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Design, Analysis and Comparative Evaluation of Twin Rotor Multi Input Multi Output System Controller

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Abstract:
An experimental model of a helicopter is the Twin Rotor MIMO (Multiple Input Multiple Output system). This two-degree-of-freedom system has multiple inputs and outputs. It is employed to verify the control methods and observers of helicopter maneuvers. For the Twin Rotor MIMO system, this study develops a linear quadratic Gaussian (LQG) controller and a linear quadratic Gaussian controller with integral action (LQGI). To verify that each controller can tolerate the required conditions, both control approaches are applied to the Twin Rotor MIMO system in the MATLAB Simulink environment.

Keywords: MIMO; Kalman filter, LQG controller, LQGI controller, and linearization.

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I. Introduction

For the Control Engineering Community, which studies the efficacy of various control strategies for helicopter maneuvers, the dual rotor MIMO system is a blessing. This system has many inputs and outputs that are cross-coupled. Each side of the horizontal beam in the aerodynamic model has two rotors. Two separate DC motors power each rotor. One rotor serves as the primary rotor., while the tail rotor is the other. Pivoted beams counterbalance horizontal beams. The horizontal beam is capable of both vertical and horizontal rotation. Up and down motion is caused by the primary rotor, which produces lifting force to raise the horizontal beam about the pitch axis. Rotating the horizontal beam around the yaw axis (vertical axis) is the responsibility of the tail rotor.

The Euler-Lagrange technique forms the foundation of the conventional mathematical models used in system modelling. These models employ transfer functions that are integral to various tuning techniques aimed at determining the optimal PID gain values [1]. A Twin Rotor MIMO System (TRMS) operates under a proportional-integral-derivative (PID) controller. As a nonlinear test rig with cross-coupling, the TRMS initially utilizes a decoupling strategy to mitigate the cross-coupling effect [2]. Control of the Twin Rotor MIMO System is achieved through both LQR and PID controllers [3]. An adaptive explicit nonlinear model predictive control (AENMPC) approach, featuring a convex combination framework with multiple estimating models, is applied to a class of nonlinear MIMO systems [4].

Fractional order PID controllers, along with 1-degree-of-freedom and 2-degree-of-freedom PIDs, are employed in controlling Twin Rotor MIMO systems [5]. To the authors' current knowledge, the robust FOI-PD controller has yet to be investigated for the TRMS kit. The nonlinear interior point optimization method, utilizing the fmincon function from MATLAB's optimization toolbox, is employed to minimize cost functions and determine suitable controller parameter values within a specified range [6]. Various adaptive control strategies have been designed and assessed for managing the pitch angle in Twin-Rotor-MIMO systems [7].

A nonlinear multi-input multi-output (MIMO) system can be effectively managed using a proportional-integral-derivative (PID) control scheme integrated with stochastic optimization. This concept is illustrated through the Twin Rotor MIMO System (TRMS), which serves as a laboratory-scale helicopter model [8]. A novel approach is to devise a robust optimal control strategy for the TRMS, enhanced by Robust Generalized Dynamic Inversion (RGDI), to handle continuously changing perturbations. This strategy aims to efficiently optimize undesirable signals such as the coupling effect, unknown states, gyroscopic disturbance torque, and both parametric uncertainties and disturbances [9]. Additionally, a TRMS was developed using a generalized feedback control operator and state estimation, enabling it to follow time-varying reference configurations or manage preset configurations like pitch and yaw in a cohesive manner [10].

Effective fuzzy logic control based on entropy is implemented for a real-time non-linear system. One of the most investigated topics for fuzzy logic controller (FLC) performance enhancement is fuzzy membership function (MF) optimization [11]. The creation of an appropriate linear multi-inputs and multi-outputs model that faithfully captures the behavior of a twin rotor system when the small-signal technique is used [12]. To manage the Twin Rotor MIMO System's (TRMS) yaw orientation, a sliding mode control (SMC) with state-varying gains is suggested. Without changing the sliding modes' robustness characteristics, our suggested SMC method lessens the chattering impact [13].

The trajectory tracking capabilities of the Linear-Proportional Integral Derivative (L-PID) and Integer Order-Proportional Integral Derivative (IO-PID) controllers were experimentally verified through their design and implementation on a benchmarked Twin Rotor MIMO system (TRMS) [14]. Twin-rotor MIMO system design for a Multi-Input Multi-Output (MIMO) PID controller. A non-linear system with two inputs and two outputs is intended to be controlled by a multivariable control system with two loops [15]. Twin Rotor MIMO System (TRMS) control-oriented study using high fidelity, non-linear models [16].

