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A Novel Ship-rocking Forecasting Method based on Hilbert-Huang Transform

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Abstract. The ship-rocking is a crucial factor which affects the accuracy of the ocean-based aerospace vehicle measurement. Here we have analysed groups of ship-rocking time series in horizontal and vertical directions utilizing a Hilbert based method from statistical physics. Based on these results we could predict certain amount of future values of the ship-rocking time series based on the current and the previous values. Our predictions are as accurate as the conventional methods from stochastic processes and provide a much wider prediction time range.

1. Introduction

In the ocean-based flight vehicle measurement, a very important task is to characterize special properties of the objective from massive quantity of data. Based on this one may have a way to increase the accuracy of the measurement. To increase the accuracy of the measurement, much effort has been done to study two crucial time series: the ship rocking and the ship deformation. The current strategy is to make appropriate corrections based on these two time series, and thus to reduce or even eliminate the periodicity in the signals of interest. However, after these corrections the measurement results still show considerable difference from those basement standard results obtained through other ways, such as GPS, laser, etc[1].

In this paper we consider the ship-rocking time series based on the approach from statistical physics. To those time series which show strong periodicity, an effective method is to investigate the instantaneous analytic signal of a time series[2,3]. The instantaneous analytic signal is obtained based on a Hilbert transform. The original time series as well as its Hilbert transform construct an analytic signal at each measurement time. On the complex plane one can calculate the instantaneous amplitude and the instantaneous phase of the analytic signal. Such instantaneous amplitude and phase may reveal certain intrinsic properties of systems which are not seen from the conventional methods. For example, previous research shows that, the change of the correlation in human auto-regulation may not happen in the original signal, however it does show in the correlation of its instantaneous phase increments [2]. Here, similarly we investigate the characteristics of the analytic signal. We could predict certain amount of future values of the ship-rocking time series based on the current and the previous values.

1.1. DATA

We have obtained four groups of ship-rocking time series: GX1129JL839RW839RW840. The data starting with “GX” are those obtained when the ship navigates freely, while others are those obtained

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when the ship navigates while maintaining a fixed orientation. All other information is unknown to us. For each group we have the time series in three directions of the Euler angles: the navigation direction, the horizontal direction and the vertical direction. In the following we mark the navigation direction as “KC”, the horizontal direction as “OC”, and the vertical direction as “PC”. If not specially indicated, the unit of all angles is in radian. All time series are measured every 50 milliseconds.

1.2. BASIC TECHNIQUE

Our results in this paper are based on the Hilbert transform (HT) to a stationary time series. To any stationary time series s(t), its HT is defined as:

$$\tilde{s}(t) \equiv \frac{1}{\pi} P \int_{-\infty}^{\infty} \frac{s(\tau)}{t-\tau} d\tau$$

Where P denotes the Cauchy principal value. In the frequency domain, the Fourier component at any frequency f for the Fourier transform of ˜s(t) can be obtained very easily from the Fourier transform of s(t), i.e., that of s(t) at the same frequency f rotates 90 ◦ clockwise (for f > 0) or anticlockwise (for f < 0) in the complex plane. As a simple example, if s(t) = sin(at), then one would obtain ˜s(t) = cos(at). Based on this fact, one could define an “analytic signal” for this time series:

$$S(t) \equiv s(t) + i\tilde{s}(t) = A(t)e^{i\varphi(t)}$$

Where A(t) and phy(t) are the instantaneous amplitude and phase of s(t), respectively.

2. Results and discussion

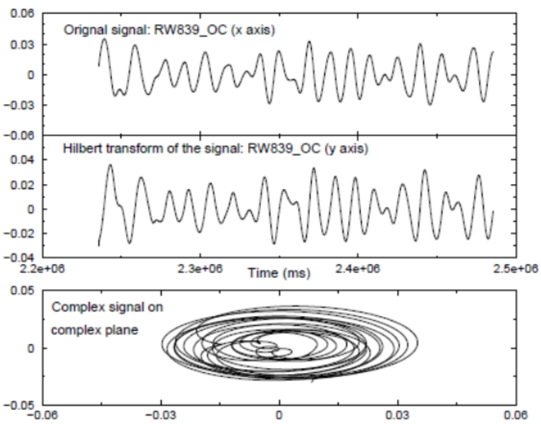

Figure 1. The original ship-rocking time series and its Hilbert transform, as well as the corresponding analytic signal for the group RW839 in the horizontal (OC) direction.

As shown in Figure 1, we show the patterns of the ship-rocking time series for the group RW839 in the OC direction. Similar behaviors are observed in signals of other groups and in other directions. In the analyses, we always remove the zero frequency part in the Fourier transform of s(t) (which is related to the average of s(t)). From the lowest panel of Figure 2 one could find that the evolution of the analytic signal S(t) is very slow when seen in the complex plane. It usually follows the similar behavior when rotating around the origin.

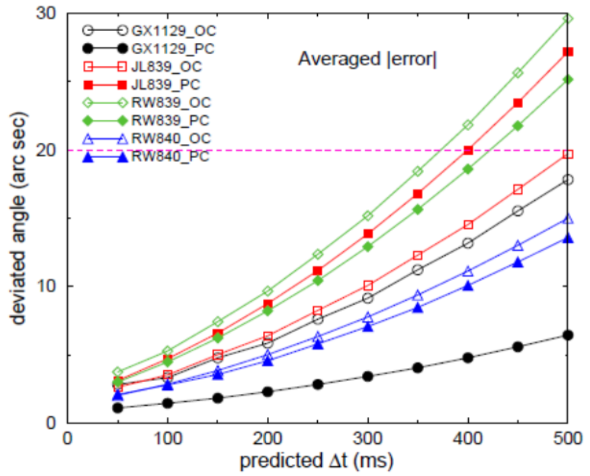

Figure 2. (color online). The absolute errors of the prediction from the Hilbert transform based method as a function of the prediction time interval.

From these known values we first construct its corresponding analytic signal. We next extend the track of the analytic signal on the complex plane from the helix model. The ten predicted values are then compared to the actual values in the original time series. The results of comparison are shown in Figure 2. From the results of both the averaged absolute error we find that our predicted values are very close to that of the original signals within a much wider range of the prediction time window than that of current methods. The results seem better in the averaged absolute error than that in the standard deviation. We attribute this to certain outliers in the instantaneous phase increments. Some tunning at positions near the outliers should be able to further improve the current accuracy.

3. Conclusion

In summary, we have analyzed four groups of ship-rocking signals in horizontal and vertical directions utilizing a Hilbert based method from statistical physics. Our method gives a way to construct an analytic signal on the two-dimensional plane from a time series. The analytic signal share the complete property of the original time series. From the analytic signal of a time series, we have found some information of the original time series which are often hidden from the view of the conventional methods. Based on these results we could predict certain amount of future values of the ship-rocking time series based on the current and the previous values. Our predictions are as accurate as the conventional methods from stochastic processes and provide a much wider prediction time range.

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