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Implementation of IMU using wavelet transform and variable IIR filter

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Abstract: Preprocessing to original signal of IMU is used for getting more reliable information. Generally, LPF(Low-Pass Filter) which has low cut-off frequency is designed to reduce noise of inertial sensors. However, in the case that an object travels with acceleration, IMU cannot determine motion of the object due to this LPF. Therefore, LPF with low phase delay has to be designed.
In this paper, suggest following algorithm to solve this problem. Design two LPF with 1Hz and 4Hz cut-off frequency. Then apply 1Hz cut-off frequency LPF at a constant velocity or stationary and 4Hz cut-off frequency LPF at acceleration. It is possible to implement IMU which has suitable response by selecting suitable filters to the conditions.
Wavelet transform to angular velocities from gyroscopes can be applied to measure the characteristic of the motion. Wavelet transform suggests the way to observe the area of interest at frequency domain through multi-level decompositions. The changes of motion characteristics are measured by the detail coefficients. Detail coefficients of gyroscopes can be used to find out start and finish points of motions. Threshold value is needed to determine which characteristic the system has. This threshold value can be used to divide condition of acceleration and a constant velocity or stationary condition. The aim of this algorithm is to get reliable control information and quick response.
In this paper, used Stewart platform in order to simulate movement of an object. We compared traditional IMU and IMU applied suggested algorithm for an acceleration condition and a constant velocity or stationary condition. Suggested algorithm shows better result in acceleration. Because LPF with 4Hz cut-off frequency shows faster response due to lower phase delay at acceleration.

Keywords: IMU, robotics, artificial life, wavelet, variable filter.

I. INTRODUCTION

Today, as the advancement of MEMS (MicroElectroMechanical Systems) technology, research into systems using SDINS(Strap Down Inertial Navigation Systems) is being developed. An IMU(Inertial Measurement Units) consists of tri-axial accelerometers and tri-axial gyroscopes. The IMU is used for determination of velocity, position and attitude by integration of acceleration and angular velocity of an object. Since it relies on Newton's law of motion, sensor biases and noise are unbounded due to the integral windup. Noise from IMU affects velocity, position and attitude information. Therefore, the object has unbounded velocity, position and attitude errors.

Preprocessing to original signal is needed for reducing noise and bias to estimate position and attitude. This is for providing more reliable information. LPF(Low-Pass Filter) is generally used for preprocessing. Low cut-off frequency or high order LPF causes high phase delay. And high cut-off frequency or low order LPF causes bad frequency response. Therefore, suitable order and cut-off frequency have to be chosen.

In this paper, suggest an algorithm switching two LPF according to condition of an object. One has noise resistance response but high phase delay. Another has quick response but sensitive response about noise. Each one is applied at stationary or constant velocity condition and acceleration condition. Wavelet transform is used for dividing motion of an object into stationary or constant velocity condition and acceleration condition.

II. ALGORITHM

It is applied to switch two LPF which have different cut-off frequency by using wavelet transform. Then, LPF which has noise resistance at stationary or constant velocity and quick response at acceleration can be designed.

1. LPF(Low Pass Filter)

IIR LPF which has 6th order and 1Hz cut-off frequency is designed to apply at stationary or constant velocity. This filter has noise resistance. IIR LPF which has 6th order and 4Hz cut-off frequency is designed to apply at acceleration. This filter has quick response.

2. Wavelet transform

Wavelet transform represents original signal by using basis function which has finite length. Basis functions of wavelet transform are scale function called φ and detail function called ψ.

$$\varphi_{j,k}(x) = 2^{j/2}\varphi(2^j x - k) \qquad (1)$$
$$\psi_{j,k}(x) = 2^{j/2}\psi(2^j x - k)$$

$$\int \varphi(x)dx = 1 \qquad (2)$$
$$\int \psi(x)dx = 0$$

Scaling parameter is j and translation index is k. If j increases then width and height of basis function is going to be narrow and high. If k increases then basis function is going to be translated to right side.

Original function is represented by linear combination of basis function.

$$f(x) = \sum_k c_{j,k}\varphi_{j,k}(x) + \sum_j \sum_k d_{j,k}\varphi_{j,k}(x) \qquad (3)$$

Scale coefficients are $c_{j,k}$ and detail coefficients are. They are calculated by following pyramid algorithm.

$$c_{j,k} =< f(x), \varphi_{j,k}(x) >= \sum_n h_{n-2k} c_{j+1,n} \qquad (4)$$
$$d_{j,k} =< f(x), \psi_{j,k}(x) >= \sum_n (-1)^n h_{-n+2k+1} c_{j+1,n}$$

'h' is a transform coefficient of basis function and 'n' is a time index of a coefficient. Original signal is scale coefficient of the highest level. And calculate scale and detail coefficient of lower level by using equation (4). Decomposition of wavelet transform is same at every level.

