Image Fusion for Underwater images using Curvelet Transform

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Abstract— In the real world noise is often presented in the signal. Noise in the image is inserted during the process of image acquisition or the transmission process of image. Many parameters or factors like light levels and sensor temperature are there which are responsible the for the amount of noise present in the image. Acquiring clear images in underwater environments is an important issue in ocean engineering. Generally underwater images are affected by severe blur and haze caused by light that is reflected from surface and scattered by water particles and color change due to varying degrees of light attenuation for different wavelengths. So there is contrast losses and color deviation in images. In general underwater images are polluted by noises like Gaussian, and Speckle noise. So it is necessary that to denoise the image before further process. There are different filters to denoise the image like Gaussian Filter,Mean Filter, Weiner Filter and Curvelet Transform can be used. After that Fusion is performed of best filtering method and curvelet transform using Simple Average and Average using CVT. Performance can be calculated on the basis of parameter like PSNR (peak signal-to-noise ratio)& MSE (mean square error),MAE (Mean Absolute Error), Correlation. MATLAB is used for implementation of coding and to calculate the output parameter.

Key words: Underwater image, Gaussian Filter, Mean Filter, Weiner Filter, Curvelet Transform, Average Method, Average using CVT, PSNR, MSE, MAE, Correlation

I. INTRODUCTION

An image is a two dimensional function f(x, y), where x and y are plane coordinates, and the amplitude of f at any pair of coordinates (x, y) is called gray level or intensity of the image at that point. There are two types of images i.e. grayscale image and RGB image. Grayscale image has one channel and RGB image has three channels i.e. red, green and blue. Image noise is unwanted fluctuations[1]. Generally underwater images are affected by severe blur with low contradiction and signal-to-noise ratio (SNR) due to the suction and dispersion when light breeds in the water. However processing these images is an essential task for different applications especially in navy includes self underwater conveyances for undersea operations, disclosure of undersea mines and search and salvage. In order to capture images in underwater world, optical sensors required for underwater apparatus are used in terms of seizing phonic signals and transformed them into images. In fact the primary defect of optical cameras is comparatively restricted in terms of visibility that can be reached about twenty meters in pure water and less than a few meters in inshore water. While capturing such kind of images by sensors, they are endured by quality demotion due to optical scope, light quality and decreasing color[2]. Therefore the corrupted image needs to be involved in pre-processing before further actions comes into the picture like Denoising. The goal of image denoising methods is to recover the original image form a noisy measurement[3],

$$\upsilon(i) = u(i) + n(i) \qquad (1)$$

Where $\upsilon(i)$ is the observed value, $u(i)$ is the "true" value and $n(i)$ is noise perturbation at pixel ***i.*** In general underwater images are polluted by basic noises like Gaussian and Speckle noise. Noise reduction is used to remove the noise without losing much detail contained in an image. There are various noise reduction techniques which are used for removing the noise. Most of the standard algorithms use to de-noise the noisy image and perform the individual filtering process. The result is that it generally reduces the noise level. But the image is either blurred or over smoothed due to losses like edges or lines[1].This paper describes the development work on the different technique of image denoising. There is performance comparison of Gaussian Filter and other is Curvelet transform which gives better result with edges and curves and much more efficiently than other traditional transforms.

The organization of this paper is as follows: Section II gives problems in underwater image. In Section III Types of Image Noise are explained. Section IV presents an overview of Gaussian Filter, Section V presents an overview of Mean Filter, Section VI presents an overview of Weiner Filter. Section VII represents about Curvelet Transform. Section VIII shows Experimental results. Finally conclusion is given in section IX.

II. PROBLEMS IN UNDERWATER IMAGES

Generally underwater images are affected by severe blur and haze caused by light that is reflected from surface and scattered by water particles and color change due to varying degrees of light attenuation for different wavelengths. So there is contrast losses and color deviation in images[4]. In general underwater images are polluted by noises like Gaussian, and Speckle noise. So it is necessary that to denoise this image before further process. Image denoising is process of remove the noise from the image.

