DESIGN OF A ROBUST LPV CONTROL SYSTEM FOR AN UNMANNED OBSERVATION BLIMP

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Abstract

This paper applies LPV(Linear Parameter Varying) control techniques to a blimp. The aim of the project is the development of a practical technique for the unmanned aerial observation and surveillance. In order for a blimp to perform observation and detection, precise flight path control is needed. The error resulting from modeling a real system cannot be avoided, however accurate the model is. In order to aim for realistic control, robust control can compensate model uncertainty. Based on past works, the author developed a robust lateral-directional stability augmentation system in the framework of the H∞ theory that could take account of the uncertain ranges of parameters, and successfully implemented it on the blimp. A problem exits, however, that the designed control system guarantees its effectiveness for only one design speed, although in a practical situation the flight-speed may vary within a certain operation range. Therefore, this paper is aimed at designing the lateral-directional flight control system that guarantees a certain degree of stability over all the operation range. It is shown that the resulting LPV robust controller yields a better performance than the corresponding H∞ controller.

1. Introduction

A blimp, a small-sized, non rigid airship, has been drawing attention as a safer platform for remote-sensors aimed at unmanned low-altitude observation and surveillance than a heavier-than-air craft, because it is not in direct contact with the ground, and will not crash as the result of an engine failure. The operation of such a blimp presupposes the down-sizing of on-board sensors and development of autonomous flight control systems that may withstand ambient air conditions and parameter uncertainties within an operating range. The paper is focused on the development of a robust flight controller for such a blimp.

Past works(Refs.1 and 2) developed the method for experimentally identifying the linear flight dynamics about a specific, constant-speed, level flight for the blimp introduced as a platform for remote-sensors to detect metallic objects buried underground. They also proposed the analytical formulas for estimating the parameters involved in the linear dynamics, enabling one to assess the uncertain ranges of the parameters, especially those of added mass and inertia that are characteristic of lighter-than-air craft. Based on these past works, the author developed a robust lateral-directional stability augmentation system in the framework of the H∞ theory that could take account of the uncertain ranges of parameters, and successfully implemented it on the blimp(Ref.3). A problem exits, however, that the designed control system guarantees its effectiveness for only one design speed, although in a practical situation the flight-speed may vary within a certain operation range. Therefore, this paper is aimed at designing a lateral-directional flight control system that guarantees a certain degree of stability over all the operation range. The reason why only the lateral-directional control is dealt with is that the blimp at hand lacks lateral-directional stability in particular because of its tail-volume size, and in the linear sense longitudinal modes, which are sufficiently stable, are decoupled from lateral-directional modes. To this end, this work applies the Gain-Scheduling-Technique, a technique within the framework the Linear-Parameter-Varying-Systems theory: The lateral-directional control gain is continuously scheduled according to the flight speed. At the same time, the uncertainty of the parameters is also taken into consideration in the H∞ sense.

The paper is structured as follows: Following Introduction, Section 2 shows the original nonlinear equations of motion and corresponding linearized ones. For the latter, how the parameters change according to the flight speed, and the uncertain ranges at discrete flight speeds are also demonstrated. Section 3 shows formulation of the Gain-Scheduling Technique and designs a Gain-Scheduling controller for the lateral-directional modes of the blimp in Section 4. The result of simulations and examinations are discussed in Section 5, and finally conclusions are shown in Section 6.

2. Dynamic Equations of Motion of a Blimp

Development of the equations of motion for a blimp must take into account two significant factors: buoyancy and added mass and inertia. Through the use of Lagrange's equation, general nonlinear equations of motion can be described with respect to a body-fixed-axis system with the origin placed at an arbitrary point in the hull. For control purposes, linearized equations of motion must be derived. To simplify the problem, the following assumptions are set:

1. The trimmed condition is a steady rectilinear level flight.
2. Ambient atmosphere is stationary.
3. The mass of the blimp is constant.
4. The origin of the body-fixed-axis system is placed at the center of buoyancy as shown in Fig. 1
5. The blimp is symmetric about the oxz plane, and both the center of gravity and the center of buoyancy lie in that plane.

