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H_∞BASEDOBSERVER FOR DISTURBANCE COMPENSATION IN DECOUPLED TRMS USING LMI OPTIMIZATION

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Abstract - Twin Rotor MIMO System is a laboratory model of helicopter. In this paper, the problem of disturbance rejection in TRMS is dealt with. Using disturbance observers, without any additional sensors is an attractive method to attenuate the effects of disturbances as they are highly cost effective. This method uses a simple form of DOBs, which does not need to solve the plant model inverse, and uses H_∞control method using LMIs to design the Q-filter in the DOB. The estimation capability of DOB is verified using simulation results in frequency domain as well as in time domain.

Keywords*- Twin Rotor; TRMS; Disturbance Ohserver; Disturbance Rejection; linear matrix inequalities; H_∞ control.*

I. INTRODUCTION

Paper presents an application of the H_∞ control framework using linear matrix inequalities (LMIs) to a Twin Rotor MIMO System (TRMS), which is a laboratory sized helicopter model, for achieving disturbance rejection using observers.

The helicopter is easily subjected to external disturbances in the form of unexpected air currents, vibration etc. The structural vibrations occurring due to the presence of rotor load at the end of the cantilever beam and motor torque, induces a bending movement, while in operation. These vibrations induce oscillations with long settling time in the system response. Thus it is important to reject these incoming disturbances to ensure smooth operation of the TRMS. However, there haven't been sufficient researches in the area of disturbance rejection in TRMS. This paper is oriented in this direction.

The idea of using disturbance observer (DOB) to improve the performance of servomechanism was introduced in 1970s [1][2] where with the disturbances assumed to be generated by a linear time-invariant dynamic system and then estimated from the system measurements using Luenberger observer. The effects of the disturbances were compensated by feeding back the disturbance estimates into the system. However, the disturbance model is not always available in linear time-invariant form and the identification of disturbance model is not always easy. Subsequently, a new type of DOB that does not need the assumption that the disturbance model is linear time invariant nor require the full information of the disturbance model have been introduced [3]. However, the model of the controlled plant needs to be known accurately and must be invertible. Various ways to design, implement and represent disturbance observers were discussed in [4]. In [5] a simple disturbance observer is introduced that does not need to solve the plant model inverse. The DOB consists of two transfer functions which can be derived directly from the plant model and a Q-filter. As majority of the disturbances are of low frequency, the Q-filter is designed as a low pass filter. An H_∞ control-based method is applied to the design of Q-filter.

H_∞ methods are used in control theory to synthesize controllers achieving robust performance or stabilization. In the standard H∞ control problem the stabilizing controllers are obtained by the solution of a set of Riccatti equations [6]. But the Riccatti approaches have some inherent restrictions tending to limit the scope and performance of control systems. To get around such problems, we give an alternative to the parameterization of ***H***∞ controllers based on the LMI approach. The LMI approaches yield not only existence conditions valid for singular as well as regular problems but also characterizations of H∞ controllers leading to a convex or quasiconvex optimization problem. These resulting optimization problems can be solved numerically very efficiently using recently developed interior-point methods. [7][8].

In this paper, the design procedure of the DOB in [5] is extended to the TRMS set up. The TRMS nonlinear model obtained from the Feedback systems operation manual [9] and [10] is linearized and decoupled using classical decoupling techniques given in [11]. In order to reduce the complexities related with controller design,the simple PID controller is used to ensure that the outputs follow the reference commands [12]. The design of DOB is done using the H∞ control method with the help of LMI algorithms in MATLAB using LMI toolbox provided with it [13].

The remainder of the paper is organized as follows: a description of the system along with the mathematical model is exposed in Section II, followed by an introduction of the disturbance rejection using DOB and the model of the DOB in section III. In Section IV an application of the DOB framework is provided for the TRMS, and simulation resultsare shown and discussed in Section V. Finally, the majorare conclusions drawn are given in Section VI.

