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Building of the Controller for the Longitudinal Channel of the Gliding Flight Equipment

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A B S T R A C T

This research aims to build an optimal controller by focusing on maximizing control within a given bandwidth, along with minimizing the influence of noise and the number of erroneous inputs. Based on the vertical mathematical model of gliding flight equipment, we will build a controller for the longitudinal motion channel of this type of gliding flight equipment. By using control theory in the extremely standard Hardy vector space, the article presents a controller capable of meeting the application well with the required quality criteria, minimizing the impact of noise, and bad input as well as fixed variables and model systems. Survey results on Matlab Simulink show the effectiveness of this controller in eliminating noise effects and errors in the model due to the systematized linear process, thereby achieving a high level of control desired for vertical channel switching of gliding flight equipment.

Keywords: H infinity, Linear Time Invariant

Introduction

Control theory H_∞ is considered one of the most advanced control methods today, which is fast response and high stability. The controller H_∞ has been researched and applied by many Vietnamese and world scientists. In the document [1], the author introduced the theory of modern controllers and focused on analysis, giving examples and applications of controllers H_∞. Based on the content of this document, researchers can apply it to systems on specific devices in practice. Meanwhile, the author [2] uses the classic PID controller and the improved PID controller to control the height of the glide bomb. The effectiveness of the algorithm is demonstrated by simulation on Matlab and the results show that the improved PID controller has outstanding performance in the presence of noise. On the other hand, Kemin Zhou and John C. Doyle present detailed content on sustainable control, how to build and enhance controllers H_∞ and practical applications. The content of the document is an important basis for researchers to learn more about the application of the controller H_∞.

On the other hand, Mikael Johansson introduced a theoretical system of modern controllers such as fuzzy logic, sliding mode, H_∞, and hybrid controllers. The new approach helps researchers have a different perspective on today's new controllers. Author [5]; [6] presents the controller in detail; and its practical applications. The article [7] presents the problem of optimizing the long range trajectory for guided bombs operating in the subsonic and subsonic ranges based on the application of a two stage trajectory scheme. In particular, the optimization of the early orbital phase is the focus of the article, with the desire to make the most of the kinetic and potential energy from the initial conditions of the orbit. The research purpose of the article is to create a long range reference trajectory for a controlled bomb in the form of a mathematical polynomial to serve the problem of bomb control.

The above studies are mostly theoretical and have not included specific evaluations of actual equipment. Therefore, in their study, the authors applied the H_∞ controller to a gliding flight equipment. Based on the H_∞ controller method, it can be used to design automatic controllers for dynamic systems. On the other hand, this method focuses on maximizing control efficiency within a certain frequency range, along with minimizing the influence of input noise and errors. The block diagram of the standard $P-K$ controller is shown in Figure 1.

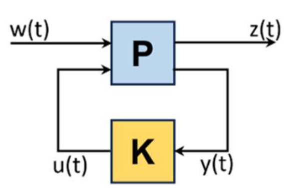

Fig.1. Diagram of controller H_∞ using form $P-K$

2. Material and methods

2.1. Mathematical model of the vertical motion channel of the gliding flight equipment

The gliding flight equipment model and its motion parameters are shown in Figure 2.

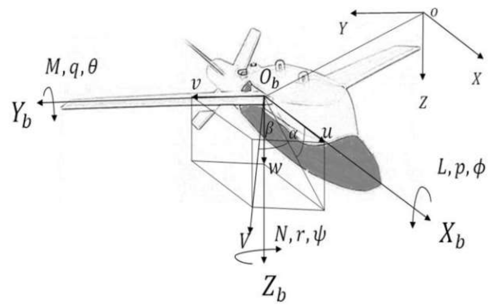

Fig.2. Parameter of the gliding flight equipment

Where: X, Y, Z- position coordinates; u, v, w- velocity coordinates;

ϕ, θ, ψ- roll, Pitch, Yaw angle; p, q, r- roll, Pitch, Yaw rate;

M, L, N- coordinate moments; α- Attack angle; β- Slide-slip angle;

The system of longitudinal motion equations of the gliding flight equipment has the form [2]:

$$\dot{v} = \frac{F_y}{m} - ru - pw \tag{1}$$

$$\dot{q} = \frac{1}{I_y}\left(M + \left(I_z - I_x\right)rp\right) \tag{2}$$

$$\dot{\theta} = qcos\phi - rsin\phi \tag{3}$$

Where: $I_x; I_z$ moment of inertia along the respective axes ($kg.m^2$).