II. Proposed Modelling

In order to make the concept dependable in a real-world setting, a linear quadratic Gaussian controller was created. Advanced control methods such optimum controllers enable the system to monitor the reference signal. The system can track references with 0% steady state error thanks to the integrated action, and the fast tracking LQG controller is an extra benefit that makes the controller dependable and strong in real-world settings. The TRMS's LQG and LQGI controller design is covered in the section that follows.

a. Gaussian Linear Quadratic Controller-

Optimal control is achieved using the linear quadratic Gaussian (LQG) controllerA linear system with white Gaussian noise that is additive, imperfect state information, and quadratic cost control is the subject of this study. The linear dynamic feedback control rule, which is the unique solution to the LQG control problem, is simple to implement. Combining a linear quadratic regulator plus a Kalman filter results in a linear quadratic Gaussian controller. Due to the separation concept that underlies LQG, It is possible to construct and compute the Kalman Filter and Linear Quadratic Regulator independently.

Both linear time changing and linear time invariant systems can be used with LQG controllers. The linear time invariant system is being addressed in this paper. The robustness of the system is not guaranteed when it is designed using a LQG controller. After the LQG controller has been designed, the system's resilience should be examined. Figure 1 displays the LQG controller's block diagram.

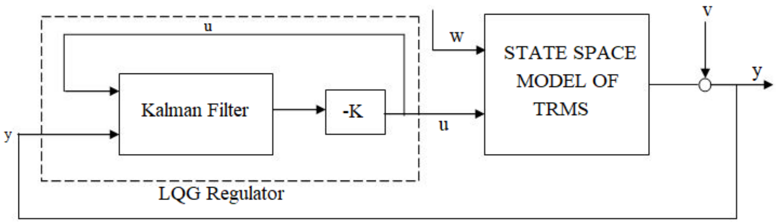

Fig. 1: shows how the Twin Rotor MIMO System (TRMS) works, with an LQG controller calling the shots

If you check out Figure 4.3, you will see that the Linear Quadratic Gaussian (LQG) controller is really two things working together: a Kalman Filter (it figures out what is going on with the system) and a Linear Quadratic Regulator (LQR), which keeps everything running smoothly. The system experiences process noise (w) along with the control input (u). Due to the stochastic nature of the plant and the presence of unknown noise, external white Gaussian noise is introduced. By adding measurement noise "v" to the system, the resulting response is observed as "y."

b. Linear Quadratic Gaussian Controller with Integral Action: -

Adding integral action to a control loop is usually the way to go if you want to make absolutely sure there's no steady-state error when you throw in a step input. The trick is to repeat the system in a way that creates extra states. The number of those states should match the number of outputs that make up the system's output error.

Robustness is another desired attribute of a controller, in addition to integral action. When a system's characteristics or dynamics change, robustness enables it to continue operating as intended. Deadbeat, sliding mode control, robust control theory, and LG-based controllers are the four control theory types that can ensure robustness. The current work makes use of the LQG controller.

The LQG controlled TRMS is enhanced with an integral action by a Linear Quadratic Gaussian Integral controller. The plant can be represented by state equations, and the integral LQG controller generates the control using noisy measurements y. The system is driven by control u and is subject to disturbances w and v,

$$\dot{x} = A\,x(t) + B\,u(t) + F(t)w(t) \quad (1)$$

$$y = Cx(t) + D\,u(t) + v(t) \quad (2)$$

Where, $v(t)$=Measuring Noise and $w(t)$ =Process Noise. Both v and w are called as White Noise.

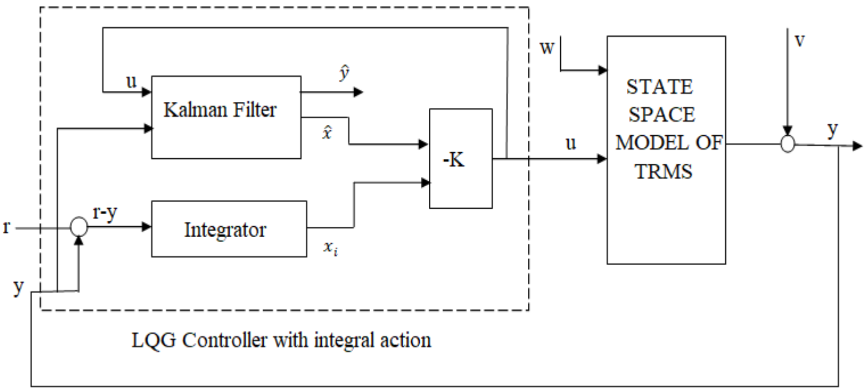

Fig. 3: TRMS block diagram with a LQGI controller

An illustration of the LQG controller with integral action is as follows:

$$\begin{bmatrix} \dot{\hat{x}} \\ \dot{x}_i \end{bmatrix} = \begin{bmatrix} A - BK_x - LC + LDK_x & -BK_i + LDK_i \\ 0 & 0 \end{bmatrix}$$

$$u = \begin{bmatrix} -K_x & -K_i \end{bmatrix} \begin{bmatrix} \hat{x} \\ x_i \end{bmatrix}$$

Where, $\hat{x}$ represents states estimated by Kalman Filter and x_i is Integrator output

III. Case Study

For the U_1=0.3 step reference signal, the pitch response of TRMS is displayed in the graph below. With a LQG controller, the reaction takes 9 seconds to settle, but with a LQGI controller, it takes 3.5 seconds. Comparing the LQGI controller to the LQR and LQG controllers, the TRMS system responds more effectively.

a. Pitch Response Comparison of LQG and LQGI Controllers:

The TRMS's pitch response for the U1=0.3 step reference signal is displayed in the graph below. Response settling times with LQG and LQGI controllers are 9 and 3.5 seconds, respectively. When compared to LQR and LQG controllers, the TRMS system responds better with the LQGI controller.

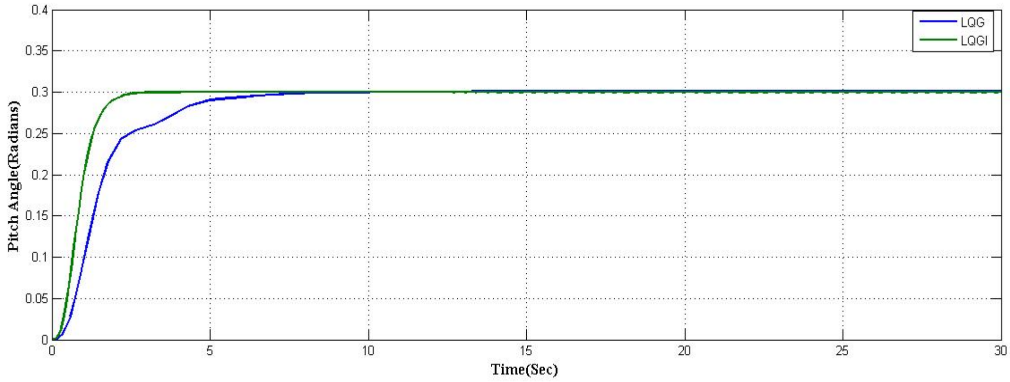

Fig. 4: Comparing TRMS's Pitch Angle Response with LQG and LQGI Controllers

Comparing the Yaw Response of LQG and LQGI Controllers:
The accompanying graph shows that it took 6 seconds for the system with the LQG controller to respond. There is a further reduction of 3.5 seconds. It is important to note that the LQGI controller works better with the TRMS than both the LQG and LQGI controllers.

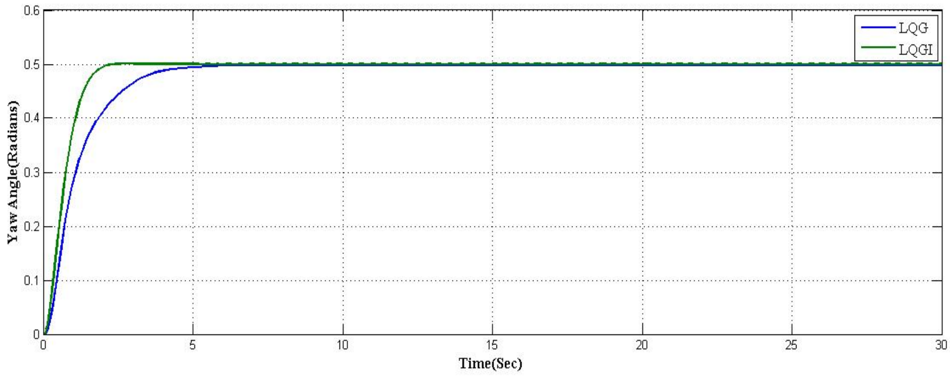

Fig. 5: Yaw Angle Response Comparison between TRMS and LQG, and LQGI Controllers

Pitch Control Input Comparison between LQG and LQGI Controllers:
The graph below illustrates the system's response to a reference step signal with U1=0.3. It was observed that the primary rotor, responsible for controlling pitch, requires a control input of 0.9 volts to function. Notably, the LQGI controllers outperformed the others with the same control input, achieving a shorter settling time.