II. SYSTEM AND MODELLING

In order to simplify the mechanical design of the system, the mathematical model employed in TRMS is designed slightly differently. Thus TRMS could be seen as a special purpose helicopter where the blades of the rotor have a fixed angle of attack and control is achieved by controlling rotor speeds. As a consequence of this, TRMS presents higher coupling between dynamics of the rigid body and dynamicsof the rotors as compared to a conventional helicopter, andyields a highly nonlinear, strongly cross coupled dynamics. The schematic diagram of TRMS is shown in Fig.1.

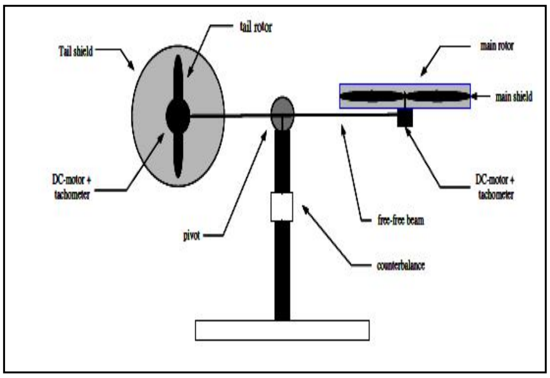

Figure 1: TRMS set up

The TRMS mechanical unit consists of a beam pivoted on its base in such a way that it can rotate freely both in its horizontal and vertical planes. At both end of a beam, there are two propellers driven by DC motors. The aerodynamic force is controlled by varying the speed of the motors. Therefore, the control inputs are the supply voltages of the DC motors. The TRMS system has main and tail rotors for generating vertical and horizontal propeller thrust. The main rotor produces a lifting force allowing the beam to rise vertically making a rotation around the pitch axis. While, the tail rotor is used to make the beam turn left or right around the yaw axis. There is a counter weight fixed to the beam and it determines a stable equilibrium position. This TRMS system has two degrees of freedom (2-DOF), the pitch and the yaw and the only mode of flight is hovering. Either the horizontal or the vertical degree of freedom can be restricted to 1 degree of freedom using the screws.

Apart from the mechanical unit, the electrical unit placed under the unit pays an important role for TRMS control. It allows for the measured signal transfer to PC and the control signal application via an I/O card. The measured signals are: position of beam in space, i.e. two position angles. The controls of the system are the motor supply voltages. A change in the voltage value results in a change of rotation speed of the propeller which results in a corresponding change in position of beam. Thus there are two inputs– horizontal and vertical motor voltages and two output – pitch and yaw angles which make TRMS a MIMO system.

TRMS MODEL

Various forces acting on the system are represented in Fig:2 [9]. According to the electrical-mechanical figure the nonlinear model of the system can be developed:

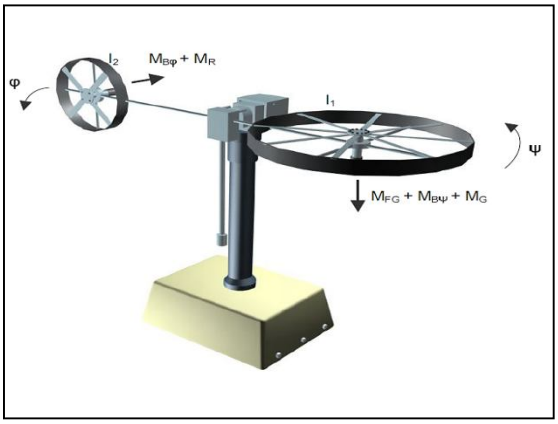

Figure 2: TRMS phenomenological model

As far as the mechanical unit is concerned, the following momentum equations can be derived for the vertical movement, where $\boldsymbol{\psi}$ represents the pitch angle and $\boldsymbol{\phi}$ the yaw angle.

$$I_1.\ddot{\psi} = M_1 + M_{FG} + M_{B\psi} + M_G \quad (1)$$

where.