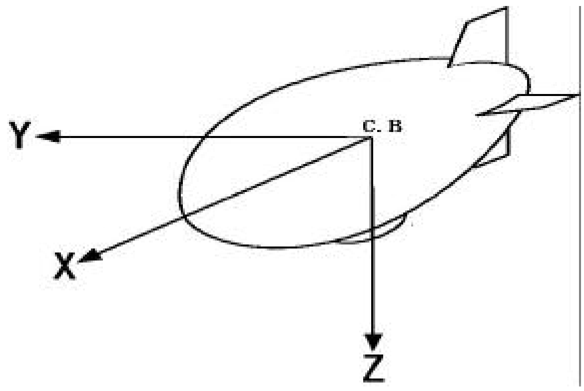


Fig.1 Body axis system.
(C.B.: Center of buoyancy)

The resulting linearized equations of motion can be divided into the longitudinal set and lateral-directional set as[1)]

(Longitudinal set)

$$\mathbf{M}_{LG}\dot{\mathbf{x}}_{LG} = \mathbf{A}_{LG}\mathbf{x}_{LG} + \mathbf{Q}_{LG}\,, \qquad (2\text{-}1)$$

$$\mathbf{x}_{LG} = [u \quad w \quad q \quad q]^{\mathrm{T}}\,, \qquad (2\text{-}2)$$

$$\mathbf{Q}_{LG} = [X \quad Z \quad M \quad 0]^{\mathrm{T}}\,, \qquad (2\text{-}3)$$

and

(Lateral-directional set)

$$\mathbf{M}_{LT}\dot{\mathbf{x}}_{LT} = \mathbf{A}_{LT}\mathbf{x}_{LT} + \mathbf{Q}_{LT}\,, \qquad (2\text{-}4)$$

$$\mathbf{x}_{LT} = [v \quad p \quad r \quad f \quad y]^{\mathrm{T}}\,, \qquad (2\text{-}5)$$

$$\mathbf{Q}_{LT} = [Y \quad L \quad N \quad 0 \quad 0]^{\mathrm{T}}\,, \qquad (2\text{-}6)$$

where

u, v, w : perturbed linear velocities,
p, q, r : perturbed angular velocities,
f, q, y : perturbed Eulerian angles,
X, Y, Z : perturbed external forces, and
L, M, N : perturbed external moments.

In Eqs. (2-1) and (2-4), coefficient matrices are given as

$$\mathbf{M}_{LG} = \begin{bmatrix} m_{11}^{LG} & m_{12}^{LG} & m_{13}^{LG} & 0 \\ m_{21}^{LG} & m_{22}^{LG} & m_{23}^{LG} & 0 \\ m_{31}^{LG} & m_{32}^{LG} & m_{33}^{LG} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \qquad (2\text{-}7)$$

$$\mathbf{A}_{LG} = \begin{bmatrix} a_{11}^{LG} & a_{12}^{LG} & a_{13}^{LG} & a_{14}^{LG} \\ a_{21}^{LG} & a_{22}^{LG} & a_{23}^{LG} & a_{24}^{LG} \\ a_{31}^{LG} & a_{32}^{LG} & a_{33}^{LG} & a_{34}^{LG} \\ 0 & 0 & 1 & 0 \end{bmatrix}, \qquad (2\text{-}8)$$

$$\mathbf{M}_{LT} = \begin{bmatrix} m_{11}^{LT} & m_{12}^{LT} & m_{13}^{LT} & 0 & 0 \\ m_{21}^{LT} & m_{22}^{LT} & m_{23}^{LT} & 0 & 0 \\ m_{31}^{LT} & m_{32}^{LT} & m_{33}^{LT} & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}, \qquad (2\text{-}9)$$

$$\mathbf{A}_{LT} = \begin{bmatrix} a_{11}^{LT} & a_{12}^{LT} & a_{13}^{LT} & a_{14}^{LT} & 0 \\ a_{21}^{LT} & a_{22}^{LT} & a_{23}^{LT} & a_{24}^{LT} & 0 \\ a_{31}^{LT} & a_{32}^{LT} & a_{33}^{LT} & a_{34}^{LT} & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}, \qquad (2\text{-}10)$$

where

$\mathbf{M}_{LG}, \mathbf{M}_{LT}$: mass matrices including added mass effects, and

$\mathbf{A}_{LG}, \mathbf{A}_{LT}$: stability-derivative matrices.

