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A Literature Review on Control Loading System for Helicopter Simulator

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Abstract

This paper presents a brief review of the control loading system and control techniques used in the helicopter simulator. The control loading system gives the pragmatic flight control forces in the helicopter simulator. So, the pilot gets the real feel of flying the helicopter. Once the control loading system implementation is done, a series of checklists are to be performed to validate the results on how the control loading system is performing. This is compared to a chart available to public released by various flight regulatory bodies. This is followed by an explanation of the different control techniques and their impact on the main objective. The paper also provides a comparative study of the different control techniques showing the benefits over others. This work can be used for further study for helicopter simulators.

Keywords: Control loading system (CLS), Matlab, Qualification test guide (QTG), Simulink

1. INTRODUCTION

The process of re-creating the flight path and the environmental conditions in which the helicopter flies for training new pilots is called simulation and the device through which it is done is called Helicopter simulator. It helps the pilot to replicate the experience of the real time flight. Apart from pilot training, it is also used in design, development and research purposes and helps the operator learn controlling handling qualities. For more accurate experience, the qualities of handling the helicopter and the pilot ratings are to be satisfied which includes longitudinal, lateral direction and static control check tests. Due to hardware constraints, full scale flight simulators are usually found very expensive and often found dependent on type of helicopter. Therefore, a need for the design of flight simulators using virtual reality is observed and worked on.

A simulator helps the pilot to experience a broad range of situations that are involved in a real flight without being in the situations and avoid the risk. An essential part of any flight simulator is the so-called control loading system. The number of instances of flight gear is used to manage the motion of helicopter, control of flight and instrumentation of cockpit. The system comprises both hardware and software parts. The software modules support the simulation, between which one controls the cockpit motion in 6 degrees of freedom and the other implements a load reproducing system on cockpit controls. Full digitally controlled electric control loading system has technical and economic advantage over hydraulic system, thus an ideal choice for large simulator. The use of flight simulators for pilot training has played a major role in improving flight safety over the last few decades. Current standards for regulatory qualification of flight simulators involve matching a prescribed set of flight test data within set tolerances on various helicopter parameters.

2. A MATLAB/SIMULINK-BASED INTERACTIVE MODULE FOR SERVO SYSTEMS LEARNING

A. Servo Systems and Control

Despite the development of more advanced control techniques, the PID controller is still the most common algorithm used in servo systems applications. The attractiveness of PID resides in the fact that an accurate model is not required and its control capabilities have been proven to be adequate for controlling servo systems. Indeed, PID controllers are used in many dedicated motion-control, such as LM628/629, Magellan, Galil boards, or the Quanser dc motor model for training and education. In practical servo systems, PID controllers can perform poorly when used alone. To enhance the system performance, several additional mechanisms—such as handling the windup effect properly, combining the feedback with feed-forward control, or using a trajectory generator—are adopted as technical solutions. For example, the elimination of the steady-state error in servo systems has long been performed using the integrator action. However, this action has the disadvantage of causing the windup effect, which occurs when the calculated control signal exceeds its saturation limits, the controller is unable to respond immediately to changes in the error signal. To prevent the windup effect, the operating range of the control signal should be limited to the range of the voltage input of the servo. This *ad hoc* solution provides instant recovery when the error signal changes signs. Feed-forward is another technique used to improve servo systems performance and is essentially used to reduce the tracking error in high-performance motion control problems. Theoretical developments show that the feed-forward transfer function is the inverse dynamic of the servo. In general, feed-forward compensation is performed through the required acceleration and velocity. Finally, the position step references are rarely used since they can cause controller saturation and lead to significant overshoot. To overcome these problems, references known as S-curves, such as parabolic or trapezoidal profiles, are used instead. These S-curves are provided by a trajectory generator, which is an algorithm at the top of control hierarchy. The step response is used as a measure of system performance.

3. MODELLING, SIMULATION AND IMPLEMENTATION OF HELICOPTER PITCH CONTROL SYSTEM

Vertical flight control is considered as important topic for researchers and scientists in the field of UAV; however, helicopter configuration always has important altitude control issues associated with it [1]-[3]. In practice different flight modes are observed for helicopter such as vertical take-off or landing, lateral or longitudinal flight and hovering control, but disturbances in hovering and take-off require time to time improvement in design such as flight of a helicopter near seaside with heavy winds [4],[5]. This study will discuss about the vertical flight control strategies. In the following sections, different techniques will be analyzed to control the pitch angle of the helicopter. The controllers used for this project includes PID, Pole placement and LQR.