$$M_1 = a_1.\tau_1^2 + b_1\tau_1 - nonlinear\ static\ characteristic$$

$$M_{FG} = M_g.sin\psi - gravity\ momentum$$

$$M_{B\psi} = B_{1\psi}.\dot{\psi} + B_{2\psi}.sign(\dot{\psi}) - frictional\ forces\ momentum$$

$$M_G = K_{gy}.M_1.\dot{\phi}.cos\psi - gyroscopic\ momentum$$

The motor and the electrical circuit are approximated by a first order transfer function. Thus in Laplace domain, the motor momentum is given by,

$$\tau_1 = \frac{k_1}{T_{11}s+T_{10}}.u_1 \quad (2)$$

Similar equations refer to the horizontal plane motion:

$$I_2.\ddot{\phi} = M_2 - M_{B\psi} - M_R \quad (3)$$

where. $.\tau_2^2 + b_2\tau_2$

$$- nonlinear\ static\ characteristic$$

$$M_{B\psi} = B_{1\psi}.\dot{\psi} + B_{2\psi}.sign(\dot{\psi}) - frictional\ forces\ momentum$$

The cross reaction momentum is approximated by,

$$M_R = \frac{k_1(T_0 s + 1)}{(T_p s + 1)}.\tau_1$$

Again, the DC motor with electrical circuit is given by,

$$\tau_2 = \frac{k_2}{T_{21}s+T_{20}}.u_2 \quad (4)$$

Table 1shows the experimentally obtained values of the various parameters of the TRMS set up available at the Lab. Using the values the nonlinear model and later the linear model have been obtained and are given in section IV.

PARAMETERS	VALUE
I_1 – moment of inertia of vertical motor	6.8 x 10^{-2} kg m^2
I_2 – moment of inertia of horizontal motor	2 x 10^{-2} kg m^2
a_1 – static characteristic parameter	0.0135
b_1 – static characteristic parameter	0.0924
a_2 – static characteristic parameter	0.02
b_2 – static characteristic parameter	0.09
M_g – gravity momentum	0.32 N m
$B_{1\psi}$ – friction momentum function parameter	6 x 10^{-3} N m s/rad
$B_{2\psi}$ – friction momentum function parameter	1 x 10^{-3} N m s^2/rad
$B_{1□}$ – friction momentum function parameter	1 x 10^{-1} N m s/rad
$B_{2□}$ – friction momentum function parameter	1 x 10^{-2} N m s^2/rad
K_{gv} – gyroscopic momentum parameter	0.05 s / rad
k_1 – motor 1 gain	1.1
k_2 – motor 1 gain	0.8
T_{11} – motor 1 denominator parameter	1.1
T_{10} – motor 2 denominator parameter	1
T_{21} – motor 1 denominator parameter	1
T_{20} – motor 2 denominator parameter	1
T_p – cross reaction momentum parameter	2
T_0 – cross reaction momentum parameter	3.5
k_0 – cross reaction momentum gain	-0.2

Table 1 :TRMS Model parameters

III. DISTURBANCE REJECTION

Using disturbance observers, without any additional sensors is an attractive method to attenuate the effects of disturbances as they are highly cost effective. Disturbance Observers (DOB) are used to estimate the disturbance and disturbance estimate is injected into the designed control law to improve the disturbance rejection performance.

Several techniques exist to incorporate disturbance rejection requirements in a linear controller design. Contrary to, for example the H-infinity controller design technique where only one degree of freedom is available to obtain both disturbance rejection and performance, a DOB adds a degree of freedom, thereby enabling a separate design of the disturbance rejection and the performance. A simple form of DOB which does not require the calculation of plant inverse is discussed in the following section [5].

