying SRAD filter

3.3 Wavelet denoising by average filter

Wavelet filter is also used to suppress the noise i.e the Gaussian noise are naturally present in the camera images and other type of instrument images.
While transferring the images Gaussian noise can be added. This wavelet denoising gives very good results compared to other denoising methods because, unlike other methods, it does not assume that the coefficients are independent. Indeed wavelet coefficients in natural images have significant dependencies. Moreover the computation time is very short. The algorithm can be described as follows:

1.) Average filter is used for wavelet denoising method
2.) Some of the resulting wavelet coefficients correspond to details in the data set (high frequency sub-bands). If the details are small, they might be omitted without substantially affecting the main features of the data set.
3.) The idea of thresholding is to set all high frequency sub-band coefficients to zero that are less than a particular threshold.
4.) Next these coefficients are used in an inverse wavelet transformation to reconstruct the data set with average filter.

Two parameters used here are the noise signal and the threshold point. A sample noise signal is shown below, whose dimension is 256. First forward DWT is computed over 4 scales (J=4). Then a denoising method called soft thresholding is applied to wavelet coefficients through all scales and subbands. After soft thresholding, inverse wavelets transform is applied.

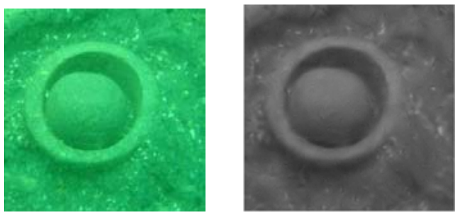

a) Original image b) filtered image

Fig - 3 Original image and image after applying wavelet filter

Fig -3 shows the images before and after applying of wavelet filter.

4. Results and Discussion

An attempt is made to evaluate the performance of the three edge preserving filters used for underwater images. Experimental setup, the images are processed using the tool Matlab.

Comparisons of different filters are done by calculating the Mean Square Error (MSE) & Peak Signal to Noise Ratio (PSNR). The values are calculated by the following expression.

$$PSNR = 20 \log_{10} \frac{256}{sqrt(MSE)}$$

Where MSE represents the mean square error of the estimation. The size of the image must be 256X256 pixels. For *homographic filtering* the underwater image is given as input and after filtering the performance is calculated. The MSE value is1.6463 and the PSNR value is 6.512 for Gaussian noise. For speckle reduction *anisotropic filtering* the same performance measures are calculated. The MSE value is 479.38 & PSNR value is 23.7129 for speckle noise. Using *wavelet denoising* the same image is tested for performance. The MSE & PSNR values are 193.125 & 27.168 respectively. The best filter must give its performance high in PSNR value and low MSE value. The results obtained out of the three algorithms for different noise applications are shown in the following table 1.

Table 1 PSNR & MSE value for linear filtering technique for underwater images

Method	PSNR value	MSE value	Noise type
Homomomorphic filter	7.477265	1.35E+04	Speckle noise
	6.51281	1.64E+04	Gaussian noise
	7.141598	1.41E+04	Salt & pepper noise
SRAD anisotropic diffusion filter	23.7148	479.3894	Speckle noise
	19.63416	2.02E+03	Gaussian noise
	18.27324	1.47E+03	Salt & pepper noise
Wavelet by average filter	27.16868	193.1325	Speckle noise
	28.99486	1.86E+02	Gaussian noise
	31.69203	48.73131	Salt & pepper noise

From table 1, it can be observed that wavelet denoising by average filter gives better performance.

The three edge preserving algorithms are also compared for performance depending on the number of iterations taken to converge. In the case of anisotropic diffusion, as iteration continues, the noise level in image decreases (till it reaches the convergence point), but in a slow manner. However in case of homomorphic filtering, it just cuts the frequencies above the threshold in a single step. An iterative homomorphic filtering will not incur any change in coefficients PSNR & MSE. Considering the speckle reduction by anisotropic diffusion, the threshold for anisotropic diffusion is recalculated each time after every experiment as a result of two successive noise reduction step, it approaches the convergence point much faster than homomorphism filtering. Wavelet denoising is taken which gives less number of iteration to converge or to reach the optimum point. The filter used here is an average filter or dual filter. The comparison of three filters with different noises are shown in the fig 4a-fig 4f