It is possible to estimate the parameter values in matrices Eqs. (2-7) ~ (2-10) by using analytical formulas such as those described in Ref.4 for added mass effects and those collected in Ref. 5 for stability derivatives, while a constrained flight test method for identifying the parameters was developed in Refs. 1 and 2, which uses a real blimp (presented in Fig. 2). The dimensional data of the blimp are shown in Table 1.

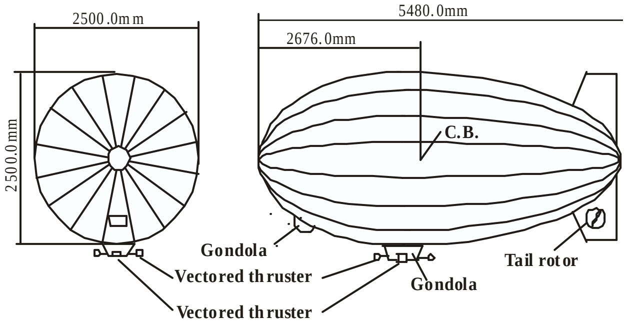


Fig.2 The blimp, Sky Probe-J.

Table 1 Dimensional data for Sky Probe-J

Mass [Kg]	21.87
Length [m]	5.50
Width [m]	2.50
Moment of inertia, I_{xx} [kg·m^2]	22.98
Moment of inertia, I_{yy} [kg·m^2]	40.98
Moment of inertia, I_{zz} [kg·m^2]	27.69
Product of inertia, I_{xz} [kg·m^2]	3.941
X_G [m]	0.06690
Z_G [m]	0.5470
X_{thrust} [m]	0.60
Z_{thrust} [m]	0.13
X_{tail} [m]	2.40
Z_{tail} [m]	0.80
Volume [m^3]	18.0
Propulsion : 4 vectoring thrusters, and a pair of tail rotors	 400gf for each 100gf for each
Fins (Cross-wing)	NACA0008

In this motion model, it is found that the yawing-motion mode is unstable, showing that lateral-directional movements become unstable. Therefore, control is needed in order to stabilize the divergent mode. Seeing to it that there exist parameter uncertainties, robust SASs(stability augmentation systems) are designed here as a yaw damper (i.e., yaw rate(r) feedback controller) with the use of a pair of tail rotors as the controller.

3. Gain-scheduled Controller Design by LMI

The technique of designing a gain-scheduled controller using LMI in the form appropriate for the purpose is explained.

First, suppose that the generalized plant as shown in Fig. 3 is given.

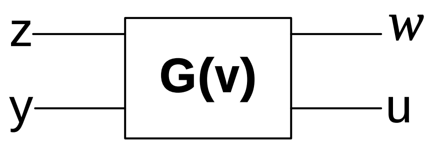


Fig.3 Generalized plant.

At this time, a linear parameter-varying(LPV) plant G(v) with state-space realization is

$$\begin{cases} \dot{x} = A(v)x + B_1 w + B_2 u \\ z = C_1 x + D_{11} w + D_{12} u \\ y = C_2 x + D_{21} w \end{cases} . \qquad (3\text{-}1)$$

The time-varying parameter of velocity $v = [v_1, v_2, \cdots, v_L]^T$ as well as its rates of variation $\dot{v}_i$ are assumed bounded as follows.