A. DOB Model

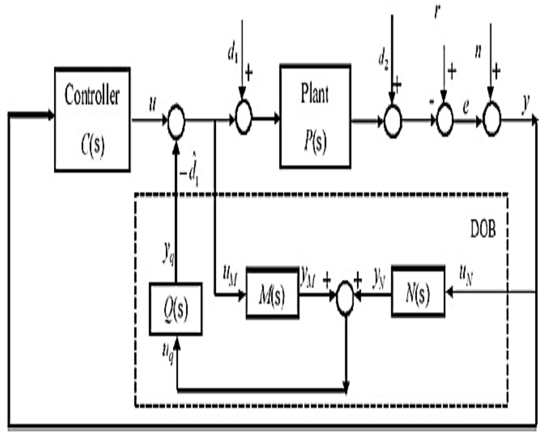

Figure3: DOB model

Fig. 3 shows the block diagram of the DOB structure [5], where C(s) is the feedback controller, P(s) is the model of the plant, d_1 is the input disturbance, d_2 output disturbance, n measurement noise. The DOB aims to compensation d_1 using its estimate .

If the model of the plant P be expressed as:

$$P(s) = \frac{B(s)}{A(s)}$$

with,

$$B(s) = b_m s^m + b_{m-1} s^{m-1} + \cdots + b_0$$

$$A(s) = s^n + a_{n-1} s^{n-1} + \cdots + a_0$$

The components of the DOB M(s) and N(s) can be obtained as,

$$M(s) = \frac{B(s)}{s^m}; \qquad N(s) = \frac{A(s)}{s^n} \qquad (5)$$

Thus, the design of DOB reduces to the design of the Q-filter Q(s). The H∞ optimization method will be applied to design Q(s).

IV. APPLICATION TO TRMS

Since, the DOB model discussed in [5] is designed for a linear SISO plant, the TRMS model needs to be linearized and decoupled into two different SISO plants. PID controller is used as the controller C(s)and is tuned to ensure that the pitch and yaw are following the desired reference commands. Here the DOB is designed to compensate external disturbance,$d_2$using its estimate , as its effect was found to be significantly affecting the system performance.

A. Linearization and Decoupling of TRMS

From the nonlinear differential equations given in (1) to (4), the state equations were derived after

Jacobian linearization, the states are pitch angle ψ, yaw angle ⍰, pitch rate , yaw rate , main rotor torque τ_1, tail rotor torque τ_2 and cross reaction M_R. Two output variables can be measured and feedback for control purpose and the two control inputs to two DC motors are two manipulated signals. Using dynamic equations given by operation manual for TRMS [9], the state space model of linearized plant is derived as below.

$$\begin{bmatrix} \dot{\psi} \\ \dot{\phi} \\ \ddot{\psi} \\ \ddot{\phi} \\ \dot{\tau 1} \\ \dot{\tau 2} \\ \dot{MR} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ -4..7 & 0 & -0.088 & 0 & 1.35 & 0 & 0 \\ 0 & 0 & 0 & -5 & -10 & 4.5 & -50 \\ 0 & 0 & 0 & 0 & -0.909 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & -0.1 & 0 & -0.5 \end{bmatrix} \begin{bmatrix} \psi \\ \phi \\ \dot{\psi} \\ \dot{\phi} \\ \tau 1 \\ \tau 2 \\ MR \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 0.8 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u1 \\ u2 \end{bmatrix}$$

$$\begin{bmatrix} \Psi \\ \phi \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \psi \\ \phi \\ \dot{\psi} \\ \dot{\phi} \\ \tau 1 \\ \tau 2 \\ M_R \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u1 \\ u2 \end{bmatrix} \qquad (6)$$

From the state model, the transfer matrix of TRMS can be obtained. The system can now be decoupled into two SISO subsystems using classical decoupling techniques[11]. The decoupled system has been obtained as below:

$$D(s)G(s) = \begin{bmatrix} \frac{1.359}{s^3 + 0.9091 s^2 + 4.706 s + 4.278} & 0 \\ 0 & \frac{3.6}{s^3 + s^2} \end{bmatrix} \qquad (7)$$

whereD(s) represents the decoupler transfer matrix and G(s), the TRMS transfer matrix.

