3D Simulation for TRMS Flight Control

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Abstract: The nonlinear nature of helicopters, and their operation in the presence of several defects and imperfection, causes a drop in performance. The main objective of this work is to use and to create a simulator of a Twin Rotor Mimo System (TRMS) helicopter flight using SlidWorks and Simscape, and use anLinear Quadratic Regulator (LQR) and Link Quality Indication (LQI) control to assure a tracking of a setpoint, in spite of the presence of different disturbances. The simulation results obtained using MATLAB/Simulink show the effectiveness of this control strategy and our simulated TRMS.

Keywords: Helicopter, Linear Quadratic Regulator (LQR) and Link Quality Indication (LQI) control, Twin Rotor Mimo System (TRMS), simulation

1. Introduction

Today's world has seen many developments in different fields, particularly in aeronautics. The systems developed are more and more complex and difficult to control, for this there are several control laws which have also been the subject of numerous research works. Differences between the mathematical model and the real system are often expressed in quantities, to this can be added the need to have a linear model of the system to be able to apply most of the control methods. The control techniques based on the state representation and the use of matrix formalism are very interesting for the computing power and their generality.

A Twin Rotor Mimo System (TRMS) helicopter is a multivariable system with one input and one output for each of the two horizontal and vertical subsystems which are strongly coupled and non-linear. In order to stabilize them and reduce the interactions present between them, our work consists in modeling this system and applying a few commands, in order to ensure its proper functioning and improve its performance in terms of energy efficiency despite the presence of several disturbances due to change of different conditions. We have chosen to show these performances through a TRMS flight simulator, in order to save time and reactivity to improve the model. The flight simulation is undergone using SolidWorks and Simscape.

After this introduction, Section 2 is dedicated to the TRMS description. The control laws, more specifically the LQR and LQI control, are given in Section 3. The simulation of the TRMS flight, which is the aim of this work, is presented in Section 4. Finally, a conclusion and some perspectives finish the paper.

2. Twin Rotor MIMO System

Several prototypes are implemented in order to test the commands before applying them to the real system. The Twin Rotor Mimo System (TRMS) helicopter simulator is one of these prototypes that support the implementation of various commands and then apply them to aeronautical processes.

TRMS is an aerodynamic physical system designed for the development and implementation of new control laws. This includes, modeling system dynamics, identification, analysis and design of various controllers by classical and modern methods. The behavior of the TRMS resembles that of a helicopter from a control point of view; it is a higher order nonlinear system with significant couplings [1].

Let:Inputs :$U = [U_1 U_2]$, state vector:$X = \left[\psi, \dot{\psi}, \tau_1, \varphi, \dot{\varphi}, \tau_2\right]^T$ and measured outputs $Y = [\psi\varphi]^T$where the variables are: ψ: Pitch angle (evaluation), $\dot{\psi}$: Evaluation angular velocity, φ: Yaw angle (azimuth), $\dot{\varphi}$: Angular speed of azimuth, τ_1: Moment of the main rotor, and τ_2: Moment of the tail rotor.

The non-linear model [2] has been linearized around an equilibrium point. The equilibrium point is calculated by setting the inputs of the commands and the derivatives of the states equal to zero (static regime). After application to the various equations of state of the system, we find the following equilibrium point: x_0 = [0, 0, 0, 0, 0, 0]. Let: $x_1 = \psi$, $x_2 = \dot{\psi}$, $x_3 = \tau_1$, $x_4 = \varphi$, $x_5 = \dot{\varphi}$, $x_6 = \tau_2$

After replacing the different variables by the model parameters which have been chosen more or less experimentally [3], we obtain the following system state space representation:

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases} \tag{1}$$

$$A = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ -4.7058 & -0.0882 & 1.3588 & 0 & 0 & 0 \\ 0 & 0 & -0.909 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1.616 & 0 & -5 & 4.5 \\ 0 & 0 & 0 & 0 & 0 & -1 \end{pmatrix}, B = \begin{pmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0.8 \end{pmatrix}, C = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

3. TRMS Control

3.1. LQR Linear Control

Let a system be described by state space equations as in (1).

