Improving Accuracy of Inertial Measurement Unit using Discrete Wavelet Transform

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Abstract

In this paper, using discrete wavelet transform in the way of noise removal. wavelet analysis has been used to denoise a digital image corrupted by noise in the acquisition step. Previous studies use Low-pass filter or moving average filter for removing noise. But these filters are corresponded unsuitably for the rapidly changing data. This correspondence cause distortion of the original signal and cause another error for removing noise. In order to compensate for these disadvantages, discrete wavelet transform is applied.

Keywords: Discrete Wavelet Transform, Inertial Measurement Unit, Thresholding, Noise Removal .

1. Introduction

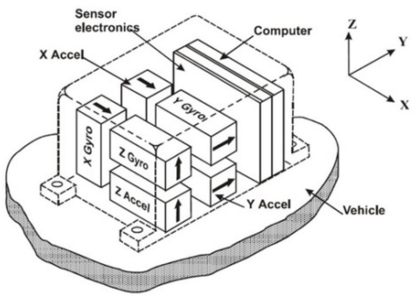

Fig. 1 The structure of Inertial Measurement Unit

Inertial measurement unit is a single of Integrated unit that consist of the accelerometer which can measure the movement of inertia and the gyroscopes which can measure the rotation of inertia, the earth magnetic which can measure the azimuthal.

In order to measure the free movement in three-dimensional space, this unit has each sensor (acceleration, gyroscopes, earth magnetic) that consists of a 3-axis. Here, ARS(Attitude Reference System) measures the attitude with accelerometer and gyroscopes. And AHRS(Attitude Heading Reference System) measures the attitude with accelerometer, gyroscopes and geomagnetic.

An acceleration sensor is not to measure the moving distance but to use a combined data of acceleration and gyro by calculating the angle with acceleration due to gravity. AHRS is the combined form of fusion of the two sensors and a geomagnetic sensor.

Currently, these inertial measurement units are widely used in localization, attitude control and navigation at water, ground and air. In particular, this unit is applied to an inertial navigation. And this system comes into the spotlight in the field of localization.

But such inertial measurement unit includes instantaneously changing noises and internally generated noises. If these slight noises of data are continued, as time goes fatal cumulative error will be generated in the case of localization

Besides, biasing and misalignment errors generated by the sensor will also affect the antibody, including noise and quantization error, non-aligned mounting error, and the error caused by inaccuracy of the sensor[1]

For this reason, the study for improving the performance with applying to a variety of signal processing algorithms in the inertial navigation system is becoming an issue.

In order to reduce the error when operating localization, attitude control and navigation system, by the wavelet transform which is relatively new signal processing technique, a data of the inertial measurement unit is processed to a more accurate value [2],[3].

Using a characteristic of the wavelet transform, original studies mainly perform a similar role like the low-pass filter or the high-pass filter which remove the data for a specific frequency range [2].

But in this paper, generated errors in the inertial measurement unit more efficiently is reduced with thresholding which is one of the techniques of removing noise.

2. Wavelet transform

2.1. *Discrete wavelet transform*

Wavelet transform is a signal conversion technique which is utilized most with FFT (Fast Fourier Transform) and STFT (Short Time Fourier Transform) in the recent signal processing field.

Among them, FFT is often used as a signal processing technique and a solution of the differential equation. But because signal analysis is possible only in frequency domain, this technique has disadvantage that can't know the time information and the frequency information of signal at the same time. To overcome this limitation, STFT which is called the window function and is added the time-dependent weighting function at Fourier building blocks is introduced.

However, because analysis region is always constant for a time-frequency, STFT has disadvantage that can not efficiently analyze non-stationary signal which has the change of stochastic characteristics according to the change of time.

In contrast, the wavelet transform compose a measure using a expansion or contraction of the mother wavelet without the window function. And because functions that occur by a result of moving are used as building blocks, this technique can accomplish time-frequency analysis more efficiently than STFT.