III. IMAGE NOISE

Noise in images is caused by the random fluctuations in brightness or color information. Noise represents unwanted information which degrades image quality. Digital image noise may occur due to various sources. During acquisition process, digital images convert optical signals into electrical one and then to digital signals and are one process by which the noise is introduced in digital images. Due to natural phenomena at conversion process each stage experiences a fluctuation that adds a random value to the intensity of a pixel in a resulting image[5]. Noise may be classified as substitutive noise (impulsive noise: e.g., salt and pepper noise, random valued impulse noise, etc.), additive noise (e.g., additive white Gaussian noise) and multiplicative noise (e.g. speckle noise)[6]. However, in this paper the investigation has been done in Gaussian noise and speckle noise. In general, the goal of any noise removal scheme is to suppress noise as well as to preserve details and edges of image as much as possible.

A. *Gaussian Noise:*

Gaussian noise is statistical in nature, Its probability density function equal to that of normal distribution, which is otherwise called as Gaussian distribution. In this type of noise, values of that the noise are being Gaussian-Distributed. A special case of Gaussian noise is white Gaussian noise, in which the values always are statistically independent. For application purpose, Gaussian noise is also used as additive white noise to produce additive white Gaussian noise [5]. Gaussian noise is commonly defined as the noise with a Gaussian amplitude distribution, which states that nothing the correlation of the noise in time or the spectral density of noise. Gaussian noise is otherwise said as white noise which describes the correlation of noise. Gaussian noise is sometimes equated to be of white Gaussian noise, but it may not necessary the case.

B. *Spekle Noise:*

Speckle noise is a type of granular noise that commonly exists in and causes degradation in the image quality. Speckle noise tends to damage the image being acquired from the active radar as well as synthetic aperture radar (SAR) images. Due to random fluctuations in the return signal from an object in conventional radar that is not big as single image-processing element. Speckle noise occurs. Speckle noise increases the mean grey level of a local area. Speckle noise is more serious issue, causing difficulties for image interpretation in SAR images. It is mainly due to coherent processing of backscattered signals from multiple distributed targets[5].

IV. GAUSSIAN FILTER

Gaussian Filters are designed to give no overshoot to a step function input while minimizing the rise and fall time. This behavior of Gaussian Filter causes minimum group delay. Mathematically, a Gaussian filter modifies the input signal by convolving with a Gaussian function. The Gaussian filter is usually used as a smoother. The output of the Gaussian filter at the moment is the mean of the input values[1]. Image is smoothed by Gaussian kernel,

$$I_1(x,y) = A(x,y) * \exp\left(\frac{-x^2+y^2}{2\sigma^2}\right) \Big/ 2\pi\sigma^2 \quad (2)$$

The resulted image is labeled as $I_1(x,y)$ smoothed by Gaussian kernel and $A(x,y)$ is the image corrupted by noise.

Some properties of Gaussian Filter are

1) The weights give higher significance to pixels near the edge (Reduces edge blurring).
2) They are linear low pass filter.
3) Computationally efficient (large filter are implemented using small 1D filters).
4) Rotationally symmetric (perform the same in all directions).
5) The degree of smoothing is controlled by σ (large σ for more intensive smoothing).

V. MEAN FILTER

Mean Filter or average Filter is Windowed Filter of linear class, that's smoothes signal (image). The Filter works as low pass one. The basic idea behind the Filter is for any element of the signal (image) take an average across its neighbourhood [1]. To understand how that is made in practice, let us start with window idea, thus Mean Filter smooths image data, thus eliminating noise.This Filter performs spatial filtering on each individual pixel in an image using the grey level values in a square or rectangular window surrounding each pixel.

For example: a1 a2 a3
a4 a5 a6 3×3 filter window
a7 a8 a9

The average filter computes the sum of all pixels in the filter window and then divides the sum by the number of pixels in the filter window:

Filtered pixel = (a1+a2+a3+a4+a5+a6+a7+a8+a9)/9

VI. WEINER FILTER

It is used to reduse noise present in a signal by comparison with estimation of desired noiseless signal.The design of the Weiner Filter is of different approach.The weiner filter is a linear estimation of the original image. The approach is based on a stochastic framework [1].Weiner filter is characterized by the following:

1) Assumption: signal and (additive) noise are stationary linear with known spectral characteristics
2) Requirement: The filter must be physically causal system.
3) Performance criterion: minimum MSE