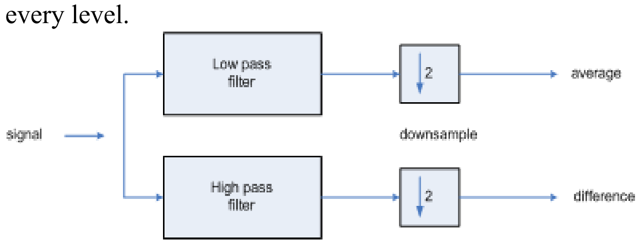

Fig.1. Decomposition of wavelet

3. Haar wavelet transform

In this paper use basis functions of Haar wavelet transform. Haar wavelet transform is easy to implement and fast to calculate. Following functions are basis functions of Haar wavelet transform.

$$\varphi(x) = \begin{cases} 1, (0 \le x < 1) \\ 0, (otherwise \end{cases}$$

$$\psi(x) = \begin{cases} 1, (0 \le x < \frac{1}{2}) \\ -1, (\frac{1}{2} \le x < 1) \\ 0, (otherwise \end{cases} \qquad (5)$$

4. Recognition of acceleration condition

Sampled data with 50 Hz frequency are applied wavelet transform. Wavelet transform of 6th level gives information that shows changes of low frequency data from gyroscope. Detail coefficient of 6th level is used for information that shows which condition the system is in. Two LPF are changed according to the condition of a system from detail coefficient of 6th level. Threshold value of detail coefficient is determined experimentally.

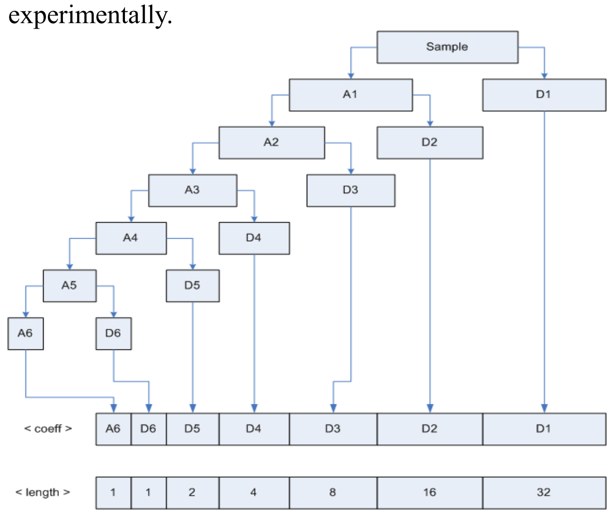

Fig.2. Decomposition of multi-level 6.

III. EXPERIMENT

A system has gyroscope, accelerometer and compass sensor. Stewart platform is used for measuring performance of suggested algorithm. In this paper use IMU made by Crista to compare with suggested system. The IMU has at most 200 Hz data output rate and 1 kHz internal A/D rate. It consists of 300 degree/s gyroscopes and 10g accelerometers at 3-axis. Stewart platform for HILS(Hardware In the Loop Simulation) is used for modeling movement of the system. Stewart platform has resolution of 0.1 degree and was proved its accuracy.

1. Component of system

A. Gyroscope

ADIS16100 gyroscope is used for measuring condition of an object. The gyroscope can measure angular velocity at most ±300 degree/s. SPI interface is used for accessing gyroscope. Each 3 gyroscope consist of 3-axis.

B. Accelerometer

SCA3000-D01 accelerometer is used for measuring acceleration. An accelerometer can measure acceleration of 3-axis. Maximum measurable acceleration is ±2g. SPI interface is used for accessing accelerometer.

C. Compass sensor

CMPS03 compass sensor module is used for implementation of IMU. The compass sensor is not important in this paper. This is a component of IMU.

D. Controller

TMS320F2812 32bit DPS made by Texas Instrument is used for IMU. It operates at 150 MHz frequency.

2. Result of experiment

A. External noise

In this paper supposed two situations. One is normal situation with no vibration. Another is special situation with vibration when Stewart platform moves as fast as possible. Vibration occurs at start and stop point of moving.

Table 1. Setting of situation

	Velocity [mm/s]	Acceleration [mm/s^2]	Movement (angle of roll)
Normal	48.6	50	0→30→0→30 Degree
Special	48.6	1504	

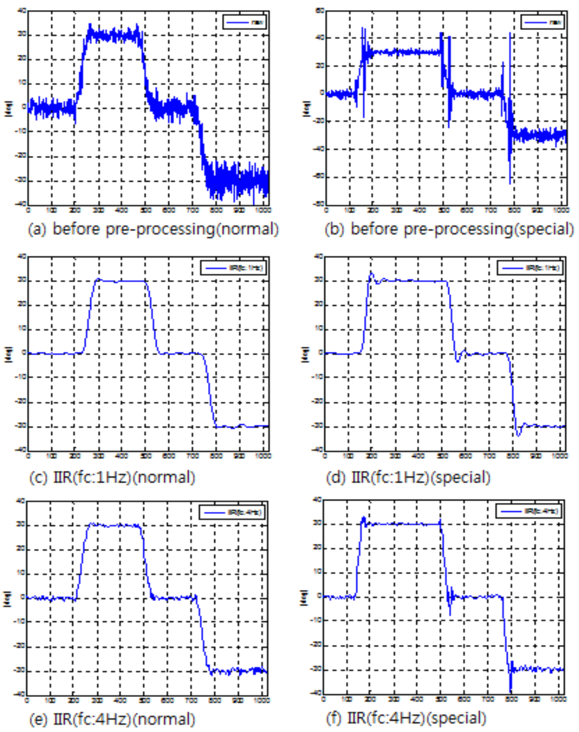

Fig.3. Comparison of 1Hz and 4Hz LPF

B. Transient section of the two conditions

Define transient section of the two conditions by applying suggested algorithm. The lowest detail coefficient of raw data is -0.026 at a normal situation and -0.068 at a special situation. Therefore, -0.025 is applied as suitable threshold value. If IMU switches their LPF, hold for 1500 cycle of their control period.