Wavelet transform which is the way to extract partial scale component of the signal with wavelet which can change a size can be defined as Eqs. (1) ~ (2) [4],[5].

$$W_f(b,a) = \int_{-\infty}^{+\infty} f(t)\psi_{b,a}^{*}(t)dt \qquad (1)$$

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \qquad (2)$$

The function ψ as the mother wavelet, can be expanded, contracted by the compression coefficient and shifted by the transition coefficient.

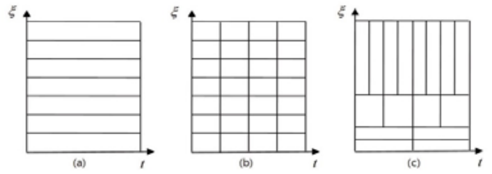

Fig. 2 Time-frequency analysis area by
(a) Fourier transform, (b) Local Fourier transform,
(c) Wavelet transform

Discrete wavelet transform provide Multi-resolution analysis for the signal. And from a signal processing point of view, this is closely related to reconstruction of each band signal based on the filter bank. Multi-resolution analysis can divide into approximation which is the low-frequency component and detail which is the high-frequency component. This process can be expanded by the concept of two kinds of filter using the low-pass filter and the high pass filter at same time [4],[2],[5].

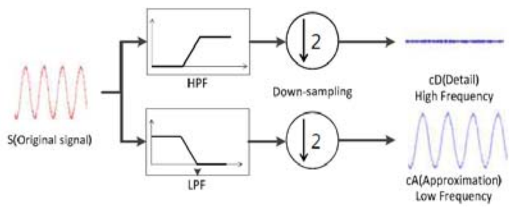

Fig. 3 Multi-resolution analysis of
Discrete wavelet transform

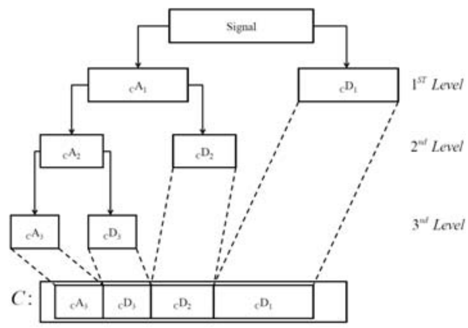

Fig. 4 Multi-resolution decomposition of
Discrete wavelet transform

2.2. *Wavelet Thresholding*

The technique to reduce the noise with the wavelet transform is developed in order to remove noise contained in the image. The most common way of noise removal techniques is wavelet shrinkage technique which is represented by thresholding technique [6],[3].

If the wavelet coefficients calculated by performing wavelet transform do not reach the threshold value, the wavelet thresholding technique makes the wavelet coefficients to zero. This way assumes that the size of the actual signal is greater than the noise level and the noise is mixed by the frequency area. In this case, if the value of the specific frequency component has a smaller data than the known noise level of the actual signal, its value is made of zero by considering the noise.

Because of the characteristics to remove all frequencies components above a specific frequency, typical low-pass filter bring the actual signal loss. In particular, the accelerometer signal for the signals of the inertial sensor is instantaneously changed when there is the acceleration of a vehicle. And if the accelerometer signal goes through the low-pass filter, this signal is made to be slow by distorting a momentary change of the signal.

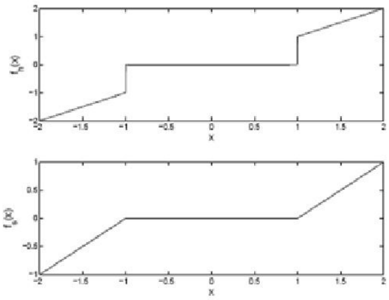

Fig. 5 Hard thresholding function and Soft thresholding function

The thresholding technique is divided into the soft thresholding and the hard thresholding. Ep. (3) is hard thresholding function and Ep. (4) is soft thresholding function.

$$T_{\lambda}^{hard} = \begin{cases} u & if \ |u| \geq \lambda \\ 0 & otherwise \end{cases} \quad (3)$$

$$T_{\lambda}^{soft} = \begin{cases} (u - sign(u)\lambda) & if \ |u| \geq \lambda \\ 0 & otherwise \end{cases} \quad (4)$$

The value u which is wavelet coefficients makes the coefficients below the reference value to zero.

