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Accelerometer North Finding System Based on the Wavelet Packet De-noising Algorithm and Filtering Circuit

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Abstract: This paper demonstrates a method and system for north finding with a low-cost piezoelectricity accelerometer based on the Coriolis acceleration principle. The proposed setup is based on the choice of an accelerometer with residual noise of 35 $ng \cdot Hz^{-1/2}$. The plane of the north finding system is aligned parallel to the local level, which helps to eliminate the effect of plane error. The Coriolis acceleration caused by the earth's rotation and the acceleration's instantaneous velocity is much weaker than the g-sensitivity acceleration. To get a high accuracy and a shorter time for north finding system, in this paper, the Filtering Circuit and the wavelet packet de-nosing algorithm are used as the following. First, the hardware is designed as the alternating currents across by filtering circuit, so the DC will be isolated and the weak AC signal will be amplified. The DC is interfering signal generated by the earth's gravity. Then, we have used a wavelet packet to filter the signal which has been done through the filtering circuit. Finally, compare the north finding results measured by wavelet packet filtering with those measured by a low-pass filter. Wavelet filter de-noise data shows that wavelet packet filtering and wavelet filter measurement have high accuracy. Wavelet Packet filtering has stronger ability to remove burst noise and higher engineering environment adaptability than that of Wavelet filtering. Experimental results prove the effectiveness and project implementation of the accelerometer north finding method based on wavelet packet de-noising algorithm. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Accelerometer, North finding, Coriolis acceleration, Wavelet packet, De-noising.

1. Introduction

North finding is a key factor in many location systems and is typically obtained by using digital magnetic compasses [1]. There are many instruments capable of achieving degree north finding accuracies. However, the magnetic compass north finding system can be easily degraded by nearby ferrous materials or by electromagnetic interference [2]. Gyroscope compass using the comprehensive effect of earth rotation angular velocity [1], [3]. The piece of the gyroscope north finding system is too high. The celestial north finding system can't work on the ground well, and it does not work underground [4], [5].

In the 21st century, traditional natural resource is relatively scarce [6]. Before nascent energy appears, the smaller reserves of resource exploitation and traditional resources secondary exploitation seem to be particularly important. One of the key technologies for the resources secondary exploitation and smaller reserves resource exploitation is north finding technology, which need low cost and high accuracies. With the continuous improvement of the accuracy of the accelerometer and maturity of digital signal processing technology [7], making the accelerometer north finding system which based on Coriolis acceleration becomes a reality.

The plane of turntable error, sampling error et al. restrict the measurement accuracy of the north finding based on accelerometer. There are many improvements, such as choosing more performance accelerometer to measure the Coriolis acceleration [8], improving the accuracy of the sampling circuit, or increasing the speed of the turntable. These improvements can improve the north finding measurement accuracy. However, this hardware improvement requires higher cost and longer time. In this paper, we discuss the most significant error sources that degrade the performance of accelerometer north finding system. This is done in order to maximize the performance of the accelerometer. Theoretically, if the errors of accelerometer are compensated, it is possible to measure very small acceleration, and we can get a high level of the system's measurement. First, the signal of the accelerometer will be filtered through the filter circuit. In this part, the direct current signal will be removed from the signal, which is caused by the gravity. Then it is unused for the north finding. The AC signal will be amplified by the OP07. Finally, the wavelet packet will further filter the noise component of the AC signal. This method further effective combination of hardware and software to achieve low cost, strong anti-interference north finding system.