1) Each parameter v_i ranges between known extremal values $\underline{v}_i$ and $\overline{v}_i$

$$v_i(t) \in [\underline{v}_i, \overline{v}_i] \quad \forall t \geq 0 . \qquad (3\text{-}2)$$

2) The rate of variation $\dot{v}_i$ is assumed well-defined at all times and satisfies

$$\dot{v}_i(t) \in [\underline{b}_i, \overline{b}_i] \quad \forall t \geq 0, \tag{3-3}$$

where $\underline{v}_i \leq \overline{v}_i$ and $\underline{b}_i \leq \overline{b}_i$ are known lower and upper bounds.

The gain-scheduled output-feedback control problem consists of finding a dynamic LPV controller, $K(v)$, with state-space equations

$$\begin{cases} \dot{x}_K = A_K(v,\dot{v})x_K + B_K(v,\dot{v})y_K \\ u = C_K(v,\dot{v})x_K + D_K(v,\dot{v})y_K \end{cases} \tag{3-4}$$

which ensure internal stability and a guaranteed L_2-gain bound g for the closed-loop operator Eqs. (3-1)-(3-4) from the disturbance signal w to the error signal z, that is

$$\int_0^T z^T z dt \leq g^2 \int_0^T w^T w dt, \quad \forall T \geq 0 \tag{3-5}$$

and for all admissible trajectories $(v, \dot{v})$ and zero-state initial conditions. Note that A and A_K have the same dimension. The formulation of such controllers can be handled via an extension of the bounded real lemma with quadratic parameter-dependent Lyapunov functions $V(x_{cl}, v) = x_{cl}^T P(v) x_{cl}$ where x_{cl} stands for the state vector of the closed-loop system. The controller state-space matrices are allowed to depend explicitly on the derivative of the time-varying parameter v. The controller of Fig. 4 is a certain value showing the control performance to disturbance.

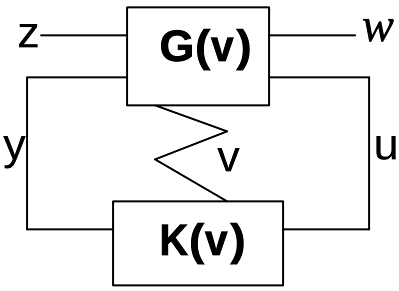


Fig. 4 Gain-scheduled feedback controller.

Except for the usual smoothness assumptions on the dependence on v, the problem data and variables will be unrestricted in the subsequent derivations. The basic characterization of gain-scheduled controllers with guaranteed L_2-gain performance is presented in the next theorem where the dependence of data and variables on v and $\dot{v}$ has been dropped for simplicity.

Theorem 1)
Consider an LPV plant governed by Eq. (3-1), with parameter trajectories constrained by Eqs. (3-2), (3-3). There exist a gain-scheduled output-feedback controller Eq. (3-4) enforcing internal stability and a bound g on the L_2 gain of the closed-loop system Eq. (3-1) and Eq. (3-5), whenever there exist parameter-dependent symmetric matrices Y and X and a parameter-dependent quadruple of state-space data $(\hat{A}_K,\ \hat{B}_K,\ \hat{C}_K,\ D_K)$ such that for all pairs $(v, \dot{v})$ the following LMI problem holds as shown in Eq. (3-7) at the bottom of the page, together with

$$\begin{bmatrix} \dot{X}+XA+\hat{B}_K C_2+A^T X+C_2^T\hat{B}_K^T & \hat{A}_K+(A+B_2D_KC_2)^T & XB_1+\hat{B}_K D_{21} & (C_1+D_{12}D_KC_2)^T \\ \hat{A}_K^T+A+B_2D_KC_2 & -\dot{Y}+AY+B_2\hat{C}_K+YA^T+C_K^TB_2^T & B_1+B_2D_KD_{21} & (C_1Y+D_{12}\hat{C}_K)^T \\ (XB_1+\hat{B}_KD_{21})^T & (B_1+B_2D_KD_{21})^T & -gI & (D_{11}+D_{12}D_KD_{21})^T \\ C_1+D_{12}D_KC_2 & C_1Y+D_{12}\hat{C}_K & D_{11}+D_{12}D_KD_{21} & -gI \end{bmatrix} < 0 \tag{3-7}$$