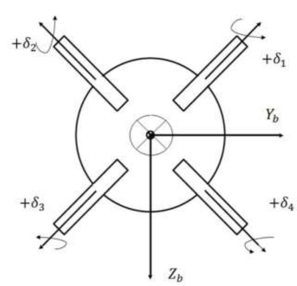

Fig.3. Positive deflection of control fins viewed from the rear

Based on the results of the survey and experimental verification, optimal parameters have been calculated and given for the relationship between the two pairs of rudders and the three control channels of the adjusted aircraft. This relationship is expressed through equation (4):

$$\begin{bmatrix} \delta_r \\ \delta_p \\ \delta_y \end{bmatrix} = \begin{bmatrix} 0.25 & 0.25 & 0.25 & 0.25 \\ 0.25 & -0.25 & -0.25 & 0.25 \\ 0.25 & 0.25 & -0.25 & -0.25 \end{bmatrix} \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \end{bmatrix} \tag{4}$$

However, a problem is that the above differential equations are non-linear, and it is difficult to solve these equations directly even with available mathematical and computational tools. To overcome and simplify the solution of the above equations, people linearize the system mathematical model through the quantization of differential equations at the same working time.

$$\Delta\dot{v} = \frac{-R_y^v}{m}\Delta v + \left(\frac{-R_y^r}{m} - u_0\right)\Delta r + g\cos\theta_0\Delta\varphi + \frac{R_y^{\delta_y}}{m}\Delta\delta_y \tag{5}$$

$$\Delta\dot{q} = \frac{M^u}{I_y}\Delta u + \frac{M^w}{I_y}\Delta w + \frac{M^q}{I_y}\Delta q + \frac{M^{\delta_p}}{I_y}\Delta\delta_p \tag{6}$$

$$\Delta\dot{\theta} = \Delta \mathrm{q} \tag{7}$$

Based on the linearization model, the transfer function according to the roll, pitch, and yaw motion channels of the corrected flight device are respectively:

$$\frac{\phi(s)}{\delta_r(s)} = \frac{-256.1}{s(s+41.01)} \tag{8}$$

$$\frac{\theta(s)}{\delta_p(s)} = \frac{-312.33(s+1.729)}{s\left(s^2+3.034s+129.3\right)} \tag{9}$$

$$\frac{\psi(s)}{\delta_y(s)} = \frac{267.6(s+0.063)}{s\left(s^2+1.034s+61.32\right)} \tag{10}$$

The system's actuator transfer function for each channel has the following form:

$$\frac{\delta_{\text{out}}(s)}{\delta_{\text{in}}(s)} = \frac{60}{s+60} \tag{11}$$

Where: δ_{in} - command deflection from the controller, δ_{out} - actuator output deflection of the controller.

Based on equations from 8 to 11, in this study, an examination was conducted on the reaction exhibited by the angular and oscillation characteristics of the command deflection angle signal in Matlab Simulink under ideal conditions, excluding any noise interference. The findings obtained from this investigation have been visually represented in Figures 4 through 7.

