Design of a Pedestal Part for the Marine Surveillance Night Vision System

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Abstract: This paper presents the design of a surveillance night vision system for marine ships. Both a hardware system and software modules for tracking control are developed. In order to control each control axis with compensation for ship motion, the two-degree of freedom(TDF) PID controller is designed and its parameters are tuned using a real-coded genetic algorithm(RCGA). Simulation demonstrates the effectiveness of the proposed system.

Key words: marine surveillance night vision system, TDF PID controller, real-coded genetic algorithm

1. Introduction

A marine surveillance night vision system(MSNVS) is an equipment that can collect evidence of the marine criminal act. Design of a MSNVS needs high precision manufacturing and control technique for pedestal which is mounted with a performance searchlight and day/night camera[1-4]. The MSNVS should has ability of tracking a moving target by the receipt of a message from Automatic Radar Printing Aids(ARPA) radar.

The objective of this study is to develop a prototype hardware system and a control algorithm for tracking pedestal with compensation for ship motion with real time prior to develop a commercial MSNVS. A pedestal control unit(PCU) based on the TDF PID controller is designed for tracking a moving target with compensation 3 ship motions which are rolling, pitching and yawing. The parameters of the TDF PID controller are tuned using the pedestal model and a RCGA[6-7]. Compensation requires the transformation of ship motion detected with 3-axis gyro sensors into 2 rotary motion(Elevation, Azimuth). The effectiveness of the proposed system is demonstrated through simulation using real-world data.

2. Structure and Test Environment of a Pedestal

2.1 Marine Ship Motion

The motion of a marine ship under navigation can be described in 6 degrees of freedom as in Fig. 1. When the rectangular coordinate system is used, the 6 different motion components are defined as surging, swaying, heaving, rolling, pitching and yawing[1]. The first 3 motion components correspond to position and translational movement and the last 3 do to rotational movement.

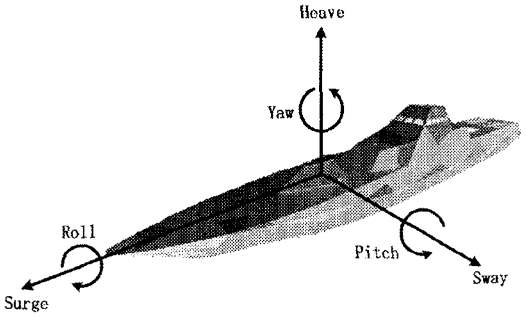


Fig. 1. 6-degree motion of a marine ship.

Rotational movement absolutely affects the performance of the MSNVS while it tracks a target. Rolling and pitching cause horizontal error and yawing does direction error. Therefore, the pedestal of the MSNVS equipped on a ship should compensate for three rotational movement with real-time.

To estimate ship motion, linear wave model approximations are usually adopted by ship control engineers, due to their simplicity. One of frequently used forms is a second-order equation with a damping term in the wave model as:

$$H(s)=\frac{K_\omega s}{s^2+2\xi\omega_0 s+\omega_0^2} \tag{1a}$$

$$K_\omega = 2\xi\omega_0\sigma_\omega \tag{1b}$$

where K_ω is the gain, σ_ω is the wave intensity constant, ξ is a damping coefficient and ω_0 is the dominating wave frequency.

2.2 Motion Base and 2-Axes Pedestal

Motion base(Photo. 1) is a mechanical simulator which can generate ship motion of 6 degrees of freedom. It can generate random rolling, pitching and yawing out of ship motion of 6 degrees of freedom. Pedestal is pan-tilt designed to move 2-axes on azimuth and elevation independently. As a test version of the pedestal of the MSNVS in this work, a 2-axes zig is designed as shown in Photo. 2.

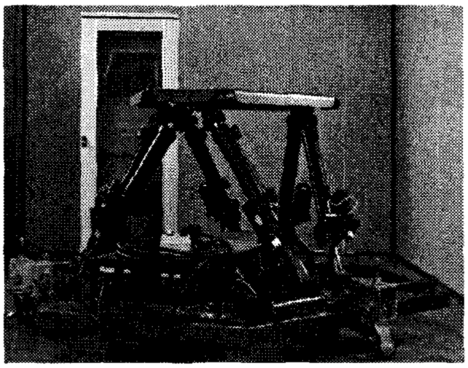


Photo. 1 Motion base.

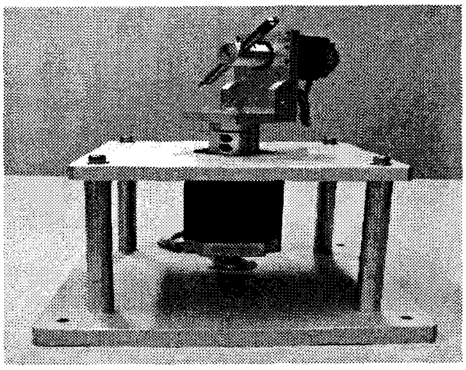


Photo. 2 2-axes zig.