The linear quadratic synthesis called LQR (Linear Quadratic Regulator) consists of the search for a gain matrix K, such that the control by state feedback $u(t) = -Kx(t)$ stabilizes the system and minimizes some quadratic criterion [4]. The status feedback control which stabilizes the system and minimizes the LQ criterion [5] is:

$$J = \int_0^{\infty} (x^T(t)Qx(t) + u^T(t)Ru(t))dt \tag{2}$$

With: $R>0$, $Q\geq 0$ is written as: $u(t) = -Kx(t)$ with $K = R^{-1}B^T\rho_0$ where ρ_0 is the positive solution of the Riccatiequation. The choice of R and Q weighting matrices is important, it is necessary to vary the values of these matrices to obtain the desired performance. These weighting matrices are, generally, chosen diagonals.

Application of the LQR Control on the TRMS: We first choose, by trial and error, the weighting matrices Q and R as follows:

$$Q = diag\{900,500,150,900,400,10\}, R = \begin{pmatrix} 100 & 0 \\ 0 & 100 \end{pmatrix} \tag{3}$$

Then we obtain the vector of feedback gains K calculated using the function "lqr" of Matlab:

$$K = \begin{pmatrix} 0.7228 & 24.9411 & 14.1331 & 5.4027 & 2.6369 & 1.1661 \\ 2.3364 & -4.2823 & 0.9329 & 29.5095 & 11.9580 & 10.7804 \end{pmatrix} \tag{4}$$

3.2. LQI Linear Control

Quadratic Integral Action Linear Control (LQI) is simple to implement, and have already been applied in a wide range of nonlinear applications. LQI control schemes are established in the same way as LQ regulators, to which an integral action is added on status feedback. The LQI controller allows output y to reach the desired reference, even if a disturbance is applied to the system to be controlled, the system will follow the desired set-point. The LQI control is well described in [6, 7].

Application of the LQI controller: We choose the weighting matrices Q and R for this LQI command by trial and error as follows:

$$Q = diag\{700, 100, 0.01,10,10,10,100,10\}, R = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \tag{5}$$

We obtain the vector of feedback gains K calculated using the function "lqi" of Matlab:

$$K = \begin{bmatrix} 9.9675 & 16.8853 & 5.9826 & 0.8964 & 0.2482 & 0.2248 & -9.9171 & -0.4063 \\ 1.6426 & -1.2214 & 0.1799 & 7.7021 & 1.7363 & 4.3219 & 1.2849 & -3.1361 \end{bmatrix} \tag{6}$$

After some simulation testsand data analysis, we conclude that the LQR command is done for the regulation of the system, in our case, with a zero input, the LQR command will regulate the system and put all the states of the system at the position d' balance, while the LQI command allows our system to follow the instructions given to it at the entrance.

4. TRMS Flight Control Simulation

Virtual simulation on Matlab'sSimscapeplatformallows experimentation with TRMS without having to undergo expensive and unsafe practices. A 3D visualization produced by the combination of the two platforms SolidWorks [8] and Simscape [9] (Multi body SimMechanics) willillustrate the flight behavior of the TRMS as well as its movements.

4.1. Creation of the TRMS Simulator on SolidWorks

SolidWorks [8] allows creating models in 3D. To make the model of the laboratory helicopter, you have to go through two steps:

- The 1st step is the creation of the parts of the model, in our case, we created 5 parts: the base of the TRMS, the beam with the 2 rotors, the articulation between the base and the beam, and the two propellers of the primary and secondary rotors.
- The 2nd step is the assembling of all the parts already created in a single file, fixing a part which is the basis of the TRMS in our case and adding constraints to define the movement of the joint between a part and another.

4.2. Exporting the Model to Matlab

To export from SolidWorks to Matlab, it is imperative to well prepare the model by respecting the following rules:

- create the system in an assembly file that respects the links (constraints) between the different parts that make up our plant.