VII. CURVELET TRANSFORM

Curvelet is one of the new multi-scale geometric analyses with powerful directional nature on which elements are highly anisotropic at fine scales. It effectively supports the geometric shapes of the objects based on the parabolic scaling basis $width \approx length^2$ [7]. It aims to provide a new phenomenon of research interest for the development of different applications. A signal involved in curvelet transform (CT) is decomposed as curvelet subbands using a filter bank of wavelet filters with the assistance of ridgelet transform[7]. Both ridgelets and bandpass filtering techniques works together to segregate various scale curvelets follows the scaling law: $width \approx length^2$. The law gives a curvature holding a superposition of miscellaneous length and width behaviors. In addition, curvelet befall at all scales, positions and orientations. According to the nature of CT, a given signal is processed into four stages includes subband coding, smooth partitioning, renormalization and ridgelet analysis. For removing noise, CT with a simple threshold is more effective than wavelet transform.

Each scale in a multi-scale transformation gives different knowledge about the signal in terms of subbands.

In CT, a series of low-pass and band-pass filters can be used to acquire different frequencies of subbands in each scale and the mathematical model is constructed as:

$$f = p_0(p_0 f) + \sum \Delta_s(\Delta_s f) \quad (3)$$

Where f is an input signal which is decomposed as a low and high frequency subbands by a low-pass filter P_0 along with a set of high-pass filters Δ_1, Δ_2 etc.

To improve the quality of the signals, wavelet transform is used in subband coding in order to satisfy energy preservation and recursive construction defined by the following functions and is defined as:

$$\Psi_{2s}(s) = 2^{4s}\Psi(2^{2s}x) \quad (4)$$

$$p_0 f = \phi_0 \times f \qquad \Delta_s f = \Psi_{2s} \times f \quad (5)$$

Here the wavelet can be utilized in obtaining the approximations of sub-bands through multiresolution wavelet decomposition. Ultimately the process of convolution can be done to decompose the input signal f into $S_{0,} D_{1,} D_{2,} D_3$.

In eqn. (3), $p_0 f$ is procured by the wavelet coefficients decomposed as $S_{0,} D_{1,} D_{2,} D_3$ coefficients and f Δs is received by D_{2s} and D_{2s+1}. As the ultimate goal of CT is to present edges (arcs) [7] without losing significant details, it introduces a concept called dyadic square which can be computed as:

$$Q_{s,k_1,k_2} = \left[\frac{k_1}{2}, \frac{k_1+1}{2}\right] \times \left[\frac{k_1}{2^s}, \frac{k_2+1}{2^s}\right] \in Q_s \quad (6)$$

Imagine that all the dyadic squares are located in the grid.So Q_s furnish every dyadic square from the grid. Every square in the process of smoothing is involved by applying a window in size of $2^s \times 2^{-2}$.

$$h_Q = W_{Q\bullet}\Delta_s f \quad (7)$$

The procedure of each square is computed by multiplying $\Delta_s f$ and W_Q which proposes the effect of smoothing.

The grids consists of group of pixel energy distributedamong every sampling windows

$$\sum_{k_1,k_2} W^2(x_1 - k_1, x_2 - k_2) \equiv 1 \quad (8)$$

The pixel energy distributed is rebuilt by

$$\sum_{Q\in Q} W_Q h_Q = \sum_{Q\in Q_s} W_Q^2 .h = h \quad (9)$$

The connection of parserval relation is fixed by

$$\sum_{Q\in Q} \|h_Q\|_2^2 = \sum_{Q\in Q} W_Q^2 h^2 = \int \sum_{Q\in Q} W_Q^2 h^2 = \int h^2 = \int \|h\|_2^2 \quad (10)$$

In the next step, every dyadic square acquired from the previous step must be renormalized to the unit square [0,1] x
[0,1] with the aid of the equation

$$g_Q = T_Q^{-1} h_Q \quad (11)$$

Where T_Q introduces the normalization operator and Q tothe dyadic square which is formulated as:

$$(T_Q f)(x_1, x_2) = 2^s f(2^s x_1 - k_1, 2^s x_2 - k_2) \quad (12)$$

After normalizing the square, it can have the details of line, curve and angle which are named as ridges. Those ridges can be decoded in the radon transform. In radon domain, usually ridges are built up as a wavelet.