$$\begin{aligned} A_K &= N^{-1}(X\dot{Y}+N\dot{M}^T+\hat{A}_K - X(A-B_2D_KC_2)Y - \hat{B}_KC_2Y - XB_2\hat{C}_K)M^{-T}, \\ B_K &= N^{-1}(\hat{B}_K - XB_2D_K), \\ C_K &= (\hat{C}_K - D_KC_2Y)M^{-T} \end{aligned} \tag{3-9}$$

$$\begin{bmatrix} X & I \\ I & Y \end{bmatrix} > 0. \qquad (3\text{-}6)$$

In such a case, a gain-scheduled controller of the form Eq. (3-4) is readily obtained with the following two-step scheme:

• Solve for N, M, (the factorization problem)

$$I - XY = NM^T \qquad (3\text{-}8)$$

• From N and M, compute $\hat{A}_K$, $\hat{B}_K$ and $\hat{C}_K$ with Eq. (3-9) at the bottom of the previous page.

Note that since all variables are involved linearly, the constraints Eqs. (3-6) and (3-7) constitute an LMI system, infinite in number due to its dependence on $(v, \dot{v})$. The controller variables can be eliminated, leading to a characterization involving the variable Y and X only.

Consider a plant having an LFT dependence on nonlinear functions of the scheduled variable, that is, whose state-space data further satisfy

$$G(v) := F_u \left\{ \begin{bmatrix} A_r & B_r & B_1 & B_2 \\ C_r & D_{rr} & D_{r1} & D_{r2} \\ C_1 & D_{1r} & D_{11} & D_{12} \\ C_2 & D_{2r} & D_{21} & 0 \end{bmatrix}, \operatorname{diag}_{i=1}^{N}[r_i(v) I_{r_i}] \right\},$$

where $r_i(.)$, $i = 1, \cdots, N$ are differentiable functions of v. Copies of the plant's nonlinear functions, $r_i(.)$, can be introduced into the quadruple $\hat{A}_K(.)$, $\hat{B}_K(.)$, $\hat{C}_K(.)$, $D_K(.)$, and the pair $[X(.), Y(.)]$ in an affine fashion.

$$\begin{aligned}
\hat{A}_K(v) &:= \hat{A}_{K,0} + \sum_{i=1}^{N} r_i(v) \hat{A}_{K,i}, \\
\hat{B}_K(v) &:= \hat{B}_{K,0} + \sum_{i=1}^{N} r_i(v) \hat{B}_{K,i}, \\
\hat{C}_K(v) &:= \hat{C}_{K,0} + \sum_{i=1}^{N} r_i(v) \hat{C}_{K,i}, \\
\hat{D}_K(v) &:= \hat{D}_{K,0} + \sum_{i=1}^{N} r_i(v) \hat{D}_{K,i}, \\
\hat{X}_K(v) &:= \hat{X}_{K,0} + \sum_{i=1}^{N} r_i(v) \hat{X}_{K,i}, \qquad (3\text{-}10) \\
\hat{Y}_K(v) &:= \hat{Y}_{K,0} + \sum_{i=1}^{N} r_i(v) \hat{Y}_{K,i}.
\end{aligned}$$

The functional dependence of Y and X being fixed, the matrices $\hat{A}_{K,0}$, $\hat{A}_{K,i}$, $\cdots$, play the role of decision variables in the infinitely constrained LMI Problems Eqs. (3-6) and (3-7). A simple remedy for turning such problems into a finite set of LMI's is to grid the value set of v, since the derivative $\dot{v}$ appears linearly in the LMI's Eq. (3-7). The overall procedure can be described as follows:

Calculate the equation of motion for the blimp according to the change in the velocity(n) of the blimp. Then compute a controller for each operating point.

Step 1) Define a grid for the value set of v.