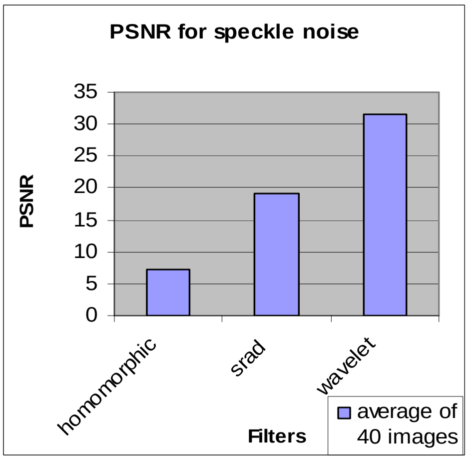


Fig 4a PSNR for speckle noise

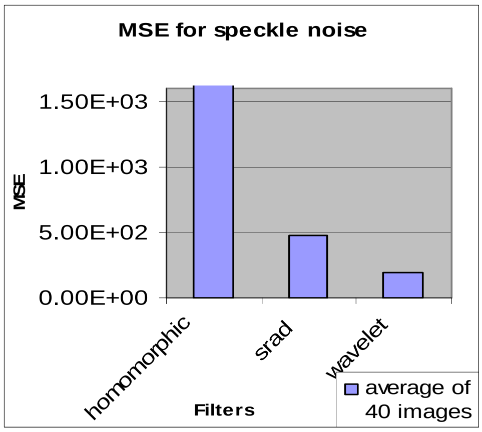


Fig 4b MSE for speckle noise

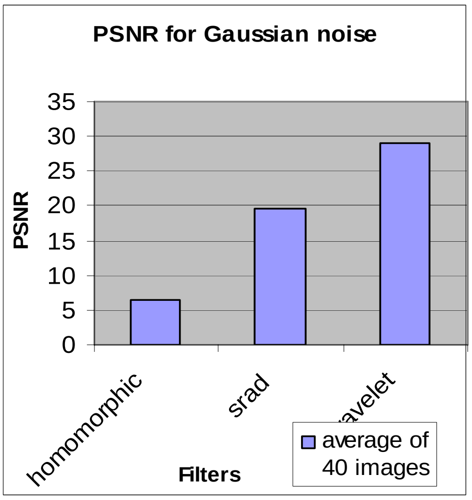


Fig -4c PSNR for Gaussian noise

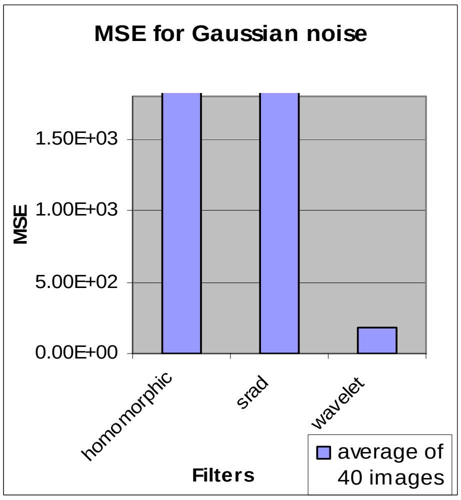


Fig -4d PSNR for Gaussian noise

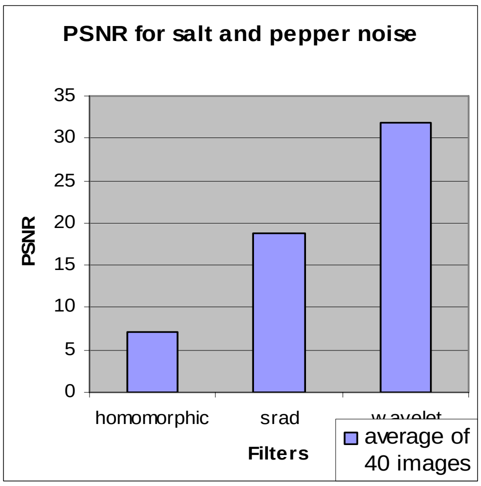


Fig -4e PSNR for salt and pepper noise

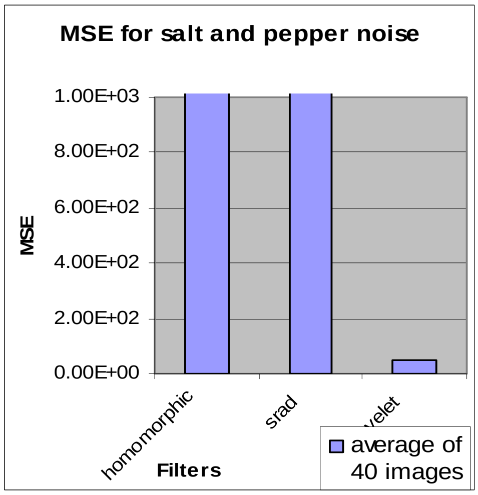


Fig -4f PSNR for salt and pepper noise

Fig-4 comparison of three filters for PSNR and MSE

Table 2 Elapsed time for different noise in sec.