The model of the 2-axes zig is described by transfer function $G_p(s)$:

$$G_p(s)=\frac{K_i}{s(1+T_i s)} \quad (i=a,e) \tag{2}$$

where K_i and T_i (i= a, e) are the parameters of the zig model and a,e denote azimuth and elevation, respectively.

2.3 3-Axes Motion Sensing Unit

The motion sensing unit(Fig. 2) composes of three angular rate sensors, two tilt sensors, a filter for temperature sensor's analog output, an A/D converter for filter's analog output changes to digital, and a controller. The controller reads A/D converter's output for make level of rolling, pitching, yawing with regular data format and transmits to PCU.

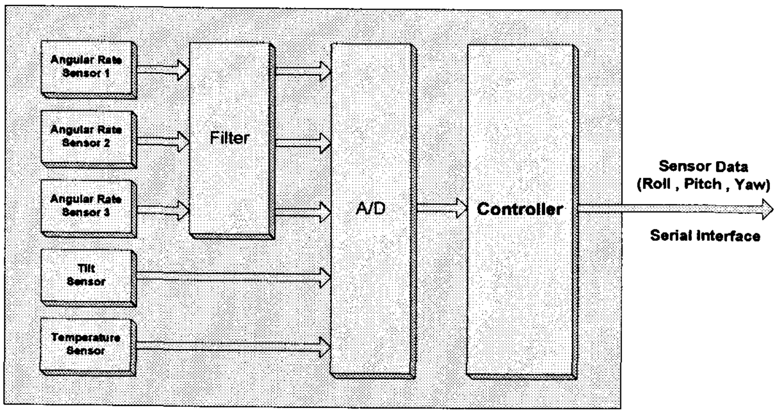


Fig. 2. 3-axes motion sensing unit.

3. Pedestal Control Unit (PCU)

The PCU is the skeleton in the MSNVS, which consists of the hardware system and software functions. It achieves the initialization of varieties of hardware and software variables and target tracking functions with compensation for ship motion due to uncertain disturbance circumstances, such as waves and winds in the sea.

3.1 TDF PID Controller

The MSNVS must not only have compensation(stabilization function) for ship motion but also tracking abilities of a target for evidences. In this study, rolling and pitching axes of the 2-axes zig are independently controlled. Then, the controlled object becomes the 2-axes zig with sensors. A two-degree of freedom(TDF) PID controller which is insensitive to disturbances and process uncertainties is chosen as a primary controller. The independent control loop is shown in Fig. 3. It is assumed that control loop time is much smaller than disturbance changing time.

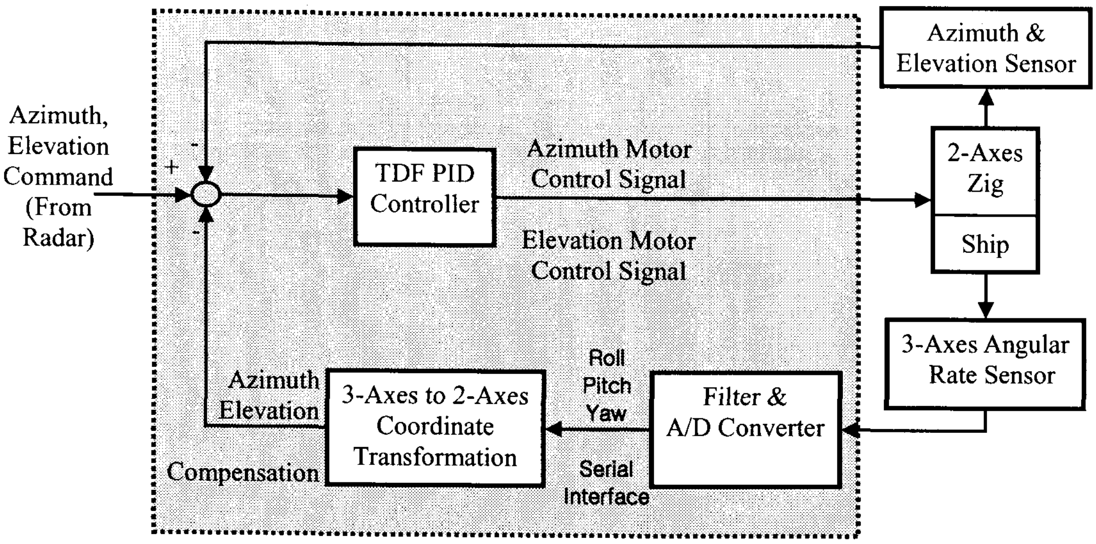


Fig. 3. TDF PID control of 2-axes zig.