Step 2) Minimize g (Supremum of the performance index) subjected to the associated LMI(Linear Matrix Inequalities) constraints.

Step 3) Check the constraints with a denser grid.

Step 4) If step 3) fails, increase the grid density and return to Step 2).

If the performance level g in Step 2 is too high, then the performance weights must be redefined. These results make use of the continuity of the LMIs over the compact parameter and rate-of-variation sets, and the fact that the solution of the synthesis LMIs is uniformly bounded away from zero. When restricted to the parameterization Eq (3-10), the basic and projected characterizations are no longer equivalent. It is checked by numerical experiments whether the resulting controller is an actually appropriate.

4. Controller Design for a Blimp

In this paper, velocity is the parameter of the linear time varying system of the equations of motion for the blimp, and only the matrix A changes according to the velocity. At this time a linear parameter varying plant is Eq.(3-1), where v is the velocity of the blimp(variable parameter). Blimp velocity v range is $0.5 \sim 2.0 m/s$. The matrix A has linear parameters and also nonlinear parameters. Therefore, it is difficult to obtain linearized controllers from the designed controllers at two operation points ; $v = 0.5,\ 2.0m/s$. Accordingly, controllers are designed for each operating range $v = 0.5 \sim 1.0m/s$, $v = 1.0 \sim 1.5m/s$ and $v = 1.5 \sim 2.0m/s$, and switching controllers work when the operating conditions change.

About each operating range, a polytopic matrix $A(v)$ is expressed as

$$A(v) = \sum_{i=1}^{2} a_i(v) A_i,\ a_i \geq 0,\ \sum_{i=1}^{2} a_i = 1\ . \qquad (4\text{-}1)$$

For example, a_1 and a_2 for the velocity range $0.5 \sim 1.0m/s$ are

$$a_1 = \frac{\bar{v} - v}{\bar{v} - \underline{v}} = \frac{1.0 - v}{1.0 - 0.5} = 2 - 2v, \qquad (4\text{-}2)$$

$$a_2 = \frac{v - \underline{v}}{\bar{v} - \underline{v}} = \frac{v - 0.5}{1.0 - 0.5} = 2v - 1,$$

$$A(v) = a_1 A_{0.5} + a_2 A_{1.0} = (2 - 2v) A_{0.5} + (2v - 1) A_{1.0}\ . \qquad (4\text{-}3)$$

From Eq. (3-4), the controller $K_i(v)$ for each operating point model is given by

$$\begin{cases} \dot{x}_{Ki} = A_{Ki}(v) x_{Ki} + B_{Ki}(v) y_{Ki} \\ u = C_{Ki}(v) x_{Ki} + D_{Ki}(v) y_{Ki} \ . \end{cases} \qquad (4\text{-}4)$$

The parameter value v, the values of $A_K(v)$, $B_K(v)$, $C_K(v)$, $D_K(v)$ are derived from the values A_{Ki}, B_{Ki}, C_{Ki}, D_{Ki}. And the gain scheduling controller within each range can be obtained from

$$\begin{bmatrix} A_K(v) & B_K(v) \\ C_K(v) & D_K(v) \end{bmatrix} = \sum_{i=1}^{2} a_i(v) \begin{bmatrix} A_{Ki} & B_{Ki} \\ C_{Ki} & D_{Ki} \end{bmatrix}. \qquad (4\text{-}5)$$

5. Performance Comparison of the Controllers (by computer simulations)

5.1. Simulation results of Gain-scheduled H¥ controller

In order to evaluate the characteristics of the feedback system corresponding to the chosen controller at each operation point, the plant output yaw rate, disturbance d (Fig.5) and the controller input are shown together with the yaw rate output for the zero disturbance and a given command. Some simulation results are shown in Figs. 6~9. The responses of the yaw rate are for the case where the reference input is a step signal (figure (a)). The results with a disturbance are the responses of the yaw rate when the peak magnitude of the disturbance is $\pm 1N$ in the force unit (figure (b)).