Method	Speckle noise	Gaussian noise	Salt and pepper noise
Homomomorphic filter	2.69835	2.441375	2.45015
SRAD anisotropic diffusion filter	1.575675	1.558825	1.555075
Wavelet by average filter	2.879375	2.8471	2.8955

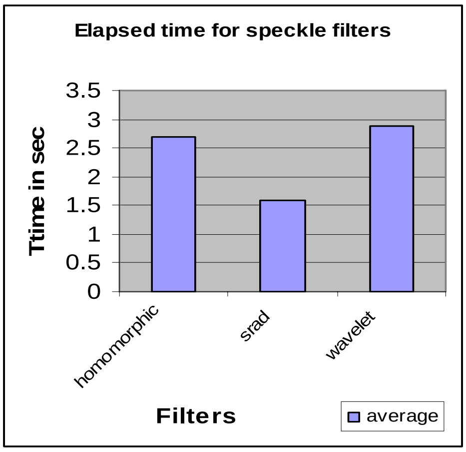


Fig -5a Elapsed time for speckle filters

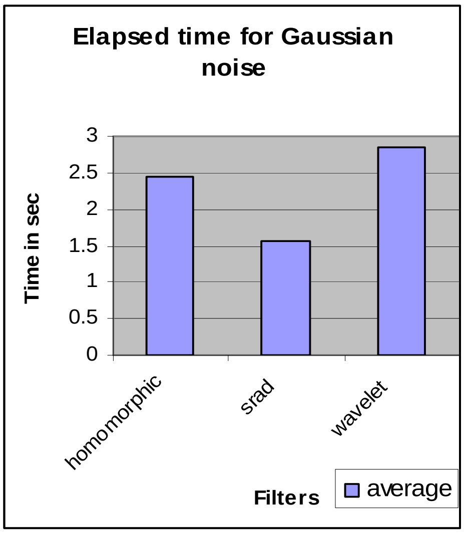


Fig -5b Elapsed time for Gaussian filters

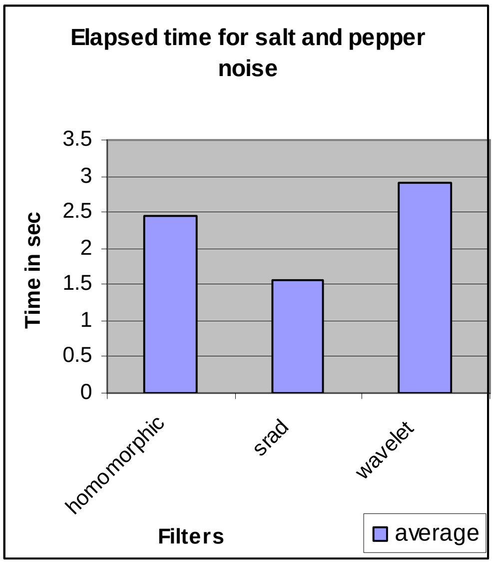


Fig 5c Elapsed time for salt and pepper noise
Fig -5 Elapsed time for different noise and filters

After careful application of the filters it is observed that anisotropic filtering method gives elapsed time at 1.575675 seconds when compare to other two filters as shown in table 2

Table 2 shows the elapsed time for different noise and filters and fig 5a – 5c shows the comparison chart. It is clearly notice that speckle reduction by anisotropic gives less no of seconds to process the filtering operation though wavelet is better in compared with PSNR and MSE value

Based on PSNR and MSE also it can be seen that the wavelet denoising method which gives high PSNR ratio and less MSE error while compare to other two method or filter. It can be seen that the wavelet denoising method which preserves images than the other method. The wavelet method is fast and gives better but speckle reduction filter which gives less no of seconds and preserve the edges.

5. Conclusion

The three edge preserving filters taken for study are homomorphic filter, anisotropic diffusion filter, wavelet denoising by average filter. Underwater image suffers from transmission properties of water, the transmission of limited range of light, disturbance of lightening, low contrast and blurring of image, diminishing color during capturing of image. Recently pre-processing is done only for correcting the non-uniform lights or color and intensity adjustment. The performances of the filters are compared and analyze by the PSNR and MSE vales for underwater images. The speckle reduction by anisotropic filter improves the image quality, suppressed the noise, preserves the edges in an image, enhance and smoothen the image. The mean square error value which must be low for an image and peak signal to noise ratio which must be high in an image. Though the wavelet filter shows high and low for PSNR and MSE. Moreover the elapsed time of the three filter is also studied to identify the suitable filters that process the operation quickly by preserving the image quality. The SRAD filter perform its operation in less number of seconds when compare to other filters.