B. GeneralH∞ control configuration

For the application of H∞ control method for the design of DOB it is required that the system is represented in the general control configuration [6]. Each of the SISO sub-systems can be represented as shown in the Fig4.

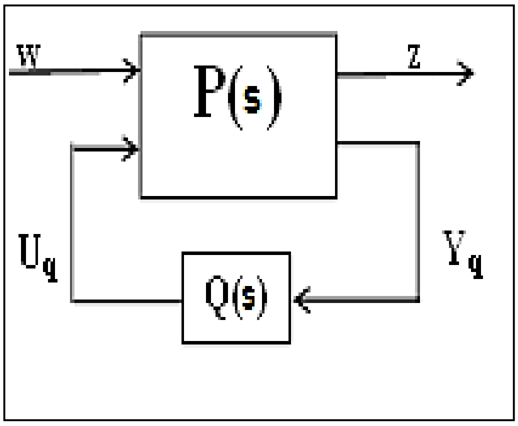

Figure: 4 : General H∞control configuration

The exogenous input vector ***w*** includes the inputs to system such as reference signal (r), input disturbance (d_1), output disturbance (d_2) and noise (n). The error signal z represents the error signal ***e*** between the reference signal and the output.The formulation can be obtained by considering one of the SISO sub-system components alone and later the same can be extended for the other. *(The suffix 1 and 2 can be used to represents the SISO sub-systems 1 and 2 separately.)*

The state space representations of each component of the block diagram in Fig 3 can be represented as:

P(s) : (A_p, B_p, C_p, D_p)

C(s) : (A_c, B_c, C_c, D_c)

M(s) : (A_m, B_m, C_m, D_m)

N(s) : (A_n, B_n, C_n, D_n)

The state vector can be taken as:

$$x_p(t) = \begin{bmatrix} x_p(t) \\ x_c(t) \\ x_m(t) \\ x_n(t) \end{bmatrix}$$

where, $x_p(t)$, $x_c(t)$, $x_m(t)$ and $x_n(t)$ represents the corresponding states of P(s), C(s) M(s) and N(s).The augmented plant can be represented in the form of general plant configuration as:

$$\begin{bmatrix} \dot{x}_p(t) \\ e(t) \\ u_q(t) \end{bmatrix} = \begin{bmatrix} A1 & B11 & B21 \\ Cz1 & Dzw1 & Dzu1 \\ Cy1 & Dyw1 & Dyu1 \end{bmatrix} \begin{bmatrix} x_p(t) \\ w(t) \\ y_q(t) \end{bmatrix} \qquad (8)$$

The component matricesof (8)can be obtained by the manipulation of the state equations of the components of block diagram.

$$A = \begin{bmatrix} Ap - \breve{B}pCpDc & BpCc & 0 & 0 \\ -BcCp & Ac & 0 & 0 \\ -BmDcCp & BmCc & Am & 0 \\ -BnCp & 0 & 0 & An \end{bmatrix}$$

$$B1 = \begin{bmatrix} BpDc & Bp & -BpDc & BpDc \\ Bc & 0 & -Bc & Bc \\ BmDc & Bm & -BmDc & BmDc \\ Bn & 0 & -Bn & Bn \end{bmatrix}$$

$$B2 = \begin{bmatrix} BpDc \\ Bc \\ BmDc \\ Bn \end{bmatrix}$$

$Cy = [-DmDcCp - DnCp \quad DmCp \quad Cm \quad Cn]$

$Cz = [-Cp \quad 0 \quad 0 \quad 0]$

Duw =

$[DmDc + Dn \quad Dm \quad -(DmDc + Dn) \quad (DmDc + Dn)]$

$Duy = [(DmDc + Dn)]$ Dzw = [1 0 -1 0] Dzy = -1

Obtaining DOB parameters

Now, the components of DOB - M(s), N(s) and Q(s) in the block diagram of Fig 3 are to be designed. The componentsM(s) and N(s) can be obtained from the plant transfer function a given in (5). The transfer functions thus obtained for the two SISO subsystems of TRMS are given below:

$$M_1(s) = \frac{8.389e{-015}\, s^2 + 3.356e{-014}\, s + 8.389e{-015}}{s^2} \quad (9)$$

$$M_2(s) = \frac{2.222e{-014}\, s^2 + 8.889e{-014}\, s + 2.222e{-014}}{s^2} \quad (10)$$

$$N_1(s) = \frac{s^3 - 3s^2 + 3s - 1}{s^3} \quad (11)$$

$$N_2(s) = \frac{s^3 - 3s^2 + 3s - 1}{s^3} \quad (12)$$

Now the design of DOB reduces to the design of the Q-filters - $Q_1(s)$ and $Q_2(s)$. They are designed based onH∞ control method using LMI algorithms. Denote the transfer function from ***w*** to ***e*** as

$$T_{ew} = [T_{ed1}\ T_{ed2}\ T_{en}]$$

where T_{ed1},T_{ed2} and T_{en}representsthe transfer functions from the disturbance d_1, $d_2$and noise n to the error e.

The H∞ optimization method is applied to design Q(s) to minimize the H_∞ norm

∞

The objective of the proposed simple DOB design can then be stated as: Given a positive scalar γ design a stable Q(s): (A_Q, B_Q, C_Q, D_Q)such that:

The H∞ control design problem can be solved via theLMIapproach as stated in [7], [8].

V. SIMULATIONS AND RESULTS

The designed DOB was implemented along with decoupled TRMS and the simulation was done on MATLAB. The LMI algorithm was realized in MATLAB using LMI Tool Box [11] provided with it. The Q- filter transfer functions as obtained from MATLAB are as follows:

1.325e009 s^10 - 3.322e012 s^9 - 6.302e012 s^8 - 1.425e013 s^7 - 7.336e014 s^6 - 8.951e014 s^5 - 9.892e013 s^4 - 9.055e011 s^3 + 5.465e009 s^2 + 0.0003766 s+ 4.371e-019

$Q_1(s)$ = ---------- ---

s^11 + 4.085e004 s^10 - 9.19e006 s^9 - 4.405e008 s^8 - 6.149e009 s^7 - 1.893e010 s^6 - 1.452e010 s^5 - 1.315e009 s^4 - 5.081e006 s^3 + 2.919e004 s^2 - 2.661e-009 s - 1.791e-023

s^11 + 1.841e009 s^10 + 1.095e014 s^9 + 1.18e014 s^8 + 4.441e014 s^7 + 3.964e016 s^6 + 4.518e016 s^5 + 1.552e015 s^4 + 3.045e013 s^3 - 1.687e011 s^2 + 0.2803 s + 2.261e-015

$Q_2(s)$ = ---

s^11 - 5.812e005 s^10 + 1.08e008 s^9 - 7.923e009 s^8 - 6.385e010 s^7 + 3.977e011 s^6 + 4.696e011 s^5 + 1.642e010 s^4 + 4.424e007 s^3 - 2.125e005 s^2 + 1.139e-006 s + 9.173e-020

where $Q_1(s)$ and $Q_2(s)$ corresponds to the filter for pitch subsystem and yaw subsystem respectively. The frequency responses of the filters are given in Fig 5(a) and 5(b).The responses show that $Q_1(s)$ and $Q_2(s)$ are low pass filters as required.

