Forecasting Method for Ship-borne Helicopter deck-landing

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Abstract. The forecasting of roll, pitch and heave of a ship determine the safety for the ship-borne helicopter. By measuring the wave data and using the RAO technique, the ship motion in different sea-states were obtained, the helicopter deck-landing forecasting will assist in the take-off, landing and flying operations of the ship-borne helicopter.

Introduction

This prediction of ship motions in advance is of great importance to identify the best time to for landing helicopters on a ship's flight deck. Ship motion data were measured by shipboard sensors . If the roll angle of the ship is more than $\pm 5^0$, pitch angle is more than $\pm 2^0$, heave is more than 2m and the wind speed is more than 15m/s , this kind of landing is very dangerous.

Ocean wave dynamical module

The prediction of sea waves is very difficult. Sea waves can be thought of the sum of many sinusoidal waves with different amplitudes, frequencies, and phases. A wave energy spectrum is suitable to describe this characteristic. As we know, the seaway can be represented by different energy spectral distributions of the summed regular waves, the system use a commonly used spectrum named "single-parameter" Pierson-Moskowitz spectrum, that is defined only by the significant wave height. Significant wave height is defined as the average of the 1/3 highest wave heights, with height defined as twice the wave amplitude, or the distance from the crest to the trough.

For simplicity, we used the ITTC Pierson-Moskowitz wave spectrum in our algorithm(Fig. 1)

$$S_\omega(\omega)=\frac{ag^2}{\omega^5}\exp\left(\frac{-4ag^2}{H_s^2\omega^4}\right) \tag{1}$$

Where $S_\omega(\omega)$ is the energy density, in m^2-sec, a=0.0081, g=9.81m/s^2, ω is circular frequency (rad/sec), H_s is significant wave height (m). Sea wave is generate using

$$A_i=\sqrt{2S_i(\omega)\Delta\omega} \tag{2}$$

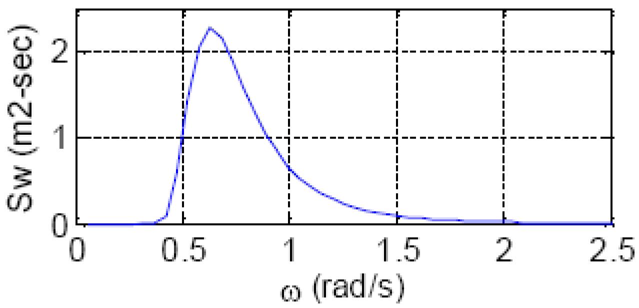

Figure. 1 Pierson-Moskowitz sea-state 5 sea spectrum

Using the superposition of sine waves to construct the wave:

$$H(x,y,t)=\sum A_i \sin((D_{ix}x+D_{iy}y)2\pi/L_i+2\pi t S_i/L_i) \quad (3)$$

Where A_i is the amplitude of sine wave; L_i is the wave length of sine wave; D_{ix}, D_{iy} is the prevailing seaway direction of sine wave and S_i is the speed of sine wave.

If the ship is regarded as a linear system, it's oscillation induced by the turmoil of non- regular wave can be regard as the superimpose of the ship oscillation induced by the regular wave which formed the non-regular wave, and can be regard as stationary linear random process to be dealt with. According to the spectral analysis theory, and the spectrum density equals to the spectrum density of waves multiplies with roll response amplitude operator.

The area under the curve of the spectrum density is m_0, it is the variance σ^2 of the random variable such as the response of pitch or heave under discussion. From the variance of the oscillation spectrum density, the statistical eigenvalue of the oscillation amplitude is deduced. For example, the 3 /1 roll amplitude is $\theta_{1/3}=2.00\sqrt{m_0}$, etc.

Ship motion module

Owing to the effect of waves, the ship in the sea undergoes complicated motions, and generally can decompose the motion of ship in six degree of freedoms. If we neglect the surge because it has smaller influence on the oscillation of the ship, then we can divide the oscillation of five degrees of freedom into vertical and the horizontal oscillation, and can be described by two catalogs of differential equations. These parameters mentioned in above differential equation group can be determined by the methods such as the available perturbation technique, and we can get the response amplitude operator (RAO) of the ship in the regular wave. Calculating several different frequencies that form the non- regular wave, we can the get RAO's curve. By using RAO technique, we obtain the ship motion in different sea-state s according to Fig. 2

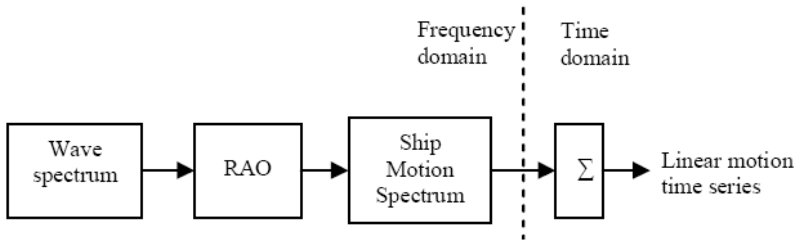

Figure. 2 RAO technique

The dynamics of a ship are described in six degrees of freedom（Fig. 3）. Three of the DOF are linear (also called translational) and three are angular (also called rotational). Both the linear and angular DOF may be described in terms of displacement, velocity, or acceleration. In theory, given any one of the three, the others may be computed by integrating or differentiating. The three linear DOF are surge (fore and aft), heave (up and down), and sway (side-to-side). The three angular DOF are pitch, roll, and yaw.