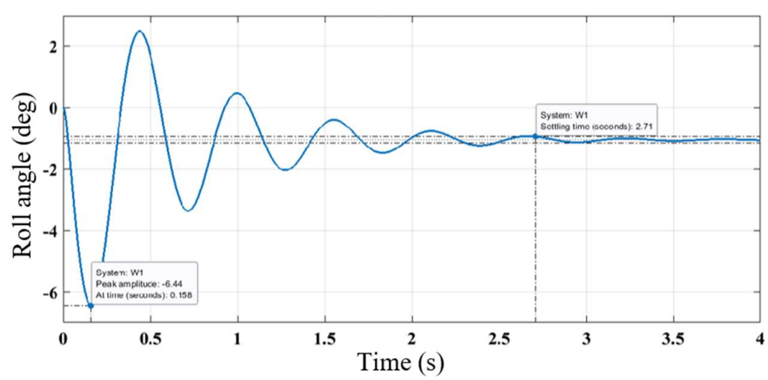

Fig.4. Roll angle step response

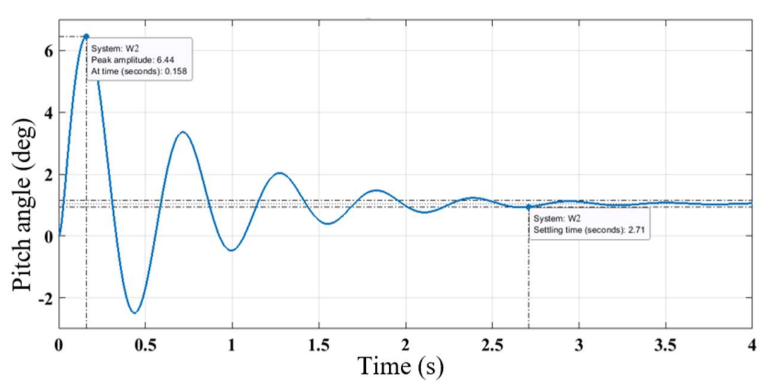

Fig.5. Pitch angle step response

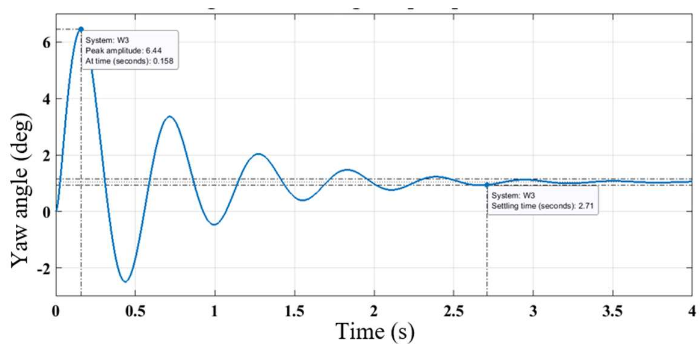

Fig.6. Yaw angle step response

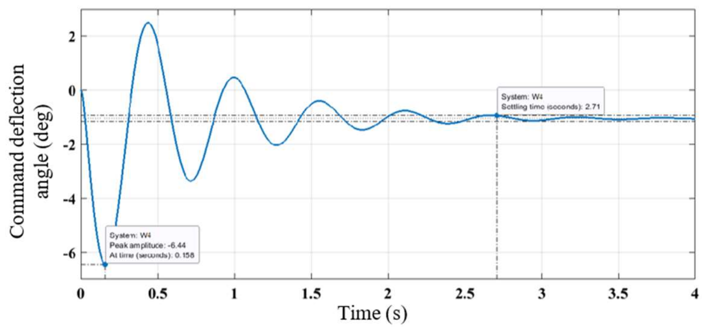

Fig.7. Command deflection angle step response

From the survey results of the longitudinal motion open loop circuit of the gliding flight equipment (Figure 4 to 7), the system's response when changing control actions is unstable. The system oscillates about 3-4 times, with large overcorrections and errors in the pitch angle and yaw angle parameters. These parameters do not meet the stability standards of an automatic control system.

2.2. Controller H_∞

2.2.1. Standard structure of $P-K$ form

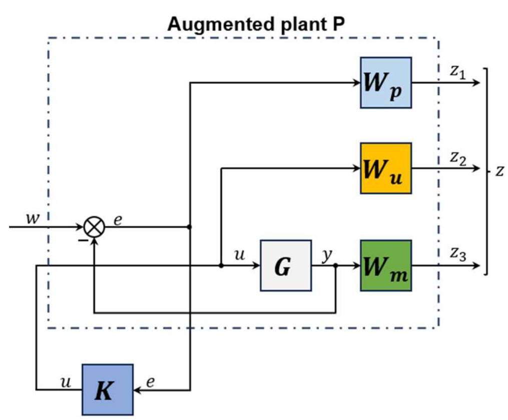

Fig.8. System diagram using controller H_∞

- Open system:

$$\begin{bmatrix} z \\ y \end{bmatrix} = \underbrace{\begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix}}_{P} \begin{bmatrix} w \\ u \end{bmatrix} \Leftrightarrow \begin{bmatrix} z \\ y \end{bmatrix} = P \begin{bmatrix} w \\ u \end{bmatrix} \qquad (12)$$

Where: w: external input signals (including set signals, noise...); z : signal to the outside; u : controller output signal; y : controller input signal; P : the expanded matrix.

- Control law: $u = -Ky$

- Closed system: $z = P_{11} + P_{12}\left[I - KP_{22}\right]^{-1} KP_{21}w$

- Closed transfer function from w to z : $T_{zw} = P_{11} + P_{12}\left[I - KP_{22}\right]^{-1} KP_{21}$

2.2.2. Optimal design problem H_∞

Design the controller K so that the minimum standard H_∞ of the transfer function $w(t)$ from to $z(t)$ satisfies:

$$\min K_{\text{stabilizing}} \left\|T_{zw}\right\|_\infty \Leftrightarrow \min_{K \text{ stabilizing}} \left\|P_{11} + P_{12}K\left[I - P_{22}K\right]^{-1} P_{21}\right\|_\infty \tag{13}$$

The optimization problem H_∞ cannot be solved in the general case. At this point, we return to the suboptimal problem H_∞.

