Control and Measurement Laboratory

Twin Rotor MIMO System

1. Introduction

The TRMS workshop serves as a model of helicopter. However some significant simplifications are made. First is the fact that TRMS is attached to a tower and second of great importance that the helicopter position and velocity is controlled through the rotor velocity variation. In real helicopter the rotor velocity is more less constant and the propulsion is varied through the rotor blades angle modification.

Nevertheless, the most important dynamic characteristics present in a helicopter are captured in the TRMS mode. Like in a real helicopter there is significant cross coupling between two rotors. If we active the vertical position rotor the helicopter will also turn in the horizontal plane

With two inputs (the voltage supplied to the rotors) and Outputs (vertical and horizontal angles and angular velocities) the TRMS is an excellent MIMO plant for laboratory exercises.

2. Description

Figure 1 shows the TRMS mechanical unit consists of two rotors placed on beam together with a counterbalance. The whole unit is attached to the tower allowing for safe helicopter control experiments

Figure 1: TRMS Mechanical Unit
In order to design any control algorithm one must first understand the physical background behind the process and carry out identification experiments. A complete control system setup presented in figure 2.

Figure 2: TRMS Control System

3. Mathematical Model of TRMS

The mechanical electrical model of the TRMS is presented in figure 3.

Figure 3: TRMS Model
TRMS models are nonlinear, that means at least one of the state (i- rotor current, $\varnothing$ – position) is an argument of a nonlinear function. In order to present such a model as a transfer function (a form of linear plant dynamics representation used in control engineering), it has to be linearized.

The following momentum equations can be derived for the vertical movements

$$I_1 \ddot{\psi} = M_1 - M_{FG} - M_{B\psi} - M_G$$

(1)

where

- $M_1 = a_1 \tau_1^2 + b_1 \tau_1$ Nonlinear static characteristic
- $M_{FG} = M_g \cdot \sin \psi$ Gravity momentum
- $M_1 = B_1 \psi \dot{\psi} + B_2 \psi \text{sign} (\dot{\psi})$ Friction force momentum
- $M_G = K_{gy} M_1 \dot{\psi} \cos \psi$ Gyroscopic momentum

The motor and the electrical control circuit is approximated by a first order transfer function thus in Laplace domain the motor momentum is described by:

$$\tau_1 = \frac{k_1}{T_{11}s + T_{10}} \cdot u_1$$

(6)

Similar equations refer to the horizontal plane motion:

$$I_1 \ddot{\varphi} = M_2 - M_{B\varphi} - M_R$$

(7)

where

- $M_1 = a_1 \varphi^2 + b_1 \varphi$ Nonlinear static characteristic
- $M_1 = B_1 \varphi \dot{\varphi} + B_2 \varphi \text{sign} (\dot{\varphi})$ Friction force momentum

$M_R$ is the cross reaction momentum approximated by

$$M_R = \frac{k_c (T_o s + 1)}{(T_p s + 1)} \cdot \tau_1$$

(10)

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

$$\tau_2 = \frac{k_2}{T_{21}s + T_{20}} u_2$$

(11)
4. System Identification

The TRMS is a MIMO plant – multiple input multiple output. Figure 4 presents a simplified schematic of the TRMS.

The TRMS is controlled with two inputs the $u_1$ and $u_2$. The dynamics cross couplings are one of the key features of the TRMS. The position beams is measured with the means of incremental encoders, which provide a relative position signal. Thus every time the Real-Time TRMS simulation is run one must remember that setting proper initial conditions is important.

As mentioned in the previous description the MIMO is a nonlinear plant with significant cross couplings between the rotors (Figure 4). To keep the identification simple, the model can be treated as two linear rotor models with two linear couplings in between. Thus four linear model have to be identified: two for the main dynamics path from $u_1$ to $\psi$ (pitch) and $u_2$ to $\phi$ (yaw) and cross coupling dynamics paths from $u_1$ to $\phi$ (yaw) and $u_2$ to $\psi$ (pitch).

**Exercise 1: Voltage applied to input $u_1$ and $u_2 = 0$**

In this part, the results are used to identified the model $G_{11}$ that describe the relation between the control voltage $u_1$ and the angle $\psi$ (pitch) and the model the model $G_{12}$ that describe the relation between the control voltage $u_1$ and the angle $\phi$ (yaw). The identified experiment is carried out using the model called *(Exercise 1.mdl)*. This model excites the TRMS and records its response. The excitation signal is composed of several sinusoids. Two signals are collected in the form of vectors and available in the Workspace.
Exercise 2: Voltage applied to input $u_2$ and $u_4 = 0$

In this part, the results are used to identified the model $G_{21}$ that describe the relation between the control voltage $u_2$ and the angle $\psi$ (pitch) and the model the model $G_{22}$ that describe the relation between the control voltage $u_2$ and the angle $\varphi$ (yaw).

The identified experiment is carried out using the model called (Exercise 2.mdl). This model excites the TRMS and records its response. The excitation signal is composed of several sinusoids. Two signals are collected in the form of vectors and available in the Workspace.