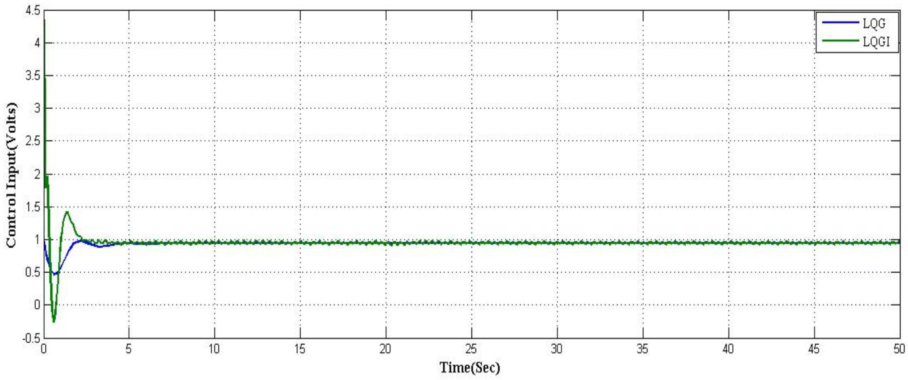

Fig. 6: Pitch Control Input Comparison of Controllers for LQG and LQGI

b. Input Yaw Control Comparison for LQG and LQGI Controllers:
The graph below shows the control input given to the tail rotor in order to reach 0.5 radians. Both of the control methods showed that. To run both at 0.5 volts, the same control voltage of -3 volts is required.

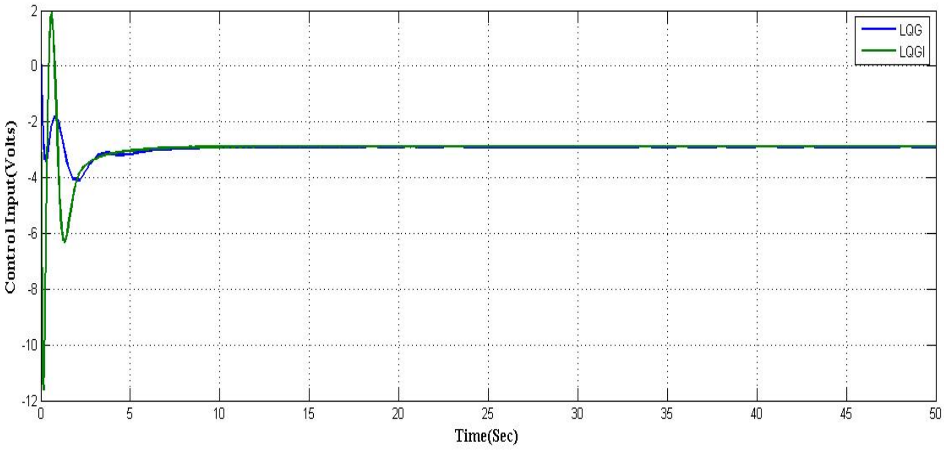

Fig.7: Comparison of LQG and LQGI Controllers' Yaw Control Input

IV. Observations and Discussions

Table 1: Performance of TRMS with LQR, LQG and LQGI controllers in terms of time domain specifications

Controller	Parameter	Delay Time (t_d) (Sec)	Rise time (t_r) (Sec)	Settling Time(t_s) (Sec)	% M_p	% error
LQR	Pitch	1.75	3	8.5	0	0
	Yaw	1.2	3	6.5	0	0
LQG	Pitch	1.75	3	8.5	0	0
	Yaw	1.2	3	6.5	0	0
LQGI	Pitch	0.95	0.75	3.5	0	0
	Yaw	0.9	1.5	3.5	0	0

II. CONCLUTION

In this study, the TRMS model was developed using both LQG and LQGI controllers. The tasks involved implementing and analysing linear quadratic Gaussian controllers, as well as those with integral action, for MIMO twin rotor systems. It has been noted previously that the linear quadratic When compared to the LQR controller, the Gaussian controller provides a better response. Additionally, the current study shows that the LQGI controller for TRMS provides a better response in terms of time domain specifications than the LQG controller—all while using the same control energy.

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