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Annexure –I
Underwater Images

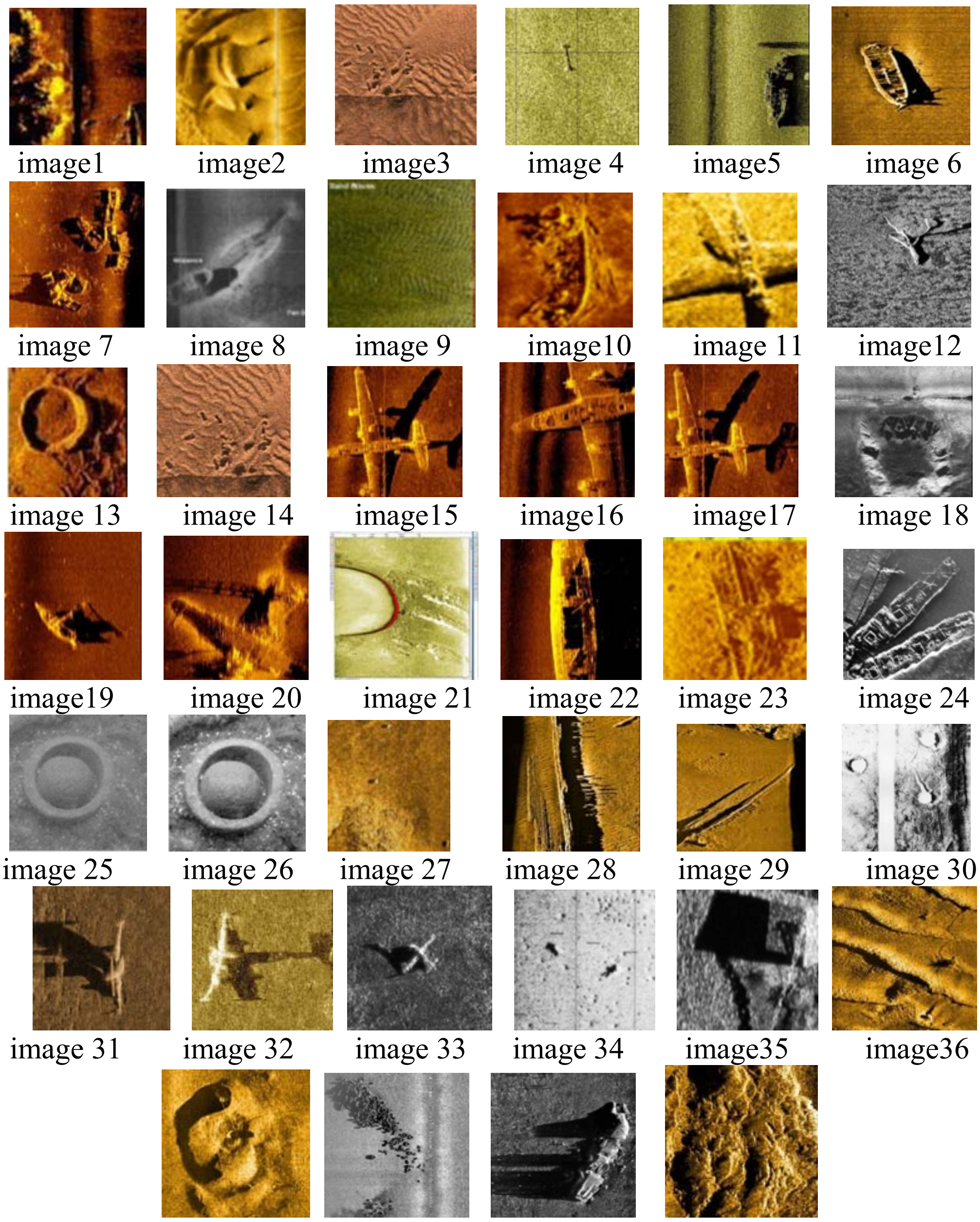

image1 image2 image3 image 4 image5 image 6
image 7 image 8 image 9 image10 image 11 image12
image 13 image 14 image15 image16 image17 image 18
image19 image 20 image 21 image 22 image 23 image 24
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