The TDF PID controller composing of feedforward and feedback elements is in the form of transfer functions $F_1(s)$ and $F_2(s)$, respectively

$$F_1(s) = -(\alpha + \beta\tau_d s) \tag{3a}$$

$$F_2(s) = K_p\left(1 + \frac{1}{\tau_i s} + \frac{\tau_d s}{1 + \frac{1}{N}s}\right) \tag{3b}$$

In (3), $\alpha, \beta, K_p, \tau_i, \tau_d$ and N are the controller parameters. Proper tuning of its parameters will ensure that the zig tracks the desired command. Especially N is a noise filtering constant which can be chosen by user's experience. Coordinate transformation is cooperated to convert 3-axis motion signal measured by sensing units into 2-axis motion signal.

3.2 TDF PID Controller Tuning

The model and RCGA-based scheme is used to tune the TDF PID control parameters[5]. The estimating and tuning procedure is summarized as follows:

Step 1: Get data sets {u, y} through experiment;

Step 2: Estimate the model parameters K_i, T_i(i= a, e) of the controlled object using its model and a RCGA;

Step 3: Tune the TDF PID controller parameters {α, β, K_p, τ_i, τ_d} using the estimated model and another RCGA;

In the model parameter estimation procedure of Step 2, the RCGA adjusts K_i and T_i such that the following objective function is minimized.

$$J_1(\varphi_1) = \int_0^{t_f} e^2(t)dt \tag{4}$$

where $\varphi_1 = [K_i, \ T_i]^T$ (i= a, e) is the solution vector consisting of the parameters of the zig model, $e(t) = y(t) - y_m(t)$. $y(t)$ is the actual system output obtained through experiment and $y_m(t)$ the model output expressed by (2). t_f is the final integral time which is long enough such that the error after this time can be ignored.

To tune the TDF PID controller parameters in Step 3, another RCGA is selected and simulation is carried out in the same way as the system model parameter estimation. But the error is differently $e(t) = r(t) - y_m(t)$ where r(t) is desired command. In this case, the RCGA adjusts the controller parameters such that the following objective function is minimized.

$$J_2(\varphi_2) = \int_0^{t_f} e^2(t)dt \tag{5}$$

where $\varphi_2 = [\alpha, \ \beta, \ K_p, \ \tau_i, \ \tau_d]^T$.

4. Simulation and results

In this section the proposed system is evaluated through experiment and simulation. Data for estimating the parameters of both the zig(controlled object) model and the ship motion model are collected through experimental test environment and the training ship HANBADA in a seaway and the TDF PID control law is verified on the estimated models. The test environment for the zig model estimation is constituted the 2-axis pedestal, the ship motion sensing units, the pedestal control unit(PCU) and the motion base with self-controller is shown in Fig. 4.

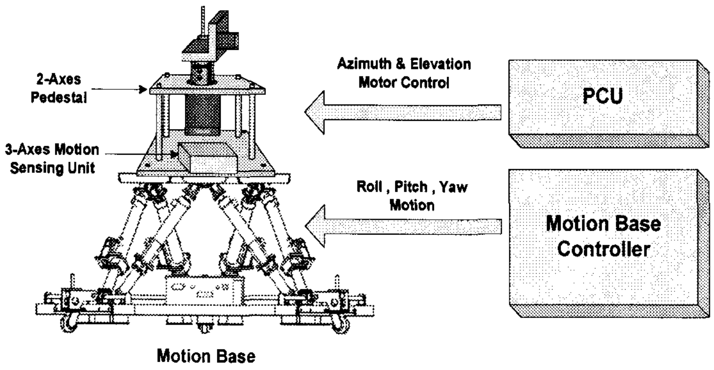
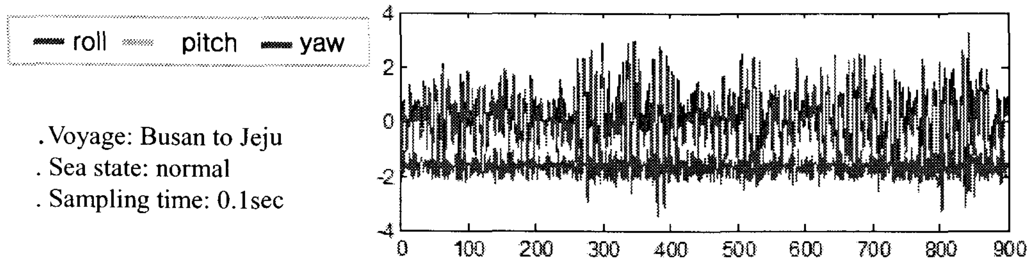
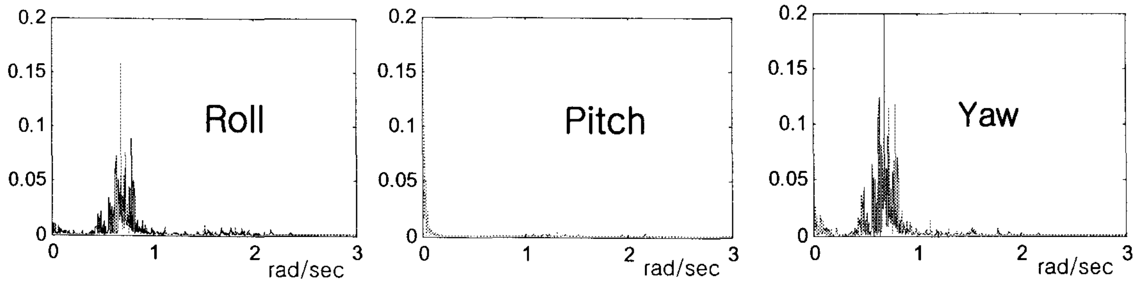