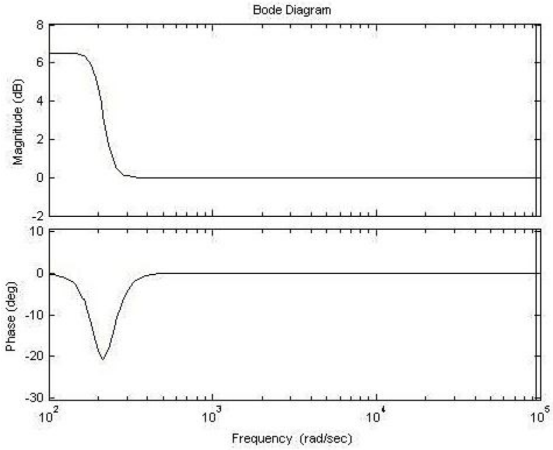

Figure 5(a) frequency response of $Q_1(s)$

The sensitivity functions corresponding to the two designed filters were obtained as given in Fig. 6(a) and 6(b). It is clear from the sensitivity function plot that the designed DOB is able to suppress the disturbances with frequency less than 30Hz. It is known that the possible incoming disturbances will be of the order of 3-5Hz. Thus it is clear that the DOB designed is successful to suppress possible incoming disturbances into the TRMS.

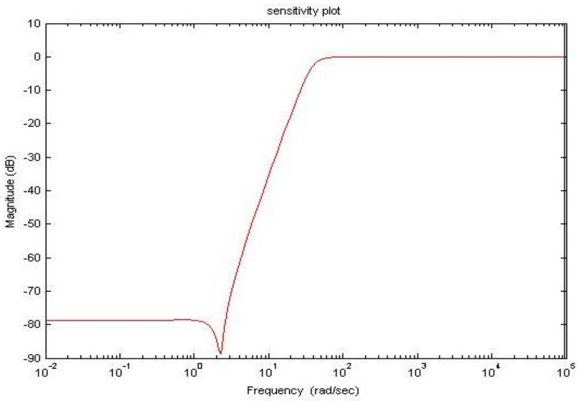

Figure 6(a) sensitivity function of $Q_1(s)$

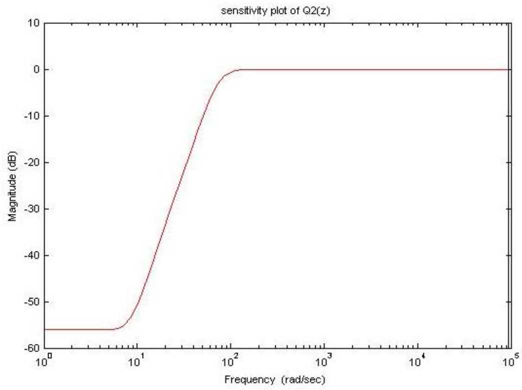

Figure6(b) sensitivity function of $Q_2(s)$

After obtaining acceptable results in frequency domain analysis, the time domain analysis of the DOB performance has been done. The designed DOB is implemented along with the TRMS model and the disturbance estimating capability was analyzed with a Gaussian white noise signal given as disturbance. The estimate obtained has been compared with the original incoming disturbance and the accuracy of the estimator was analyzed. The results obtained are shown in Fig7(a)and 7(b).