Find a controller K such that the standard H_∞ of the transfer function from $w(t)$ to $z(t)$ is less than the $\gamma > 0$ given coefficient. In the general case described by the system of state equations:

$$\begin{cases} \dot{x}(t) = Ax(t) + B_1 w(t) + B_2 u(t) \\ z(t) = C_1 x(t) + D_{12} u(t) \\ y(t) = C_2 x(t) + D_{21} w(t) \end{cases} \tag{14}$$

$$P(s) := \begin{bmatrix} A & B_1 & B_2 \\ C_1 & 0 & D_{12} \\ C_2 & D_{21} & 0 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = C\left[sI - A\right]^{-1} B + D \tag{15}$$

The conditions for the existence of a solution to the problem are: (A, B_1) controllable and (C_1, A) observable; (A, B_2) stable and (C_2, A) detectable; $D_{12}^*\left[C_1 \quad D_{12}\right] = \left[0 \quad I\right]$; $\begin{bmatrix} B_1 \\ D_{21} \end{bmatrix} D_{21}^* = \begin{bmatrix} 0 \\ I \end{bmatrix}$;

Suboptimal problem $H_\infty : \left[K_{subopt}, T_{zw}, \gamma_{subopt}\right] = h\inf syn\left(G, n_y, n_u, \gamma_{\min}, \gamma_{\max}, \gamma_{opt}\right)$; G : communication matrix of LTI; n_y : number of measured variables in the system; n_u : number of control variables in the system; $\left[\gamma_{\min}, \gamma_{\max}\right]$: gamma value range; K_{subopt} : control matrix H_∞; T_{ZW} : function that communicates the system's closing response to the controller; γ_{subopt} : the level of performance achieved with the controller.

In Figure 4 are the response results of the longitudinal motion channel parameters of the hover device when using the controller for a system that is not affected by noise.