The mathematical representation of radon transform is defined as:

$$Rf(\theta, t) = \int f(x_1, x_2)\delta(x_1\cos\theta + x_2\sin\theta - t)dxdy \quad (13)$$

Originally ridgelet transform is one of the best outcomes of one dimensional wavelet transform. So it has the main features of wavelets and helps to find out the angle and location of curves. The formula given below describes the ridgelet element in the frequency domain.

$$\hat{\rho}_\lambda(\xi) = \frac{1}{2}|\xi|^{-\frac{1}{2}}(\hat{\psi}_{j,k}(|\xi|).\omega_{i,l}(\theta) + \hat{\psi}_{j,k}(-|\xi|).\omega_{i,j}(\theta+\pi)) \quad (14)$$

From the eqn. (12), $\omega_{i,j}$ presents periodic wavelets in the interval of $[-\pi, \pi]$. Where, i provides the angular scale, $\Psi_{j,k}$ produces a set of Meyer wavelets. Finally the scale and location of ridgelet is given by j and k.

In curvelet domain, generally, noise removal can be done in two methods using i). hard threshoding, and, ii). Cycle spinning process. In this work, hard thresholding method for removing noise in the corrupted image has been proposed in curvelet domain. The basic principle of hard thresholding used in curvelet transform for denoising a signal is similar to wavelet transform. In this approach, the threshold value is determined by variances of noise image and the curvelet coefficient.

VIII. EXPERIMENTAL RESULTS AND ANALYSIS

In this section, the qualitative denoising ability of the method is tested with two important parameters namely mean squared error (MSE) and peak signal-to-noise ratio (PSNR). PSNR is mainly used to measure the quality of denoising in the reconstruction of noisy images. Generally it is shown in terms of logarithmic decibel scale due to high dynamic range of the images and is derived as:

$$PSNR = 20 \times \log\left[\frac{Max_I^2}{MSE}\right] \quad (15)$$

Where Max represents maximum pixel value of the image, obviously it is 255 when the image is gray scale. And MSE expresses the variance between denoisy and original images which is computed as:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{m-1}\|x(i,j) - y(i,f)\|^2 \quad (16)$$

Where x and y indicates reconstructed and original images
respectively.

Cross-correlation is a measure of similarity of two series as a function of the lag of one relative to the other. This is also known as a sliding dot product or sliding inner-product. It is commonly used for searching a long signal for a shorter, known feature.

Mean absolute error (MAE) is a quantity used to measure how close forecasts or predictions are to the eventual outcomes. The mean absolute error is given by

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|f_i - y_i\right| = \frac{1}{n}\sum_{i=1}^{n}\left|e_i\right| \qquad (17)$$

As the name suggests, the mean absolute error is an average of the absolute errors $|e_i| = |f_i - y_i|$. Where f_i is the prediction and y_i the true value.

This is a methodology:

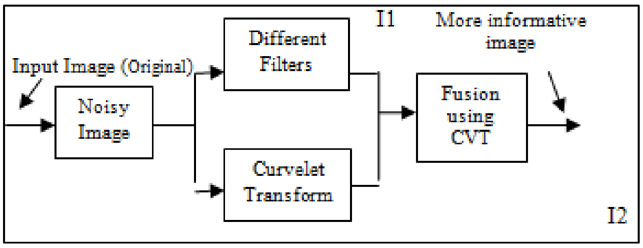

Fig. 1: Image Fusion of Output of Different Filters And Curvelet Transform using Curvelet Transform

Fig. 2: Dolphin Image Corrupted By Gaussian Noise And Denoisy Image By Gaussian Filter, Mean Filter, Weiner Filter And Curvelet Transform. Left To Right: Original Image,Noisy Image, Denoised By Filters W.R.T Gaussian, Mean, Weiner Filters, And Denoised By Curvelet Transform.

Fig. 3: Dolphin Image Corrupted By Speckle Noise And Denoisy Image By Gaussian Filter, Mean Filter, Weiner Filter And Curvelet Transform. Left To Right: Original Image,Noisy Image, Denoised By Filters W.R.T Gaussian, Mean, Weiner Filters, And Denoised By Curvelet Transform.