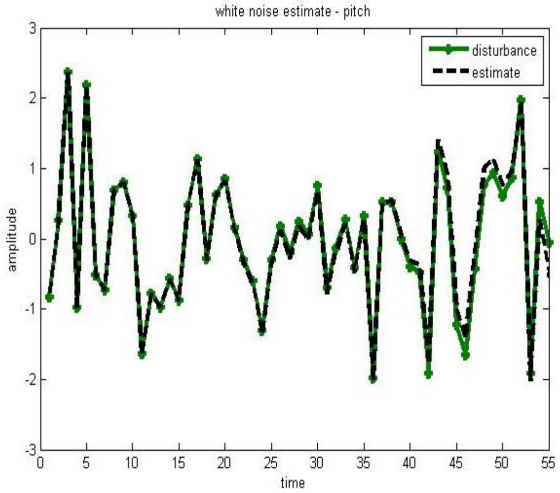

Figure7(a) disturbance estimate of the pitch

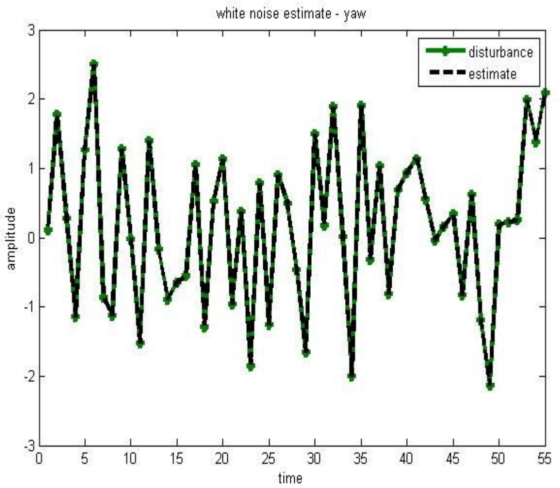

Figure7(b) disturbance estimate of the yaw

It is seen that the estimate closely follows the disturbance in both cases. Thus the designed DOB is successfully estimating the incoming disturbances which will cancel off the effects of incoming disturbance and ensure stabilized performance.

VI. CONCLUSION

The problem of disturbance rejection on TRMS has been addressed in the paper. The method of using Observers for disturbance rejection has been utilized here. A simple form of DOB has been discussed and designedbased on the H∞ control method using LMI to achieve desireddisturbance/noise rejection. The DOB does not need tosolve the plant model inverse and this benefit is of great significance especiallythus its design issimplified and this benefit is of great significance especially for non-minimum phase plant. Thesimulationresults show that theDOB designed in this paper is able to effectively improve the attenuation ofthe disturbance in frequency lower than 30Hz, and will not sacrifice the stability and performance of the nominal feedback control loop.

REFERENCES

[1] JOHNSON C.: 'Accommodation of external disturbances inlinear regulator and servomechanism problems', IEEE Trans.Autom. Control, 1971, 163, (6), pp. 635–644

[2] LEVIN V. JR., KREINDLER E.: 'Use of disturbance estimator for disturbance suppression', IEEE Trans. Autom. Control, 1976, 21, (5), pp. 776–778

[3] DAVISON E.: 'The robust decentralized control of a general servomechanism problem', IEEE Trans. Autom. Control, 1976, 21, (1), pp. 14–24

[4] Erwin Schrijvert , Johannes van Dijkt and Henk Nijmeijert: 'Equivalence of Disturbance Observer Structures for LinearSystems',IEEE Conference on Decision and Control Sydney, Australia December, 2000

[5] C. Du, H. Li C, K. Thum, F.L. Lewis, Y. Wang : ' Simple disturbance observer for disturbance compensation', IET Control Theory Appl., 2010, Vol. 4, Iss. 9

[6] Skogestad and Postlethwaite, 'Multivariable Feedback Control- Analysis and Design', John Wiley and Son,Ltd

[7] PASCAL GAHINET: ' A Linear Matrix Inequality approach to *H∞* Control', International Journal of Robust and Nonlinear Control, vol 4, 421-448

[8] PASCAL GAHINET:'Explicit *H∞* Controller Formulas for LMI-based Synthesis', *Auromorico, Vol.* 32, No. 7, pp. lOU7-1014, 19%

[9] Twin rotor MIMO system control experiments-33949s, TRMS manual, Feedback instruments, UK.

[10] TING-KAI LIU AND JIH-GAU JUANG: 'A Single Neuron PID Control for Twin Rotor MIMO System', IEEE/ASME International Conference on Advanced Intelligent Mechatronics, July 14-17, 2009

[11] M.Tham : 'Multivariable control : An introduction to Decoupling Control', MTT, July 1999.

[12] Karl Johan Astrom , 'PID Controller', Control system design, 2002

[13] Pascal Gahinet, Arkudii Nemirovskii, Aim J. Laub Muhmoud Chiluli: 'The LMI Control Toolbox', Proceedings 33rd Conference *on* Decision and control Lake Buena, vista F December 1894.

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