2. The Principle of Accelerometer North Finding System

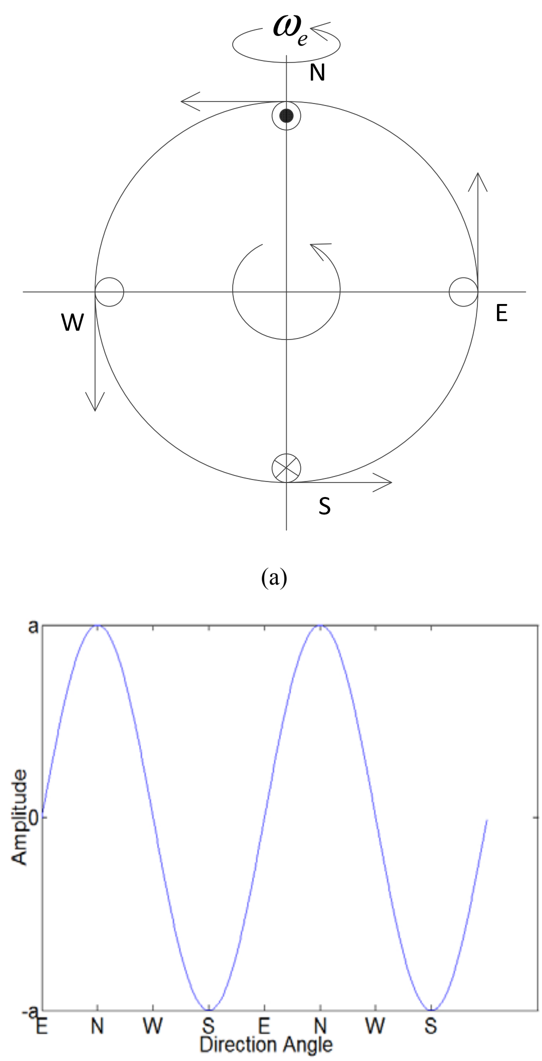
The accelerometer north finding system is based on the principle of the Coriolis acceleration. The mathematical expression for the Coriolis force appeared in an 1835 paper written by French scientist Gaspard-Gustave Coriolis [9]. At a given rate of rotation of the observer, the magnitude of the Coriolis acceleration of the object is proportional to the velocity of the object and also to the sine of the angle between the direction of movement of the object and the axis of rotation.

The vector formula for the magnitude and direction of the Coriolis acceleration [10] is:

$$a_c = -2v \times w_e , \tag{1}$$

where a_c is the acceleration of the particle in the rotating system, v is the velocity of the particle in the rotating system, and w_e is the angular velocity vector which has magnitude equal to the rotation rate ω and is directed along the axis of rotation of the rotating reference frame, and the × symbol represents the cross product operator. Just as showed the Fig. 1.

When the accelerometer moves with the turntable, the direction of the accelerometer's velocity is changing, so the angle between the direction of earth's rotation in the local plane and the direction of the accelerometer's speed is changing with the accelerometer moving. As a result, the Coriolis acceleration is only relevant to the angle. In other words, we can find the north by measuring the Coriolis acceleration. In this way, accelerometer outputs the ideal transfer curve shown in Fig. 1. The peak corresponds to the true north, so by seeking peak of the line can we achieve the north finding purposes.



(b)

Fig. 1. Schematic for (a) an accelerometer movement (b) the accelerometer output.

3. Analysis the Accelerometer Output Signal and Hardware Design

Accelerometer's output signal contains four parts: a constant value output (accelerometer sensitive gravitational field); Coriolis acceleration values; sampling circuit measurement error; and accelerometer output error. Following formula:

$$a = a_g + \varepsilon_a + \varepsilon + a_c, \quad (2)$$

Sensitive accelerometer output a_g is as a constant gravitational field; accelerometer output error ε_a is white noise; sampling circuit error ε is the same as the white noise error; a_c is the Coriolis acceleration which includes north finding information.

Coriolis acceleration just as the following:

$$a_c = -2v \times w_e = -2\omega \times r \times w_e, \quad (3)$$

where v is the linear velocity of the accelerometer, and ω is the accelerometer rotational angular velocity. r is the distance from the center of the turntable to the accelerometer, and ω_e is the angular velocity of the Earth's rotation component in the horizontal direction.

The output of the north finding systems just is as the following. The distance r between the accelerometer and the center of the turntable is 10 *cm*, and the rotation speed of the turntable is 8 *R/S*. The earth's rotation component in the horizontal direction in the 29°35′ north latitude is 6.3e-05 *rad/s*. In this way, the amplitude of the Coriolis acceleration is 7.9e-05 *G*, and the frequency is 8 *Hz*. Using original data for finding north is difficult because the Coriolis acceleration is far less than that of gravity accelerometer. In order to improve the measured signal quality, the stand procedures, such as isolation and amplification, have been used.

As mentioned above, the main purpose of the system is three-fold: first, to isolate the direct current, the value of which is much bigger than the alternating current value, the current signal will change into the voltage signal in the current sampling circuit which is provided with a resistors R0, the direct voltage will be cut-off, while alternating voltage will pass through the capacitance C1. And second, to amplify the alternating voltage was realized by using two typical operational (OP07) amplifiers, at last, the voltage to frequency converter was using AD652. The schematic circuit is just as the Fig. 2.