(a) and (b) in Fig.4. show raw data from gyroscope at each situation. (c) and (d) are detail coefficient from gyroscope. Flat section appears because detail coefficient is not necessary when IMU holds their acceleration condition.

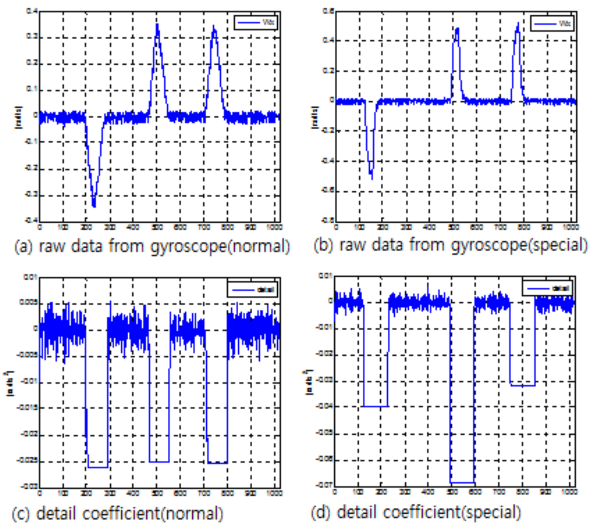

Fig.4. Transient section of the two conditions

C. Result of experiment

Fig.5. shows difference between Traditional IMU and IMU with suggested algorithm. Two IMU are almost same at normal situation. However, IMU with suggested algorithm is better at special situation. (b) shows a lot of noise at transient section. (d) shows vibration with reduced noise.

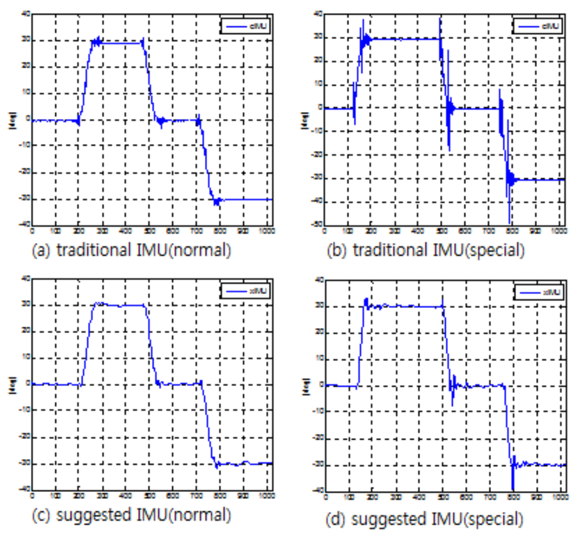

Fig.5. Comparison of the two IMU

V. CONCLUSION

In this paper, suggested IMU switching two LPF. We used data from gyroscope to improve performance of accelerometers. Detail coefficient is used for estimating condition of a system from angular velocity. The detail coefficient was calculated by using wavelet transform. Suitable LPF was chosen according to condition of a system. Then, noise of accelerometer was reduced and vibration was remained. Since inertial sensor is very sensitive to noise, reducing noise is very important at preprocessing. Furthermore, vibration has to be remained because it is very important to estimate attitude.

Stewart platform is used to estimate performance of IMU with suggested algorithm. We made static condition like stationary or constant velocity and dynamic condition like acceleration. In addition to this, vibration was added at each condition. Then, we compared traditional IMU and IMU with suggested algorithm. The result shows two IMU are almost same at stationary or constant velocity. However, IMU with suggested algorithm shows better performance at acceleration. Noise has to be removed. However, vibration doesn't have to be removed. Actually, it is very difficult to distinguish noise and vibration. Noise and vibration are high frequency area at frequency domain. Therefore, noise can be reduced by low cut-off frequency LPF at stationary or constant velocity condition because there is only noise at high frequency area. However, in acceleration condition high frequency data must be remained because vibration is important information to estimate attitude of a system.

The result of experiment shows IMU with suggested algorithm has low noise at stationary or constant velocity. It is better result than IMU with 4Hz LPF. In addition to this, IMU with suggested algorithm has quick response in acceleration. Therefore, attitude can be estimated from vibration. It is better result that IMU with 1Hz LPF. As a result IMU with suggested algorithm has low noise like 1Hz LPF and quick response like 4Hz LPF. This satisfies the aim of this paper.

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