We use the nonlinear equation to describe the ship motion Kinematics[1][2]:

$$\begin{cases} T_1T_2\ddot{r}+(T_1+T_2)\dot{r}+r+\alpha r^3=k\delta+kT_3\dot{\delta} \\ \dot{V}+a_{vv}V^2+a_{\delta\delta}V^2\delta^2+a_{rr}r^2=a_{nn}n^2+a_{nv}nV \\ T_1T_2\ddot{v}+(T_1+T_2)\dot{v}+v+bv^3=K_\beta\delta+K_\beta T_{3\beta}\dot{\delta} \end{cases} \quad (4)$$

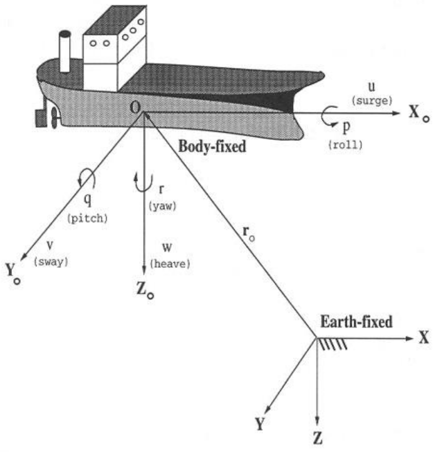

Figure. 3 Diagram of ship

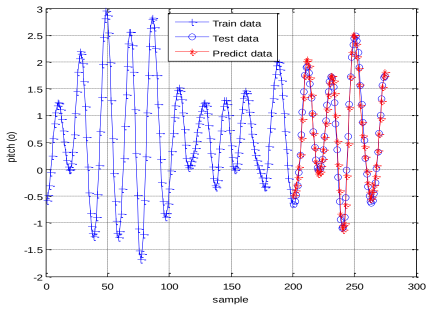

Figure. 4 The predicted result of pitch motion

where $\dot{r}, r$ represent the angle acceleration, angle speed; α, b represent the nonlinear factors; $\delta, \dot{\delta}$ represent rudder、velocity of rudder; T_1, T_2, T_3, K represent the index parameter; $a_{VV}, a_{rr}, a_{\delta\delta}, a_{nn}, a_{nv}$ and $K_\beta, T_{3\beta}$ represent the hydrodynamic combination factor; $a_{nn}n^2 + a_{nV}nV$ represent propeller thrust。

Forecasting algorithm

A software package incorporating the prediction algorithm was designed and implemented. The program, operating under the MATLAB 2010 using LSSVM algorithm[3]. The predicted result of pitch motion is in Fig.4. To ensure the landing safety, there are some requirements on the ship motion and ship-helicopter relative velocity. Take a certain type of helicopter as an example, the specified safe thresholds are:Roll: ±5° ; pitch: ±2°; heave: ±1m; relative velocity: ±3.05m/s .

The equation of vertical relative velocity V_y is:

$$V_y \approx \dot{Z} + l\dot{\phi} + \frac{d}{2}\dot{\theta} + V_0 \quad (5)$$

where Z , θ, ϕ represent heave, roll, pitch value, $\dot{Z}$, $\dot{\theta}$, $\dot{\phi}$ are their time derivatives respectively. V_0 represents the velocity thresholds ,it depends on the piloting level of airman. The landing velocity with the maximum probability is about 0.5m/s, so we define V_0 0.5m/s, l is the distance from landing point to the centroidal cross profile of vessel, d is the distance between helicopter's two wheels.

If the helicopter is hovering above the landing deck, it will take it less than 15 seconds to land on the deck. If the values of the four factors meet the four limits simultaneously in the future 15 seconds, the helicopter can land, otherwise, the safety requirements cannot satisfied, the helicopter can not land. So, if the roll angle, pitch angle, height of heave and relative velocity is smaller than the corresponding threshold simultaneously in consecutive 15 seconds the helicopter can land.

Conclusions

The main algorithm of the deck-landing forecasting is introduced, using the techniques of six DOF ship module and the ITTC Pierson-Moskowitz wave spectrum. Results show that the method satisfies the need of online forecasting.

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