4. The Principle of the Wavelet Packet

The accelerometer has been widely used in various applications, however, such analog transducer-incorporated electronic measurement system produces signal proportional to the desired input, but certain artifacts may affect the measurement response due to senor dynamic and electronic noise [11]. The accelerometer's noise and the outside interference vibration will affect the accuracy of north finding. Wavelet transform (WT) is a signal processing tool that can be considered as an extension of the traditional Fourier transform with adjustable window location and size [12]. Wavelet packet transform (WPT) is an extension of WT that provides a complete level-by-level frequency-time decomposition [13], [14]. The basic concept of the WPT and its matrix representation are briefly presented here. The main characteristic of WPT is that it also decomposes high frequency bands which are kept intact for wavelet decomposition (WT) [16]. Therefore, the time frequency information in the high frequency bands can also be analyzed in details.

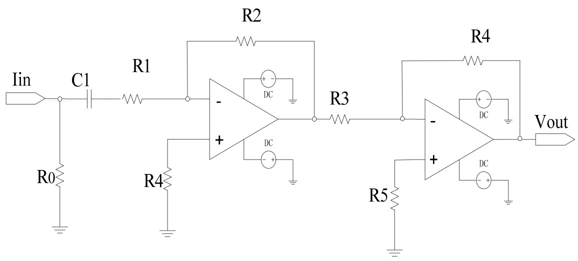


Fig. 2. The schematic circuit diagram for isolation and amplification.

It also can select corresponding frequency band adaptively according to the characteristics of the analyzed signal, matching with the signal spectrum [15], thereby increasing the time–frequency resolution. Hence, WPT has a wider range of applications than the WT since it can achieve a very fine resolution in both high and low frequency bands.

The wavelet transform can be implemented by means of a pair of low-pass and high-pass wavelet filters. Define h(k) and $g(k)=(-1)^k h(1-k)$. These filters, also known as quadrature mirror filters, are constructed from the selected wavelet function $\psi(t)$ and their corresponding scaling function $\varphi(t)$ is just as follows [17]:

$$\begin{cases} \varphi(x) = \sum_{k \in z} h_k \varphi(2t-k) \\ \psi(x) = \sum_{k \in z} g_k \varphi(2t-k) \end{cases}, \quad (4)$$

To perform wavelet packet transform of a signal at a certain level, the function in the eq. (4) is expressed as:

$$\begin{cases} u_{2n}(x) = \sqrt{2} \sum_{k \in z} h_k u_n(2t-k) \\ u_{2n+1}(x) = \sqrt{2} \sum_{k \in z} g_k u_n(2t-k) \end{cases}, \quad (5)$$

where $u_0(\mathrm{t}) = \phi(\mathrm{t})$, and $u_1(\mathrm{t}) = \psi(\mathrm{t})$. The signal is decomposed as [18], [19]:

$$\begin{cases} d_{j,2n}(k) = \sum_l h_{l-2k} d_{j+1,n}(l) \\ d_{j,2n+1}(k) = \sum_l g_{l-2k} d_{j+1,n}(l) \end{cases}, \quad (6)$$

where $d_{j,n}$ is defined as the wavelet coefficients at the level j, n is defined as sub-band, $d_{j+1,2n}$ and $d_{j+1,2n+1}$ are defined as the wavelet coefficients at the level j+1, 2n and 2n+1 and they are sub-bands, and the m is the number of the wavelet coefficients.

Reconstruction formula of the wavelet packer transform is:

$$d_{j+1,n}(k) = \sum_l h_{k-2l} d_{j,2n}(l) + \sum_l g_{k-2l} d_{j,2n+1}(l), \quad (7)$$

5. Experiment Results

In this paper, we chose the piezoelectricity accelerometer as the acceleration sensor, the measure range of the accelerometer is 5 G, scale factor is 10 V/G and the residual noise is 35 $ng \bullet Hz^{-1/2}$. The accelerometer is fixed on the small turntable, and the turntable is placed on the plane of the two axis turntable, which can help the plane of the small turntable parallel with the horizontal plane. As shown in Fig. 3.

As we know, the change of the temperature influences the accuracy of acceleration measurement. We put the system in the laboratory, and the temperature is 20° for 2 hours.

Fig. 3. The north finding experimental system.