Method	Gaussian Noise							
	I/P vs. Noisy				*I/P vs. O/P*			
	MSE	*PSNR*	*MAE*	*CORR.*	*MSE*	*PSNR*	*MAE*	*CORR.*
Gaussian Filter	79.71	67.04	0.61	0.86	42.71	73.22	0.54	0.95
Mean Filter	79.71	67.04	0.61	0.86	32.15	76.18	0.53	0.97
Weiner Filter	79.71	67.04	0.61	0.86	28.90	77.36	0.52	0.97
CVT	79.71	67.04	0.61	0.86	22.44	79.71	0.52	0.98

Table 1: Performance Comparison of Filters for Gaussian Noise

Method	Speckle Noise							
	I/P vs. Noisy				*I/P vs. O/P*			
	MSE	*PSNR*	*MAE*	*CORR.*	*MSE*	*PSNR*	*MAE*	*CORR.*
Gaussian Filter	72.76	67.95	0.52	0.89	49.12	71.88	0.52	0.94
Mean Filter	72.76	67.95	0.52	0.89	37.55	74.56	0.51	0.96
Weiner Filter	72.76	67.95	0.52	0.89	37.33	74.62	0.50	0.97
CVT	72.76	67.95	0.52	0.89	30.06	76.79	0.50	0.98

Table 2: Performance Comparison of Filters for Speckle Noise

According to above table we can conclude that Weiner Fiter gives better performance than Gaussian Filter and Mean Filter. So here we have replace Weiner Filter than another Filters in below figure and check the results.

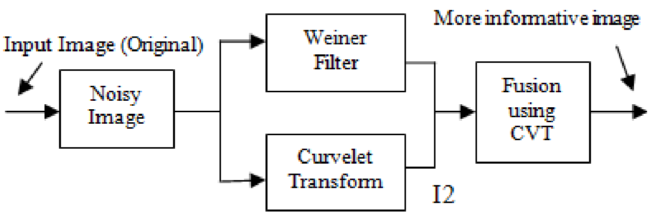

Fig. 4: Image Fusion of output of Weiner Filter and curvelet transform using curvelet transform

Fig.5: Image Fusion Of Denoised Dolphin Image For Gaussian Noise Which Are The Output Of Weiner Filter And Curvelet Transform Using Simple Average And Transform Domain Average Fusion Using Curvelet Transform. Left To Right: Original Image,Noisy Image, Output Of Weiner Filters, And Output Of Curvelet Transform, Output Of Simple Average Fusion, Output Of Average Using CVT.

Fig.6: Image Fusion Of Denoised Dolphin Image For Speckle Noise Which Are The Output Of Weiner Filter And Curvelet Transform Using Simple Average And Transform Domain Average Fusion Using Curvelet Transform. Left To Right: Original Image,Noisy Image, Denoised By Weiner Filters, And Denoised By Curvelet Transform, Output Of Simple Average Fusion, Output Of Average Using CVT.

Methods	Gaussian Noise							
	I/P vs. Noisy				I/P vs. O/P			
	MSE	PSNR	MAE	CORR.	MSE	PSNR	MAE	CORR.
Simple Avrg.	80.07	66.99	0.61	0.86	92.08	65.59	0.52	0.97
Avrg. Using CVT	80.07	66.99	0.61	0.86	22.86	79.52	0.47	1.13

Table 3: Performance Comparison of Fusion for Gaussian Noise

Methods	Speckle Noise							
	I/P vs. Noisy				I/P vs. O/P			
	MSE	PSNR	MAE	CORR.	MSE	PSNR	MAE	CORR.
Simple Avrg.	72.56	67.98	0.52	0.89	92.03	65.60	0.50	0.98
Avrg. Using CVT	72.56	67.98	0.52	0.89	30.74	76.56	0.44	1.14

Table 4: Performance Comparison of Fusion for Speckle Noise

IX. Conclusion

Here, In this research work the performance parameter like PSNR, MSE, MAE and Correlation of Gaussian Filter, Mean Filter,Weiner Filter and Curvelet Transform is measured and we can conclude that weiner Filter gives better performance than another Filters and make image fusion using output of Weiner Filter and Curvelet Transform using different methods like Simple Average and Average using CVT which gives more informative image than denoised image. Average using CVT method gives better performance than Simple Average method.

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