Mechanical Systems and Signal Processing 96 (2017) 333–347

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Identifying flight modes of Aerial Planting Projectile using Hilbert-Huang transformation

H. Goodarzi, M. Sabzehparvar *

Aerospace Engineering Department, Amirkabir University, Hafez Ave., Tehran, Iran

ARTICLE INFO

Article history:
Received 29 May 2016
Received in revised form 3 April 2017
Accepted 9 April 2017
Available online 26 April 2017

Keywords:
Aerial Planting Projectile
Hilbert-Huang transformation
Flight mode
Image processing

ABSTRACT

A novel method based on Hilbert Huang Transform (HHT) for analyzing the non-linear and non-stationary of Aerial Planting Projectile (APP) flight data signal is presented. Also an image processing method is used for acquire attitude signals of projectile. Experimental test setup includes an electrical fan, high speed digital camera and projectile that the images of projectile falling down against of fan flow is captured. The frequency components of the projectile attitude signal along separation phase and free falling are complicated. Empirical Mode Decomposition (EMD) can decompose the signal into Intrinsic Mode Functions (IMFs).

After a Hilbert transform, the instantaneous frequency and damping ratio of each IMF is obtained to get the physical meaning of each IMF. Analysis results indicate that the flight modes of APP are identified with high accuracy.

1. Introduction

Aerial plantation is one of the subjects that is absolutely dependent on designing free fall trajectory of the projectile containing a plant. Surely the dynamic and aerodynamic coefficients in each phases of separation throw the initial separation shock and flight path of free falling will have different values. Because of the nonlinear dynamics and aerodynamics of projectile in high angle of attacks in separation phase, indicating of all flight modes with classical method is difficult and also in many cases, is impossible. Most of the shock signals in the engineering practice areas are non-linear and non-stationary, such as the projectile position and attitude signals during initial moments of separation from airplane. The Fast Fourier Transform (FFT), plays an important role in signal analysis in frequency domain, but cannot reflect the detail of signal. The results will lose physics meaning when the FFT is for non-linear and nonstationary signals. Wavelet transformations can supply the partial information of the flight modes both in time domain and frequency domain at the same time, but the length of wavelets basis is limited, and the wavelet transformation may lead to energy leaking [1]. Therefore, it becomes quite difficult in make precise analysis to the time domain and frequency domain at the same time. Base on the signal partial characteristic time scale, the EMD method can adaptively divide the signal frequency band, and HHT can provide the instantaneous frequency of the signal with multi-components [2]. In this paper, the flight signal theta is calculated from image processing analysis with acquired frames through digital high speed camera. Applying HHT and EMD for four similar test data, the longitudinal flight modes have been recognized.

* Corresponding author at: Amirkabir University of Technology, 424 Hafez Ave, Tehran 15875-4413, Iran.
E-mail address: sabzeh@aut.ac.ir (M. Sabzehparvar).

http://dx.doi.org/10.1016/j.ymssp.2017.04.012
0888-3270/

2. Acquisition of projectile attitude signal

Fig. 1 shows the dimensions and geometry of the projectile.

As shows in Fig. 2, the fan air flow gives the shock to the projectile and then a high speed camera records the pictures of projectile motion response in free falling trajectory. With processing of projectile images the pitching angle (θ) and position (x,z) can be measured.

Some of recorded frames shown in one image in Fig. 3.

2.1. Image processing method

It is possible to calculate the projectile position and attitude through continuous images of the high speed camera with image spectral filtering, and applying color threshold in RGB space, as well as morphological modifications [3–5]. In this study, the dominant components in sample are calculated using sampling dimension matrix reduction, and measuring color differences by Gaussian fitting method and create the image. Converting the pixel color to its gray scale equivalent is a fundamental solution to achieve to analyzable images. Each color pixel is described by a triple color spaced and intensities for red, green and blue. By using Eq. (1), RGB values in color space are transferred into grayscales values.

$$\begin{bmatrix} Y_i \\ P_i \\ Q_i \end{bmatrix} = \begin{bmatrix} 0.2989 & 0.5870 & 0.1140 \\ 0.5000 & 0.5000 & -1.000 \\ 1.0000 & -1.000 & 0.0000 \end{bmatrix} \begin{bmatrix} R_i \\ G_i \\ B_i \end{bmatrix} \tag{1}$$

In this study, the differentiation technique, which is based on the dimension reduction, is also used to choose the best color scale. First, the basic color difference is calculated in Eqs. (2)–(4) and then the contrast reduction index of each pixel is determined using Eq. (5).

$$\Delta R_i = R_i - R'_i,\ \ \Delta G_i = G_i - G'_i,\ \ \Delta B_i = B_i - B'_i \tag{2}$$

$$\Delta Y_i = Y_i - Y'_i,\ \ \Delta P_i = P_i - P'_i,\ \ \Delta Q_i = Q_i - Q'_i \tag{3}$$

$$\Delta D_i = \sqrt{\Delta R_i^2 + \Delta G_i^2 + \Delta B_i^2} \tag{4}$$

$$C_i = \frac{\Delta D_i - \frac{1}{Y_{axis}}|\Delta Y_i|}{\Delta D_i} \tag{5}$$

A gray-scale image is produced through applying the above conversions to projectile images. The result is shown in Fig. 4b. The color intensity threshold filters can be used to separate the projectile from its background color. Considering Tl as selected threshold and I_{ij} as the light intensity in pixels with coordinates of (i,j) on the image screen, if $I_{ij} < Tl$, the regarded pixel will replaced with a white pixel and if $I_{ij} > Tl$, the corresponding pixel will be replaced with a black pixel. Fig. 4c shows the result of the above conversion. To modify the binary image and eliminate redundant components, morphological techniques should be used.

In Ref. [6], the development and erosion processes are fully described. The resulting expansion of the received image E with structural component B is an image on which B moves if reflected; it is again a subset of E. In other words:

$$E \oplus B = \left\{ \bar{Z} | (\widehat{B_{\bar{Z}}}) \bigcap^{E} \neq \sigma \right\} \tag{6}$$

After this process an edge of object can be determined and its angle relative to the referenced coordinate calculated. In Refs. [7–9], the object edge detection and calculation are described. In edge detection techniques based on the second order derivatives, the second order spatial difference is used to detect edges. In this technique, the edge position is determined by identifying the zero crossing Laplacian of the image. The two-dimensional Laplacian is defined as follows:

$$\nabla^2 f(X,Y) = \frac{\partial^2 f(X,Y)}{\partial X^2} + \frac{\partial^2 f(X,Y)}{\partial Y^2} \tag{7}$$

In digital images, the Laplacian can be obtained using the mask shown in Eq. (8).

$$W_1 = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \tag{8}$$

Since the Laplacian is a high-pass filter, the use of this operator will strengthen the noise in the image. Therefore, the image should be uniform Laplacian before computing to reduce the effect of noise. Fig. 5 shows the result of applying the above filtration on the projectile images.