In the Fig. 4, ×is the original data, the black color curve is the result of low-pass filtering, the rad color curve is the result of the wavelet filtering and the blue color curve is the result of the wavelet packet filtering. We can see from the Fig. 4 that all of the three ways of filtering can suppress the noise of the original date well. Compare with the wavelet packet filtering result, the data of wavelet filtering has a better smooth, and the wavelet filtering can show much more information. The two curves of the wavelet filtering and wavelet packet filtering are very similar, which means there is a small difference between the two kinds of the filtering. However, the wavelet packet filtering can suppress the outside interference signal which is better than the wavelet filtering. More details are shown in the Fig. 5. The Fig. 5 is just part of the Fig. 4.

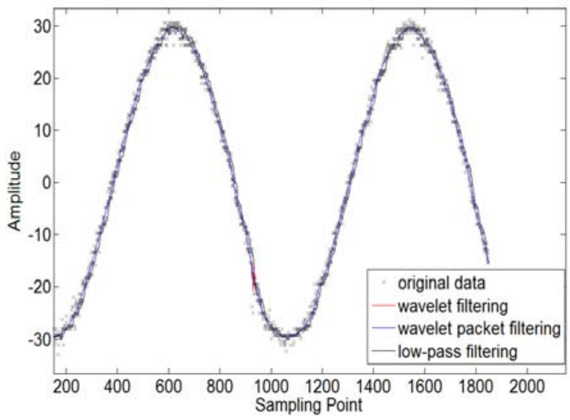


Fig. 4. The difference of different filtering result.

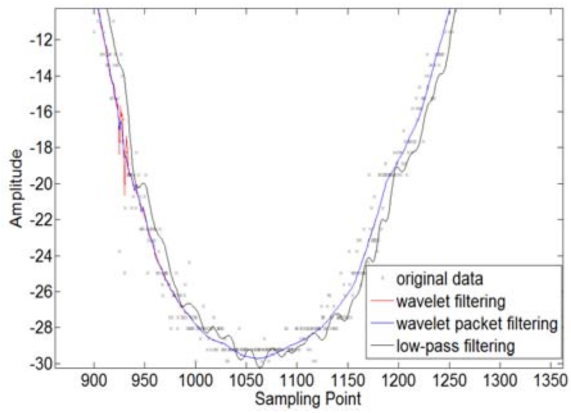


Fig. 5. The partial amplification of the filtering result.

The filtering effects of the three ways are just as the Table 1. The low-pass filtering way can get less SNR and PSNR, the SNR of low-pass filtering is 77.31 % to the SNR of wavelet filter, and 77.73 % to that of the wavelet packet filtering, respectively. The PSNR of the low-pass filtering is 79.87 % to PSNR of wavelet filter and 80.25 % to that of wavelet packet filtering, respectively. However, the result of the low-pass filtering is with bigger RMSE and worse similitude. Both of the wavelet filtering and wavelet packet filtering have less RMSE and more similitude. The SNR, PSNR, RMSE and similitude of the both filtering ways are in the same level.

Combine with the Fig. 5, we can know that in the same condition, the wavelet packet filtering can eliminate burst noise better than the wavelet packet. In other words, the north finding system with wavelet packet filtering can depress the outside interference signal well. The low-pass filtering way de-noise can get ideal result. However, the low-pass filtering way can't remove the noise. The noise's frequency is close to the frequency of the signal of the acceleration, as shown in the Fig. 5.

Table 1. The result of the different.

	Low-pass filter	Wavelet filter	Wavelet packet filter
SNR	20.2745	26.2238	26.0834
PSNR	23.6067	29.5560	29.4156
RMSE	2.0573	1.0371	1.0540
Similarity	99.53 %	99.88 %	99.88 %
The error of north finding	4°	3°	3°

6. Summary

In this paper, the wavelet packet filtering de-noise way is used in the north finding system, the isolation and amplification circuit are designed, the following experiment and test have been done, and the date shows that the north finding system de-noise with low-pass filter way can reach less SNR and RSNR level. However, it can't find the true north perfectly. The SNR, PSNR, RMSR and similitude of the both of wavelet filter and wavelet packet filter are in the same level. However, the wavelet packet filter can remove burst noise well. In this way, the system can adopt the abnormal vibration in the environment complete and it has a better robust fault tolerance. The experimental results indicated that the accelerometer north finding based on the wavelet packer filter de-noise is rationality, and the filtering way is effective. The above work gives a theoretical guidance for the accelerometer north finding system in the engineering.

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