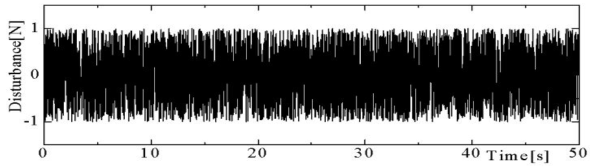
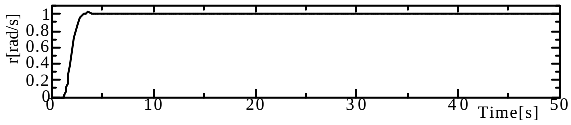
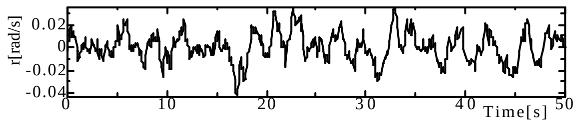


Fig.5 Disturbance signals put into the system : d(t).

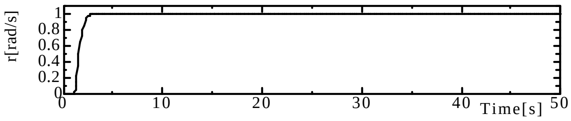


(a) No disturbance case for a step command.

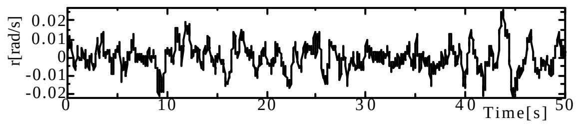


(b) With disturbance for zero command.

Fig.6 Response of yaw rate (velocity=0.5m/s).

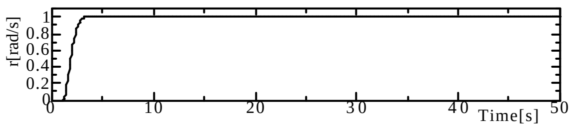


(a) No disturbance case for a step command.

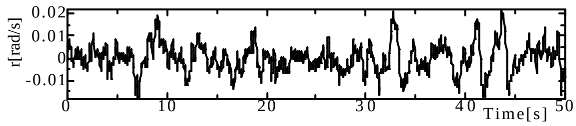


(b) With disturbance for zero command.

Fig.7 Response of yaw rate (velocity=1.0m/s).

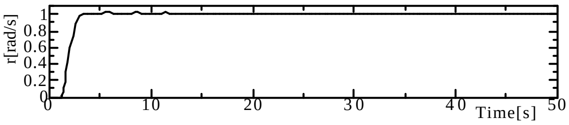


(a) No disturbance case for a step command.

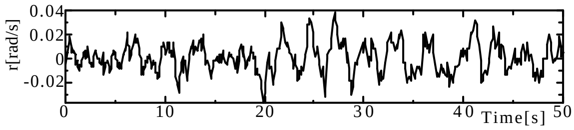


(b) With disturbance for zero command.

Fig.8 Response of yaw rate (velocity=1.5m/s).

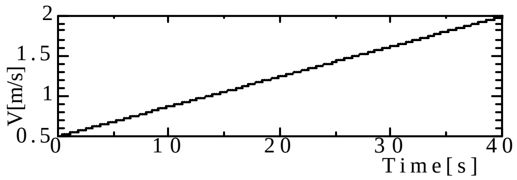


(a) No disturbance case for a step command.

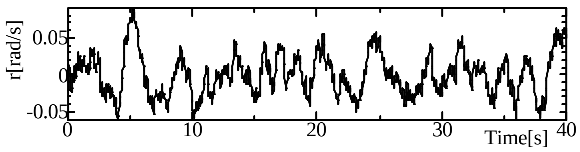


(b) With disturbance for zero command.
Fig.9 Response of yaw rate (velocity=2.0m/s).