- ensure that the assembled system works manually on SolidWorks if we want to keep the movement characteristics specific to our plant.
- clearly define the coordinate system.
- control the resolution and adjust the image quality parameters on SolidWorks in order to avoid having a too slow simulation.

Once all these parameters are set, we start the export operation: on the menu we click on Tool then on complement and we select SimscapeMultibody link [9], and the export is done by creating STL files (STEP) and an XML file. If the operation was executed successfully, a message will tell us that the import is complete.

4.3. Importing the Model into Matlab

Once the model has been exported, the folder containing the STL files and the XML file must be brought back into the Matlab workspace. The importing is done with the Smimport command ("name of file.XML") for Simscape 2nd generation models. A Simulink Simscape model will be automatically created as inFig. 1. The model shows the different joints of the 3D model created with SolidWorks as Simulink blocks, and with this we can control these joints and see the results in a window which allowed us to see the 3D animation of the TRMS (Fig. 2).

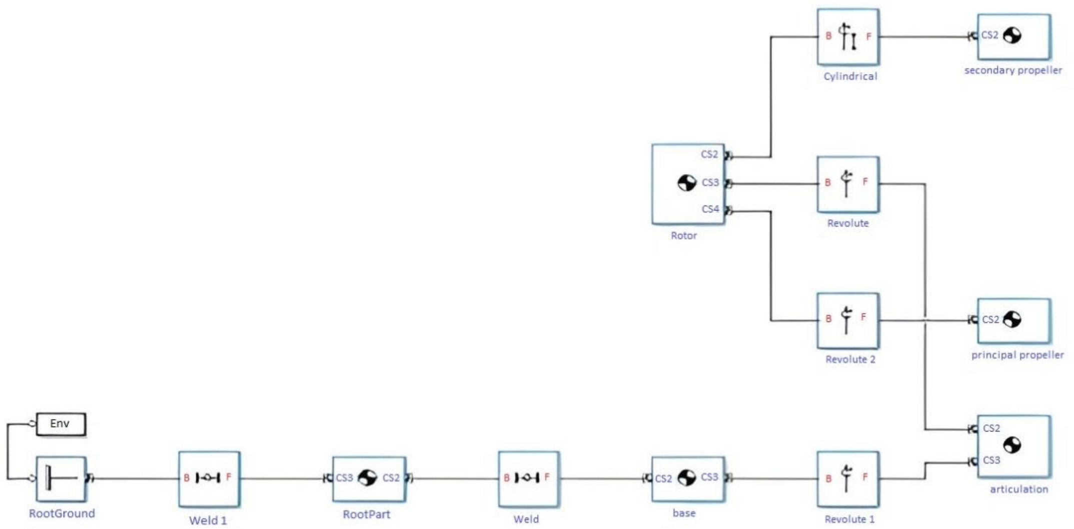

Fig. 1. 2nd generation Simscape model of TRMS.

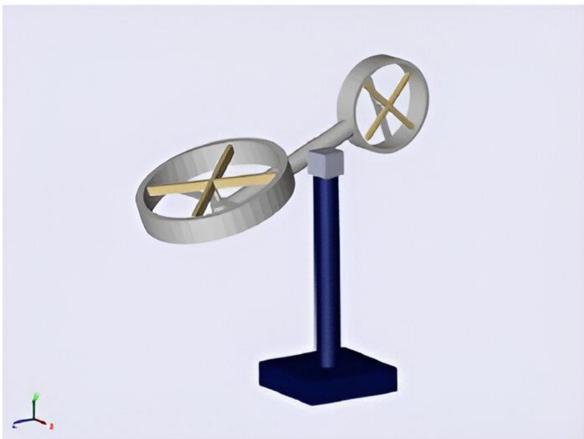

Fig. 2. TRMS 3D animation.

4.4. Controlling the Simulated TRMS

The application of the LQI controller on this simulated TRMS is done by adding actuators to each joint block in order to control the angle of rotation of the latter, we use the outputs of the controller studied previously as input variable of the actuators, and sensors are placed at the exit of the joints to see the behavior of the angles of rotation. Fig. 3 shows the different blocks of the Simscape model and the controller as well as the actuators and sensors that have been added to this model.