Fig. 4. Test environment.

Since rolling and pitching axes of the 2-axes-zig are independently controlled as mentioned previously, the pedestal's azimuth control is only considered for convenience. Firstly, the pedestal's azimuth model of (2) is considered. Its model parameters are obtained as $K_a = 1.0$, $T_a = 0.02$ using experimental data and a RCGA. The TDF PID controller parameters tuned by another RCGA are $\alpha = 0.1$, $\beta = 0.3$, $K_p = 30$, $\tau_i = 130.43$, $\tau_d = 0.03$. $N = 10$ is used in this work. The sampling time was 0.01sec. In order to generate disturbances for simulation, power spectral density functions were calculated using the measured time-series as shown in Fig. 5. The dominating wave frequencies ω_0 for rolling, pitching and yawing are 0.6 rad/sec, 0.1 rad/sec, 0.6 rad/sec, respectively.

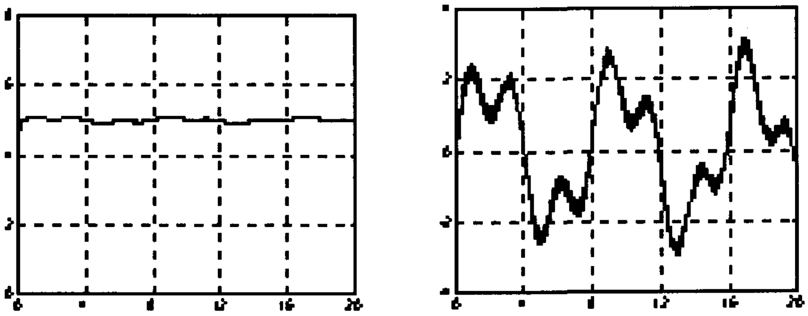


(a) Time series



(b) Power spectral density functions.
Fig. 5. Time series and power spectral density functions.

The result of simulation is shown in Fig. 6(a). As expected, the response shows stable result while disturbance in Fig. 6(b) exists.



(a) Response (b) Disturbance

Fig 6. Response and disturbance

5. Conclusion

In this paper, development of a prototype hardware system and a control algorithm for tracking pedestal with compensation for ship motion prior to develop a commercial MSNVS has been presented. The parameter estimation of the zig is carried out through the system model, experimental data sets and the RCGA. Then, the TDF PID controller is designed to control zig's azimuth. For designing the TDF PID controller, the RCGA and estimated system model are used. Simulation results demonstrated that the proposed system can provide good response with less sensitivity.

References

[1] Fossen, T. I. (1994): Guidance and control of ocean vehicles, John Wiley & Sons, N.Y.

[2] KVH Industries Inc (1994): KVH Active Stabilized Antenna Pedestal Technical Manual

[3] Horowitz, I. M. (1963): Synthesis of feedback systems, Ionnia International, Llc, MI

[4] Koh, Woon-Yong, Hwang, Seung-Wook and Jin, Gang-Gyoo (2002): Stabilization and Tracking Algorithms of a Shipboard Satellite Antenna System, Journal of Control, Automation and Systems Engineers, Vol. 8, No. 1, pp. 67-73

[5] Shin, Myung-Ho, Kim, Min-Jeong, Lee, Yun-Hyung, So, Myung-Ok and Jin, Gang-Gyoo (2006): System Parameter Estimation and PID Controller Tuning Based on PPGAs, Journal of Control, Automation and Systems Engineers, Vol. 12, No. 7, pp. 644-649

[6] Jin, Gang-Gyoo and Joo, Sang-Rae (2000): A Study on a Real-Coded Genetic Algorithm, Journal of Control, Automation and Systems Engineers, Vol. 6, No. 4, pp. 268-275

[7] Jin, Gang-Gyoo (2000): Genetic Algorithms and Their Applications, KyoWoo Sa