MECHATRONIC DESIGN AND IMPLEMENTATION OF A HELICOPTER TEST STAND

[1]AMIR MOLAEI, [2]MASOUD RAZBAN, [3]JAVAD DARGAHI

Mechanical, Industrial &Aeorospace Engineering Department of Cocnordia University, Montreal, QC,CA
E-mail: [1]amiremolaei@gmail.com, [2]razban.masoud@gmail.com

Abstract - Real time control systems have a great potential for educational applications of control engineering. They have the benefit to be used for investigation of the performance of different control schemes intuitively. This paper discuss the mechatronic design and implementation of a one degree of freedom helicopter test stand for industrial control lab. The platform is comprised of a balancing beam with two rotors at the ends, wherein the center of mass of the beam can be changed. The mechanical design of the platformis in such a way to minimize the construction time and cost utilizing two dimensionalparts using laser cutting technology. The platform is also equipped with a wireless module to communicate with computer from distance without wiring problem, while having a user interface for implementing various control schemes. In this paper, the step by step procedures along with the required electronic components and mechanical parts for implementation of the platform is discussed in detail.

Keywords - Real Time Control, Control Lab, Helicopter Test Stand

I. INTRODUCTION

Real time physical test stands are of great importance for educational purpose of control engineering. Such a test stand allows the student to learn the fundamentals of control engineering more intuitively, while considering the real world circumstances on control systems such as disturbance, noise and uncertainty. It provides the students with a well understanding of the effects of the dynamic of the system on the control scheme in order to find the required solution to compensate unwanted dynamics of the system.There are several commercially available test stand for real time control system in market, such as water level control, furnace temperature control, inverted pendulum, ball and beam, helicopter test stand, etc. Helicopter test stand is among the mostly used test stand for control laboratories. Comparing to other existing platform it is more affordable to be implemented in educational control lab, due to cost and simplicity of design and implementation. Helicopter test stands mainly comes in two and one degrees of freedom platforms. In one degree of freedom helicopter the pitch angle of the helicopter model with an eccentric center of mass is controlled through a propeller having a vertical axis of rotation, while in a 2 DOFs helicopter test stand two perpendicular axis propellers are used for the control of pitch and yaw angles.



In Fig. 1 a commercially available helicopter test stand with two degrees of freedom is shown.

The helicopter itself is just the control plant and to have a control system other communication components are required for implementation of control schemes on the system. A real time computer controlled system is comprised of a plant wherein the control input is fed into while controlling state variable of the plant. The control effort is produced via an actuator coupled to the system wherein the control signal is produced via controller. The controller produces the control signal by comparing the measure output of the plant with that of the input. The controller is mostly a PC or microprocessor with an interface to communicate data with sensors and actuators of the control system. A practical component of a typical control system of and educational test stand can be found as Fig.2.

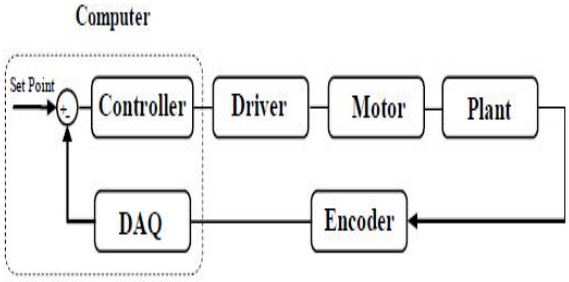


Fig.2. General Control System Scheme

In this paper the mechatronic design of a one DOF helicopter test stand is discussed in details. The presented system is comprised of mechanical parts, electronics components, as well as user interface. In order to avoid wiring problem a wireless module is used to send the data to communication unit to provide the actuators with the control signal.

After implementation of the system several controller are for pitch angle are designed and the performance of the controller is investigated in details.

II. MECHANICAL DESIGN

The mechanical design of the platform includes two main section, one for the structure of the mechanism and the other for mechanical components. The test stand itself is comprised of a two propeller on a balancing arm mounted on a fixed base. The position of the balancing arm is measured via an encoder coupled to the shaft of the rotating arm. The detailed procedure of the mechanical design process is discussed in the following.

A. Structure of the Mechanism

In order to make the manufacturing process simplified and economically reasonable, all the components of the mechanism is designed with 2D part which can be cut out of metal or plastic via laser technology. These procedure reduce the time and cost of the structure of the mechanism substantially while allowing a flexible design approach. In this stage of design Plexiglass material is used for the construction of the structure with the thickness of 15 mm.In this design, different parts of the structure are designed to be interlocked with each other to provide the connectivity of the 2D component and the precise alignment of the parts with respect to each other. A CAD model of the designed structure can is shown in Fig. 3 wherein the overall size of the structure is given.