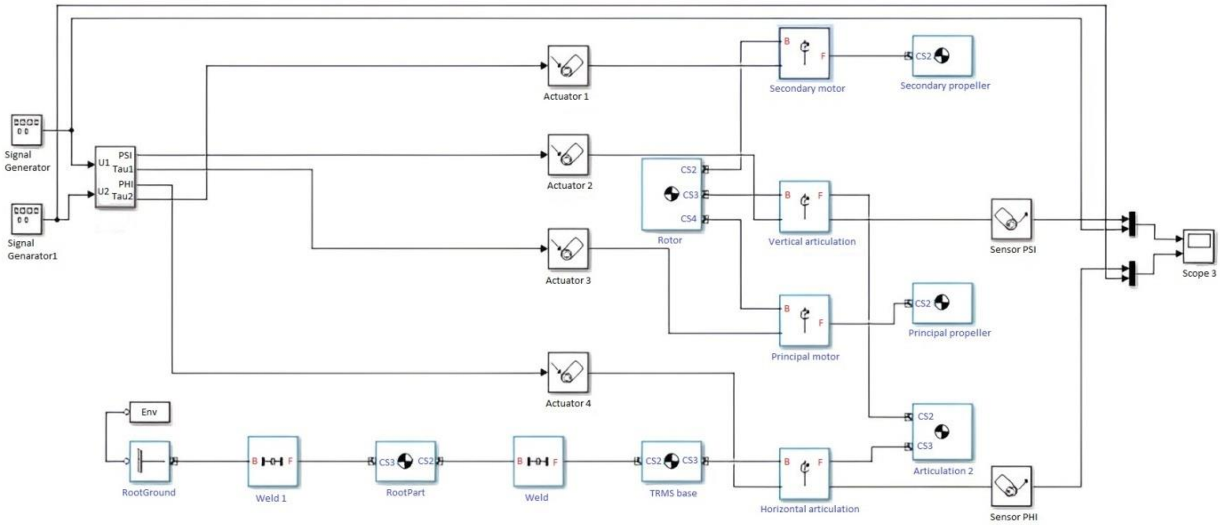

Fig. 3. Simulink model of the simulated TRMS control.

4.5. Simulation Results

The simulation of Fig. 3 on Matlab's Simulink took place with a square input signal of amplitude 0.52 rad and frequency 0.025 rad/s for input U_1, and a sinusoidal signal of amplitude 0.52 rad and frequency 0.025 rad/s for input U_2, and the input setpoint is fixed at 0 during the first half-period in order to see the initial position of the helicopter. Fig. 4 shows the simulation results of the system.