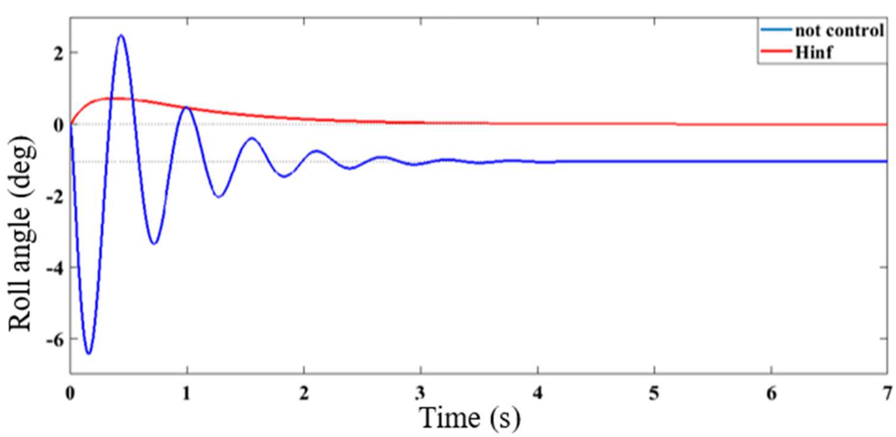

Fig.9. Roll angle step response using H_∞ control

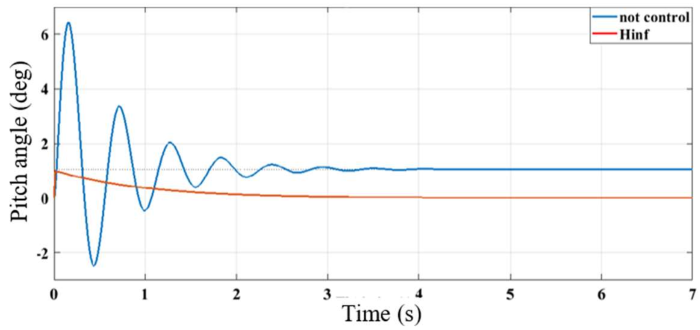

Fig.10. Pitch angle step response using H_∞ control

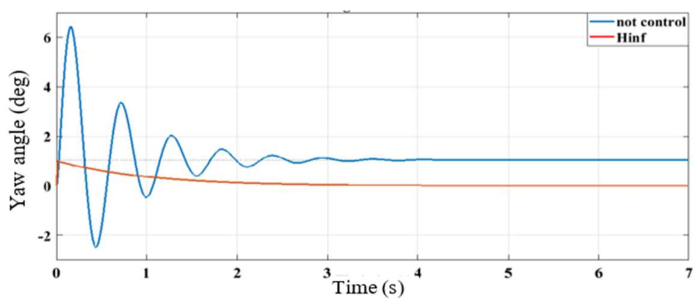

Fig.11. Yaw angle step response using H_∞ control

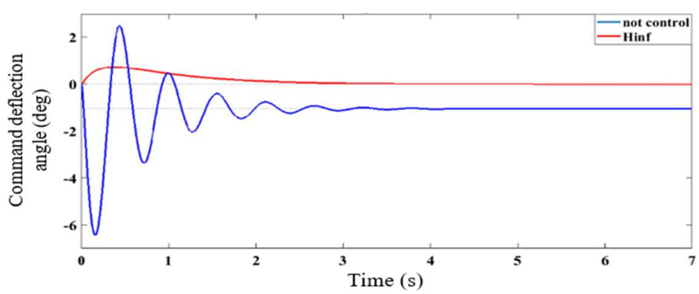

Fig.12. Command deflection angle step response using H_∞ control

Observing the results from Figure 9 to Figure 12, we see that without the control system H_∞, the longitudinal motion channel parameters of the gliding flight equipment fluctuate with a relatively large overcorrection. All have static errors (the roll angle error is about $1\deg$, the pitch angle is nearly $0.7\deg$, the yaw angle is about $0.6\deg$, command deflection angle is approximately $1\deg$). On the other hand, we see that when using the controller H_∞, the longitudinal motion channel parameters of the adjusted flight device meet the quality criteria of an automatic control system relatively well. However, when building a mathematical model to provide the system transfer function, the process of linearizing the parameters in the model causes errors compared to the actual model of the system. Therefore, during the process of building the controller, we change the parameters of the system's uncertainty model to survey and verify the quality of this newly built controller H_∞.

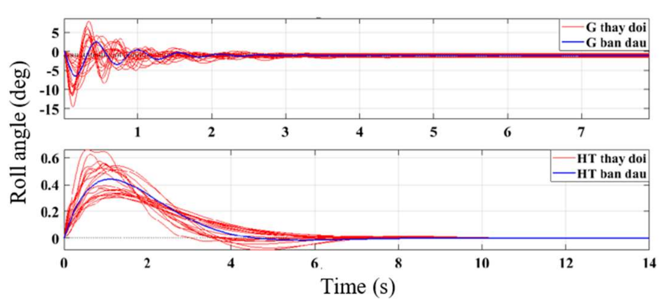

Fig.13. Roll angle step response using H_{inf} control taking into consideration the uncertain changes in model parameters

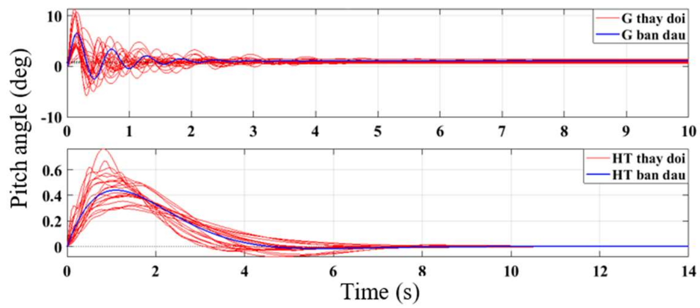

Fig.14. Pitch angle step response using H_{inf} control taking into consideration the uncertain changes in model parameters

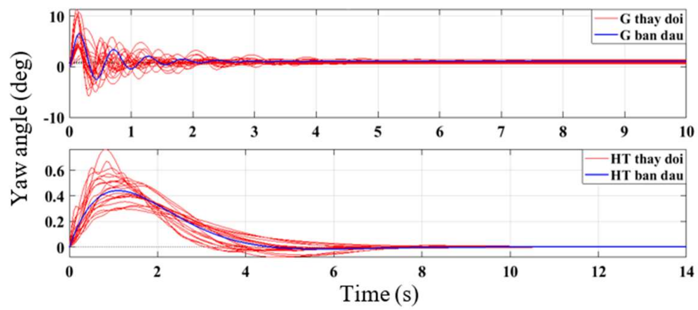

Fig.15. Yaw angle step response using H_{inf} control taking into consideration the uncertain changes in model parameters