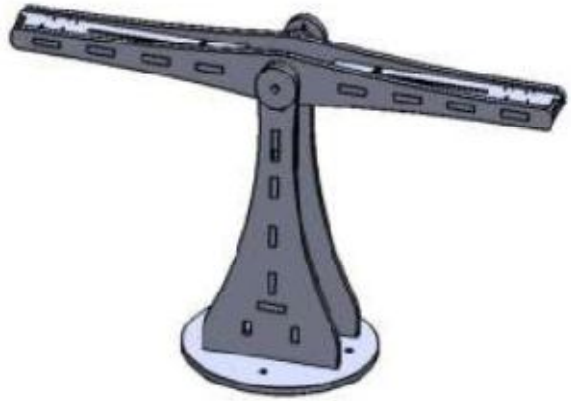


Fig. 3. Structure of the platform designed in SolidWorks

Referring to the Fig.3 the motors of the mechanism are mounted at two far ends of the balancing arm and the encoder is mounted on the joint of arm. The encoder itself is coupled to the shaft of the beam which is rigidly attached to the rotating arm. The rotating arm is mounted on a rigid platform which can be fixed to a table to prevent unwanted movement of the platform. In order to fix the base several grooves is considered for the base to in order to fix the platform in place. There are also some holes along the rotating arm to change the position of adding mass for changing center of gravity to investigate the performance of the controller in the presence of the disturbance.

B. Mechanical Components

The main mechanical components of the mechanism is the bearings, rotor blades and the shaft which is connected to the rotating arm. The extension of the shaft passes through a hollow shaft encoder which is then fixed to the encoder. Suitable nuts and bolts are also chosen to mount the motors and the encoder on the platform.

III. DYNAMIC MODELLING

A schematic view of the system can be found in the Fig. 4 wherein the unbalanced mass and the mass of motors positions the center of mass with and offset distance and angle with respect to the center of mass. The corresponding offset is represented by a distance d and angle θ_0.

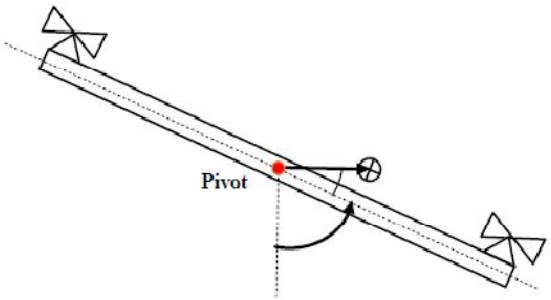


Fig.4. ASchematic view of system.

Considering a viscous damping for the joints the dynamic model of the system can be expressed in the form:

$$I\ddot{\theta} + C\dot{\theta} + mg\sin(\theta + \theta_0) = F \quad (1)$$

In this equation m is the overall of the rotating arms, considering two motors and the added mass, C is damping coefficient and I is the moment of inertia of the rotating arm. The obtained equation is a nonlinear dynamics model of the system which can be used for investigation of the nonlinear controller. This system can also be used as a suitable platform for linear control lab. In order to do a linearized model of the system can be used to investigate linear control schemes. Referring to the above obtained equation the linear model of the system for small θ will be as:

$$I\ddot{\theta} + C\dot{\theta} + mg(\theta + \theta_0) = F \quad (2)$$

For this model the offset center of mass can act as a disturbance to the system which can be easily be compensated in the controller design. Being so while working with such a system student will be familiar with the disturbance concept in linear control systems. The equation (3) can be represented in the state space form as below:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}0 & 1\\ \frac{-mg}{I} & \frac{-C}{I}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}0\\ F\end{bmatrix} + \begin{bmatrix}0\\ -mg\theta_0\end{bmatrix} \quad (3)$$

Wherein x_1 and x_2 are θ and $\dot{\theta}$ respectively.

IV. ELECTRONICS COMPONENTS

As mentioned earlier the electronics parts of the system are the brushless motors, the incremental encoder and the wireless module with two microcontrollers and the corresponding electronic

boards. More detailed description of the electronic components will be found in the following.

A. Brushless motors and drivers

The brushless motors are MT2814 with T18A drivers, both manufactured by Tigemotors, Fig.5.

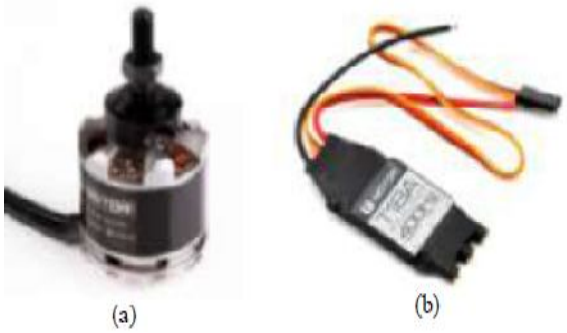


Fig.5. (a) Brushless motor, (b) Controller.