For applying the thresholding technique, general way to set the reference value depends on Ep. (5)

$$\lambda = \sqrt{2 \log n\sigma} \quad (5)$$

3. Noise removal algorithm in the wavelet

Wavelet analysis is a good tool for denoising, owing to achieving good localization in both space and scale domains, and superior separation of noise and signal contents. Because of the absence of space invariance in the Wavelet, thresholding rather than convolution is the typical technique for denoising with wavelets.[7]

4. Experiment

Experiments are performed by the test board is made for processing the wavelet transform in real time. the acceleration values that most largely include the internal noise of the Inertial measurement unit and the external noise by the external cause are used as a experimental data. And the level 3 is applied to the level of the discrete wavelet.

After receiving the acceleration value, the configured system performs resolution decomposition using discrete wavelet transform. And using the inverse discrete wavelet, this system restores removed noise acceleration data.

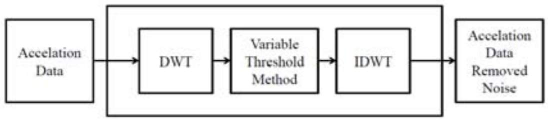

Fig. 6 Filter system block diagram of Discrete wavelet transform

Micro control unit used in the experiment is TMS320F28335. And inertial measurement unit used in the experiment is EBIMU-9DOF.

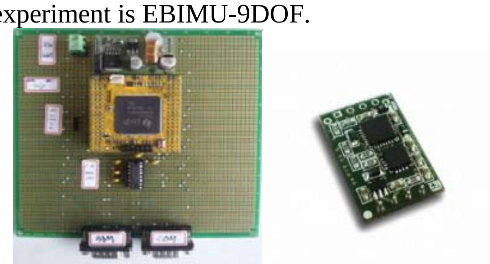

Fig. 7 Test board and inertial measurement unit

The underwater straight running experiment is tested in the 262 (w) × 175 (h) × 50 (d) cm size water tank with AUV.

Fig. 8 The underwater straight line driving experiment

To know degree of internal noise removal, filtering the acceleration data in a stopped state is performed in real-time. Fig. 9 represents that noises of data with the discrete wavelet transform are largely removed than original data.

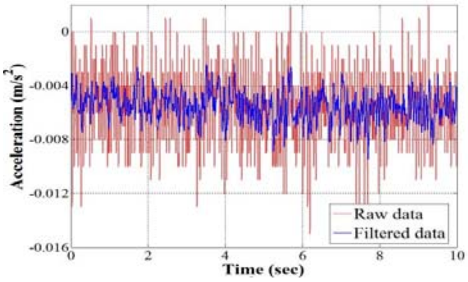

Fig. 9 Comparing original acceleration data and filtered acceleration data in a stopped state

Next experimental data is acceleration data which is measured by straight line driving for 3.5 second. Fig. 10 represents that noises of data with the discrete wavelet transform are largely removed than original data.

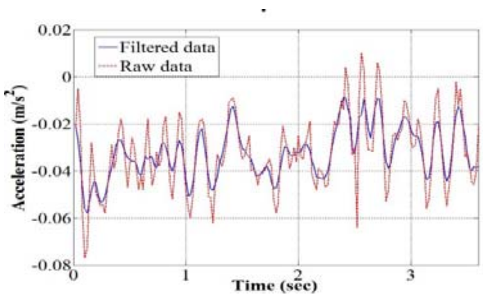

Fig. 10 Comparing original acceleration data and filtered acceleration data in underwater straight line driving

5. Conclusion

In this paper, We studied to revise the internal noise and the external noise of the IMU(Inertial Measurement Unit) using the discrete wavelet transform.

By dividing into high frequency component and low frequency component of the noise, removing noises is determined by the threshold value. And the more active filtering effect can be expected unlike the moving average filter or the low pass filter by removing or maintaining the noises.

Finally, we will apply to localization of the actual submarine or mobile robot using the wavelet transform.

In the case of localization, the cumulative error can be reduced when applying effective noise removal. And the robust localization system design will be possible for the disturbance.

Acknowledgements

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