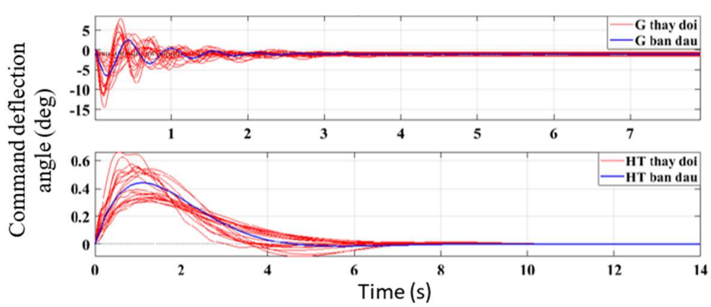

Fig.16. Command deflection angle step response using H_{inf} control taking into consideration the uncertain changes in model parameters

Figure (13-16) is the impulse response result of the original system G . The system uses a controller with changing model parameters, which is not affected by noise. The survey results show that the system with a controller satisfies the quality criteria of a system with an uncertain model without interference. To comprehensively evaluate the system with this controller, we in turn investigate the system transient response with the initial model and the uncertain model when there are disturbances.

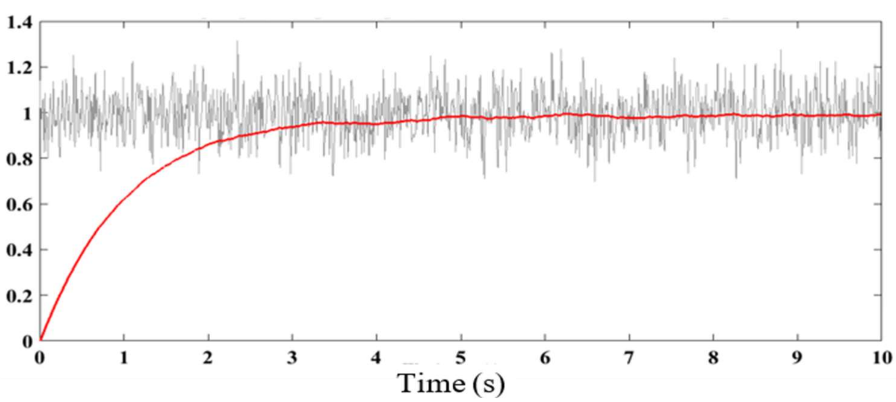

Fig.17. System response with the initial model taking into consideration disturbances

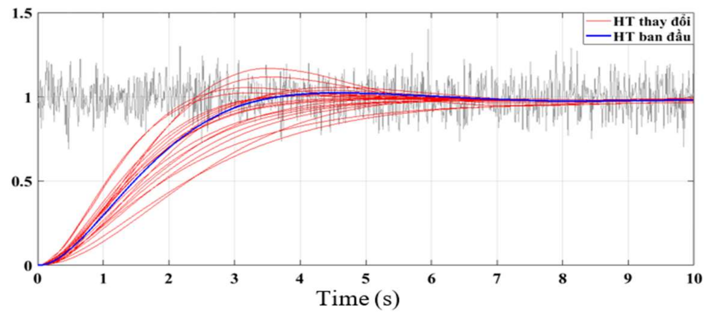

Fig.18. System response with the uncertain model taking into consideration disturbances

Through surveying the system transient response with the initial model (Figure 17) and the uncertain model when there are impact disturbances (Figure 18); when there are errors in the system mathematical model, and when there are additive disturbances, the system using the H_∞ controller satisfies the quality criteria of an automatic control system.

Discussion and conclusion

Utilize the H_∞ the controller in the conventional $P-K$ form for the longitudinal motion channel of the gliding flight equipment (Figure 4 to Figure 7). Examine the response to the longitudinal motion parameters of the gliding flight equipment with the implementation of the H_∞ controller (Figure 9 to Figure 12), considering discrepancies in the mathematical model of the system (Figure 13 to Figure 16), both in scenarios with and without dynamic additive disturbances (Figures 17, 18). Employing the H_∞ controller results in the longitudinal motion parameters of the adjusted aerial vehicle conforming to the criteria of an automated control system devoid of oscillations and static inaccuracies. Evaluation of the setup time under conditions involving dynamic additive noise is essential. Consequently, within the domain of aerospace engineering systems, researchers are capable of employing the H_∞ controller model to govern diverse intricate entities, thereby enhancing the efficacy of controlling extensive aviation systems.

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