Detail specification of the motor can be found in table 1.

Table 1. Motor specification

Mass	Max Continuous Power	Internal Resistance	Motor Efficiency	Diameter
120 gr	440W	125mΩ	83%	28mm

B. Microcontroller

Two ATmega32 AVR controller is used, one to communicate with the PC through RS232 protocol and the as well as sending data to wireless module. The other is gets the data from receiver and generates the PWM signal for speed control of the brushless motors.

C. Incremental Encoder

The encoder used for the system is a hollow shaft encoder with 8 mm shaft size and 100 pulse for one revolution. It needs a 12 Volt power supply and the data of the encoder is read using the microcontroller which sends the data of encoder to the PC microcontroller.

D. Wireless Module

The wireless module is Xbee Pro S2B bi Digi Company with 2.4 GHz working frequency and 3.3 voltage and 215 mA current for low power applications. It can be used to transfer data as long as 90 meters in enclosed area and up to 3 Km in open areas, see Fig. 6.



Fig. 6. Incremental Encoder (left) and Wireless Module (right)

E. Microcontroller

In order to communicate with pc and transmitting and receiving data two Atmega32 AVR microcontroller is used. The one at the computer side gets the data from pc and sends it through the wireless modules to the plant as well as receiving encoder data from the wireless module and sends it to the PC. The other micro controller at the plant side receives the control data and produces the suitable PWM signal for the motor driver while getting encoder position and sending it through the wireless module to the computer side microcontroller.

V. INTEGRATION OF THE SYSTEM

The integrated system is shown in the Fig. 7. With all the electronic component mounted on the structure. The communication of the platform with the PC is provided using MATLAB Function wherein the controller in the Simulink can be synchronized with the platform through RS232 port and MAX32 IC.

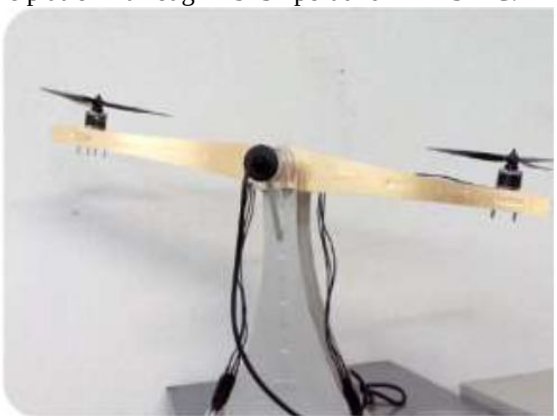


Fig.7. Integrated system

RESULTS AND CONCLUSION

The platform is designed in order to investigate the performance of various control schemes. The controller design and controlling algorithms are out of scope of this paper, but each motor has tested separately. As the motor are brushless, the only way for actuation is through the Pulse Width Modulation (PWM) method. The system has considered single impute single output.

To evaluate the performance of the system, one of the motor are given a constant speed and the speed of the other one is increasing gradually to make system unstable. This specific amount for instability has considered the maximum actuation for PWM and constant speed has considered lower amount of PMW. Therefore a step input is given to motor with lower boundary equal to PWM amount for constant speed rotation and higher boundary of equals to PMW for start point of instability. The response of system for such step actuation is plotted in Fig. 8.

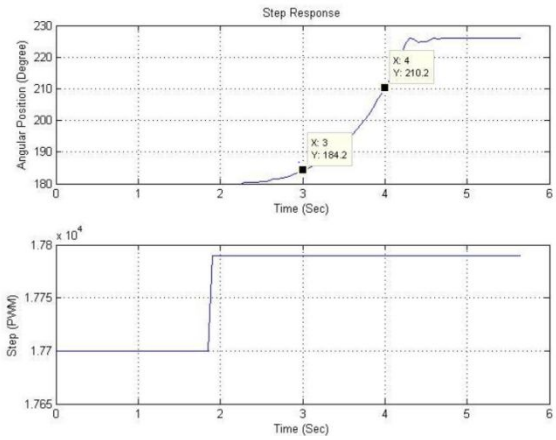


Fig. 8. Step response of system

As the conclusion, in this paper a mechanical and mechatronic implementation of a single DOF helicopter test was discussed in details. The design was based on minimizing cost of fabrication, stability and controllability of system. The system was actuated using PWM method. Different speeds are given to motors to see the instability of system and the step response of at the boundary of such condition has tested. The results that the system can reach from lower step boundary to maximum speed boundary before instability happened in less than 2 second.

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