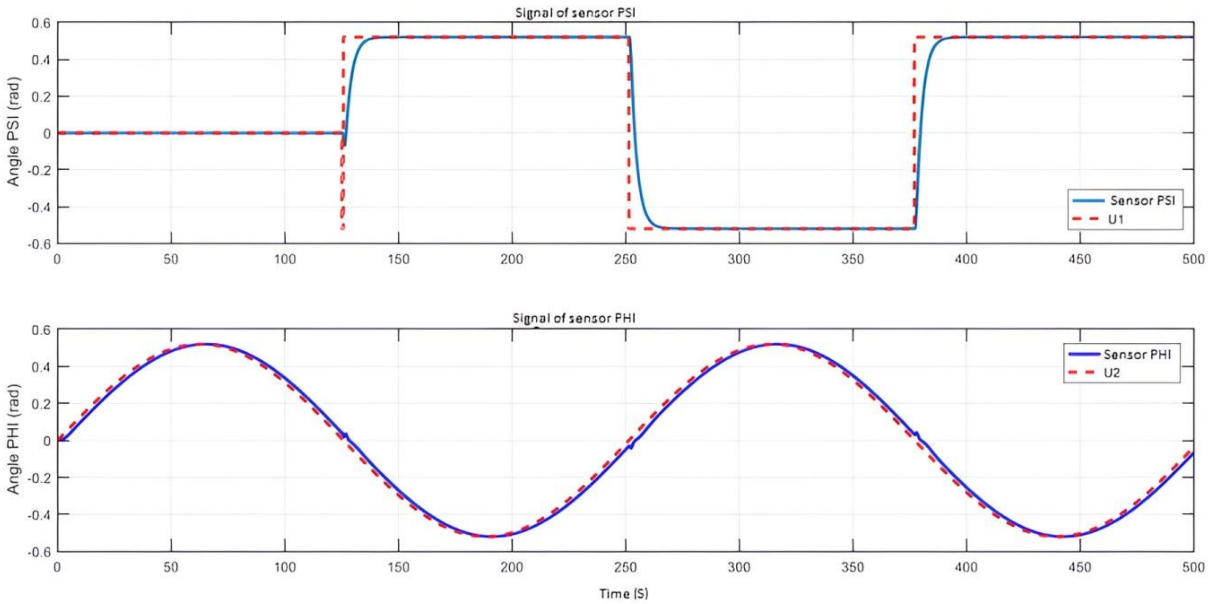

Fig. 4. Signals from pitch and yaw angle sensor signals (Test 1).

We repeat the simulation for a 2nd test of the TRMS simulator, this time with a triangular signal of amplitude 1 rad and frequency 0.025 rad/s for input U_1, and a sinusoidal signal of amplitude 1 rad and frequency 0.025 rad/s for input U_2. Fig. 5 shows the simulation results.

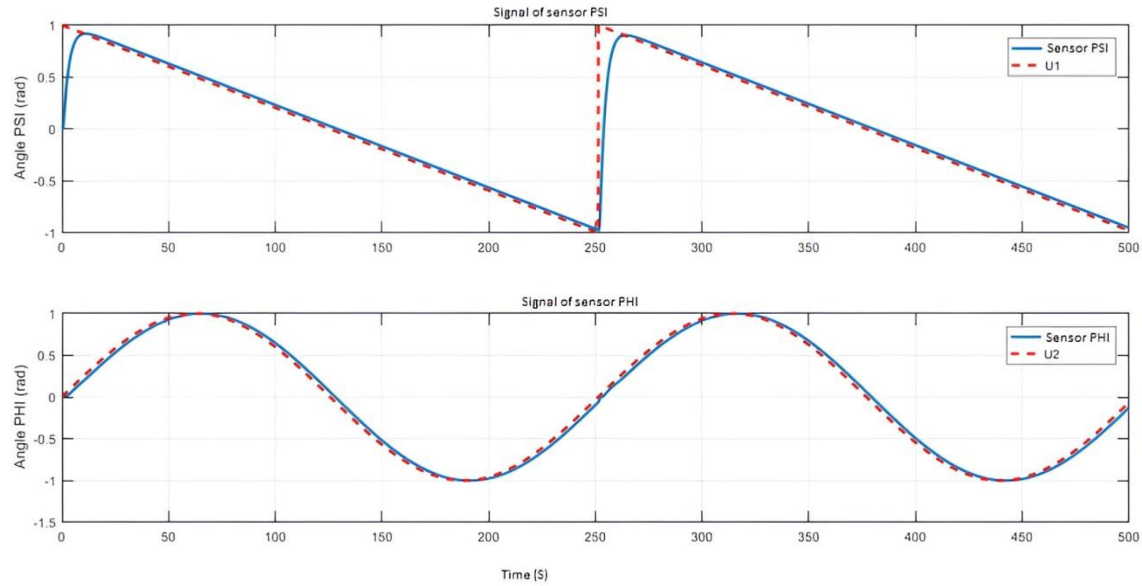

Fig. 5. Signals from pitch and yaw angle sensors (Test 2).