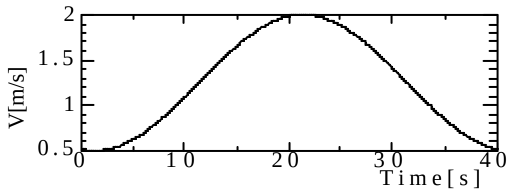
Next, the results of the responses of yaw rate are shown below when velocity changes linearly from 0.5m/s to 2.0m/s (Fig.10), and changes nonlinearly in the form of a sine wave from 0.5m/s to 2.0m/s (Fig.11).



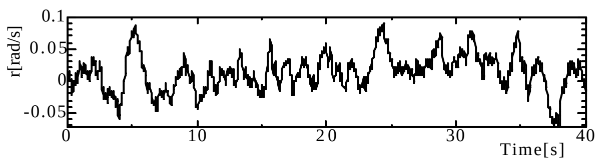
(a) Change in the velocity of the blimp.



(b) Response of yaw rate.
Fig.10 Results for a linear velocity change.



(a) Change in the velocity of the blimp.



(b) Response of yaw rate.
Fig.11 Results for a velocity change in the form of a sine wave.

5.2. Comparison between H¥ controllers [3] and Gain-scheduled H¥ controllers

The results of the comparison for the response of the yaw rate are shown below when the reference input is a step signal (Fig.12). The responses of yaw rate are shown in Fig.13 when the velocity changed in the form of a sine wave from 0.5m/s to 2.0m/s (Fig.11 (a)), together with a disturbance with its peak magnitude of $\pm 1N$ (Fig.5). Table 2 summarizes the comparison, and particular responses are shown in Figs.12~13. It may be said that the Gain-scheduled H∞ controller demonstrates a slightly better tracking capability.

Table.2 Comparison between a Gain-scheduled H∞ controller and an H∞ controller

	Gain-scheduled H∞ Controller	H∞ Controller
Convergence	Fast	Slow
Overshoot	Small	Big
Response	Oscillating	Slow rise time
Robustness	Good	Good

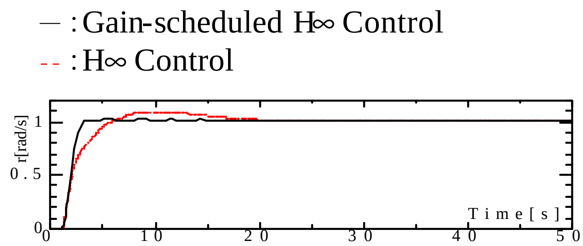


Fig.12 Response of yaw rate (velocity=2m/s).

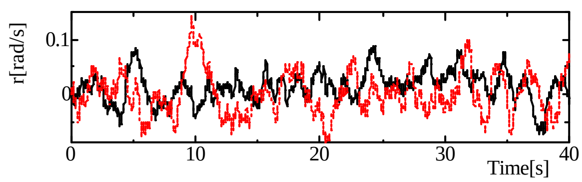


Fig.13 Response of yaw rate
(velocity change in the form of a sine wave).

6. Discussion and Conclusion

Here, "**Design of Robust Control Systems for an Unmanned Observation Blimp**" is summarized, and a future subject is proposed.
The purpose of this research was designing a stabilizing controller for a blimp. The control system design was performed using the Gain-scheduling theory. A controller that presents robust stability with respect to plants with changing velocity has been designed. Very important characteristics of the feedback control system have been attained that the controller is robustly stable, as the result of the formulation of the problem as an LPV gain-scheduled system. The Gain-scheduled H∞ controller and an H∞ controller are compared. It is difficult to talk strictly about which is better, although the Gain-scheduled H∞ controller has faster convergence and the response shows a small oscillating overshoot; while the H∞ controller has slow convergence and a large overshoot. It has been shown that the Gain-scheduled H∞ controller works well within a certain precision needed for the mission of the blimp.

Some future research subjects are summarized as follows :

1. Set up the hardware of acceleration sensors for the control.
2. Execute a real flight test and compare the data from the experiment.
3. Develop newer control methods drawing on the comparison between a Gain-scheduled H∞ controller and an H∞ controller.

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