**Task**

1) Carry out the identification experiment and collect the data from exercise 1. Identify the two model $G_{11}$ and $G_{12}$ using the MATLAB identification toolbox.

2) Carry out the identification experiment and collect the data from exercise 2. Identify the two model $G_{21}$ and $G_{22}$ using the MATLAB identification toolbox.

3) Build the Simulink Model like figure 4. Find the closed loop step response specification for two cases1: $u_1$: step input, $u_2=0$ and case 2: $u_1=0$, $u_2$: step input.

5. **TRMS Control Design**

There are numerous control algorithms. The PID controller algorithm is popular because of its simplicity. A general schematic of a simple control closed loop system is presented in figure 5.

![Figure 5: Simple control system - closed loop](image)

Assuming that the plant is represented by its linear model its transfer function can be described as

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

where (s) is Laplace operator.

The idea of control algorithm is to find a controller, which will fulfil our requirements (certain dynamic response, certain frequency damping, good response to the dynamic
change of the desired value etc.). Every controller’s input is $e(t)$ error signal, sometimes disturbance signals are also measured. Depending on the present and past values of the error signals, the controller performs such an action (changes the $u(t)$ control signal) that the $y(t)$ is as close to the $y_{desired}(t)$ value as possible at all the times.

**Exercise 3: 1 DOF Pitch Rotor Control**

In this exercise the pitch rotor will be controller To design a PID controller a model of the plant is needed. For this purpose, we can use a linearized plant model or use a model obtained in the identification experiment and design a PID controller based on that model.

**Task 1: Simulation Result**

1) Design using PID control tuner for the model obtained in the identification experiment. Make sure $u_2 = 0$ in this part.
2) Plot the simulation response of PID controller.
3) Write the parameters value of PID controller.

**Task 2: Real Time Result**

Open the Simulink file (TRMS_PID_Pitch.mdl) you will notice that this simulation is directed it an external module.

1) Plot the Response of pitch angle. Use the PID control that already designed in Task1. By change the parameters of the PID controller block (desired input is step).
2) Plot the Response of pitch angle. Set the following parameters $P=5$, $I=8$, $D=10$ of the PID controller with apply desired input is step.
3) Plot the Response of pitch angle. Set the following parameters $P=3$, $I=4$, $D=15$ of the PID controller with apply desired input is step.
4) Plot the Response of pitch angle. Set the following parameters $P=5$, $I=8$, $D=10$ of the PID controller with apply desired input is sinusoid signal).
5) Compare between the response and write your comments.
**Exercise 4: 1 DOF yaw Rotor Control**

In this exercise the yaw rotor will be controller to design a PID controller a model of the plant is needed. For this purpose, we can use a linearized plant model or use a model obtained in the identification experiment and design a PID controller based on that model.

**Task 1: Simulation Result**

1) Design using PID control tuner for the model obtained in the identification experiment. Make sure \( u_1 = 0 \) in this part.
2) Plot the simulation response of PID controller.
3) Write the parameters value of PID controller.

**Task 2: Real Time Result**

Open the Simulink file ([TRMS_PID_yaw.mdl](#)) you will notice that this simulation is directed it an external module.

1) Plot the Response of pitch angle. Use the PID control that already designed in Task1. By change the parameters of the PID controller block (desired input is step).
2) Plot the Response of pitch angle. Set the following parameters \( P=2, I=0.5, D=5 \) of the PID controller with apply desired input is step.
3) Plot the Response of pitch angle. Set the following parameters \( P=1, I=2, D=5 \) of the PID controller apply desired input is step.
4) Plot the Response of pitch angle. Set the following parameters \( P=2, I=0.5, D=5 \) of the PID controller apply desired input is sinusoid signal.
5) Compare between the response and write your comments.
Exercise 5: 2 DOF Position Control

In 1 DOF only one rotor has been used for control. The 2 DOF control includes 2 controllers working in parallel. For some MIMO plants such solution fives satisfactory results. If the cross coupling dynamics are significant, extra algorithms have to be incorporated. Either a decoupling scheme is introduced or multidimensional controllers should be designed.

The two controllers that have been designed in the previous sections are first tested in parallel.

Task 1: Simulation Result

1) Assume the desired value of two angle. And use the value of controller that was designed in exercise 3 and exercise 4
2) Plot the simulation response of PID controller.

Task 2: Real Time Result

Open the Simulink file (TRMS2DOF.mdl) you will notice that this simulation is directed it an external module.

1) Plot the Response of pitch angle. Use the PID control that already designed in Task1. By change the parameters of the PID controller block (desired input is step).
2) Set the following parameters $P=5$, $I=8$, $D=10$ of the PID controller for pitch angle, Set the following parameters $P=1$, $I=0.5$, $D=5$ of the PID controller with for yaw controller.
3) Plot the Response of pitch angle. And yaw angle for two desired input (step and sinusoidal)
4) Compare between the response and write your comments