We repeat the same test of the TRMS simulator for a third time, this time with a sinusoidal signal of amplitude 1 rad and frequency 0.025 rad/s for input U_1, and a triangular signal of amplitude 1 rad and frequency 0.025 rad/s for input U_2. Fig. 6 shows the simulation results.

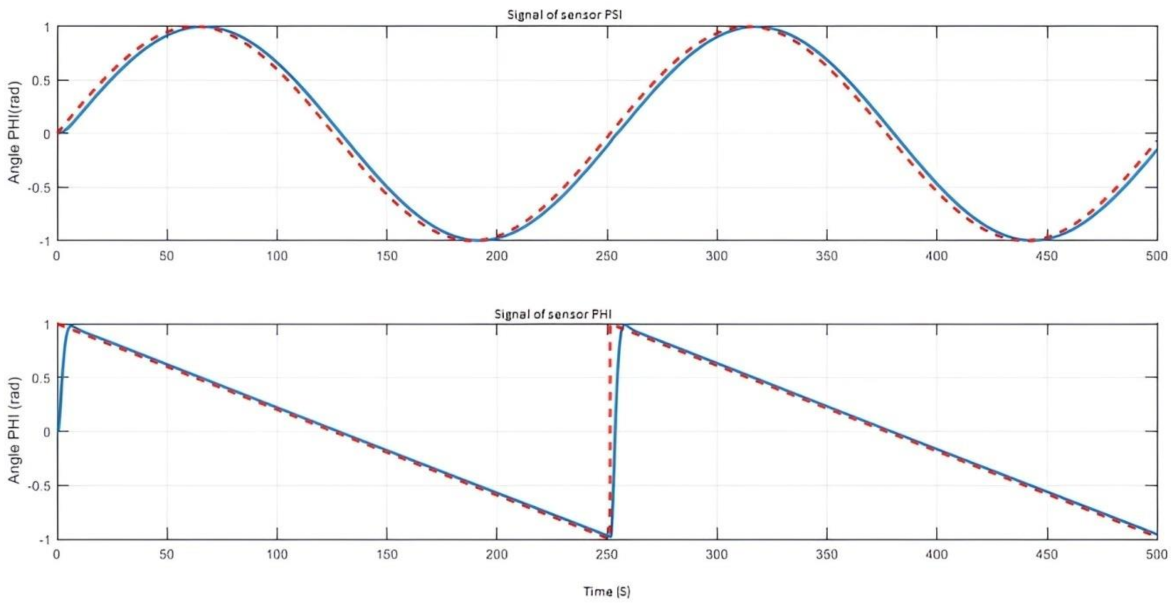

Fig. 6. Signals from pitch and yaw angle sensors (Test 3).

According to the various tests that we carried out for the simulated TRMS, we notice that it responds perfectly to the desired setpoint, the actuators are working correctly and they move correctly according to the output angles of the control. The animation responds to stimuli for both movements (vertical and horizontal) that we have implemented so far. The simulated TRMS shows that the movements of the laboratory helicopter are made according to the angles of Pitch and Yaw imposed by the LQI control.

5. Conclusion

The work presented in this paper is part of the application of control techniques, namely the quadratic linear control on a flight simulator of a TRMS type helicopter and the creation of the animation of the latter.

The LQR and LQI approaches have been applied the TRMS models coupled on Matlab's Simulink. The obtained results show that the LQI method is very efficient for controlling and tracking a nonlinear system which is the case of the TRMS, and works for all conditions, and the LQR method brings the system back to the equilibrium position despite the setpoint changes.

Finally, we created the animation of this model in SolidWorks and carried out its integration with Matlab's Simulink, to be able to follow the movement of the helicopter using the controller. This simulator allows us to study the stability and control of the TRMS without needing the model. So it will help us to do other studies more easily.

Our work remains primitive and therefore subject to improvement, such as integrating other simple and complex movements into the simulator, studying other controls, and supplementing the simulator with performance measurements.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Amine Ouchene did the research with the help of M. A. Kacimi, under the supervision of M. Yaici. Malika Yaici wrote the paper; all authors had approved the final version.

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