A. PID method

The more realistic transfer function for PID controller presented in the [2] was used.

The tuning of PID gains were done in such a way that proportional gain gives a fast response by improving the rise time, integral gain reduces steady state error and derivative gain reduces the overshoots. The system was first tuned in Simulink to get a good response. Later, in order to account for the noise, these gains were again varied in the real helicopter setup. The PID controllers are very commonly used due to their easy implementation. However, the response shows some undesirable overshoots and takes some time to settle for a given disturbance once the system is in stable state.

B. Pole Placement method

The response of the system is characterized by pole's location. Hence, pole placement is a technique whereby system response can be controlled by placing the poles at the desirable location in the Left Half Plane. Pole placement can be only applied to the system which is controllable [6]. The desired location is chosen based on factors like overshoot MP and settling time TS. An illustration of pole zero plot is shown in figure 1.

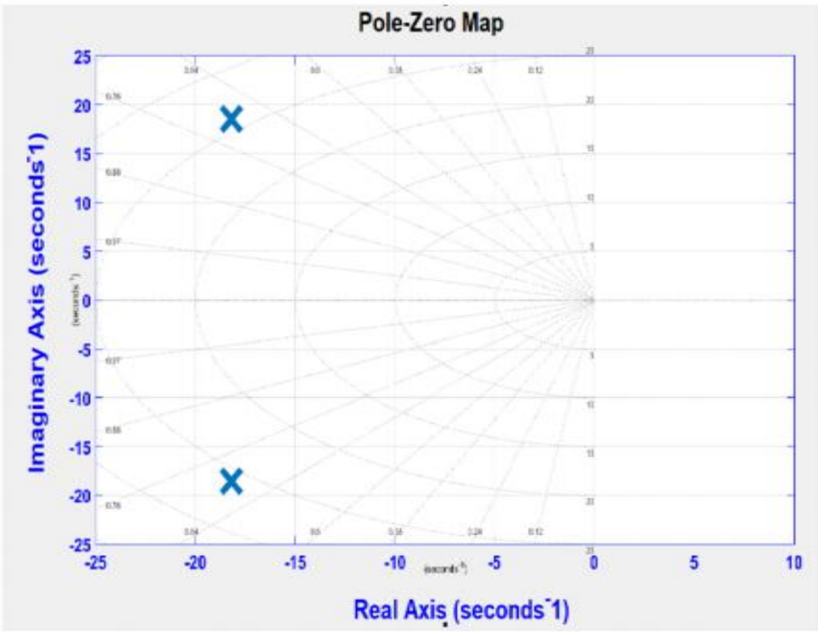

Fig 1. Pole zero map plot

C. Linear Quadratic regulator method

LQR is a controller very similar to pole placement method. However, instead of selecting the pole location, the effort is made on minimizing the cost function to obtain the design requirement.

4. AUTOMATED FLIGHT TEST AND SYSTEM IDENTIFICATION FOR ROTARY WING SMALL AERIAL PLATFORM USING FREQUENCY RESPONSES ANALYSIS

The whole experimentation in this research is conducted in X-Plane simulation.

Auto pilot system:

Advanced high-bandwidth flight control design requires models that are accurate at higher frequencies. A very effective and accurate way to obtain linear rotorcraft models is trough linear-frequency-domain system identification. Methodology are:

1. Development of PID based rotary wing autopilot
2. Development of frequency-sweep input algorithm
3. Development of simulation system in X-Plane
4. Processing the simulation data in CIFER
5. Hardware design of automated flight test system
6. Hardware in the loop (HIL) simulation

7. Processing the HIL simulation data in CIFER [7]

8. Real world experimentation to get flight data

9. Processing the real-world experimentation data in CIFER

10. Optimal Multiple Input Multiple Output (MIMO) control system development based on vehicle's model identified in CIFER

11. Real world experimentation to test Optimal MIMO control system. The research has been completed until the 4th step, so step 1 to 4 will be presented in this paper. A safe controller for rotary wing platform is needed to control the platform during frequency swept flight test. PID based controller can be used to control small rotary wing platform.

5. SYSTEM IDENTIFICATION METHODS FOR HELICOPTER FLIGHT CONTROL DEVELOPMENT AND VALIDATION

System identification is a procedure for accurately characterizing the dynamic response behaviour of a complete air- craft, subsystem, or individual component from measured data. The illustration of aircraft system identification is shown in figure 2. The input to the aircraft is the elevator deflection and the output is the angle of attack.

Careful tracking of the broken-loop and end-to-end closed-loop frequency-response behaviour from the preliminary design Modern fly-by-wire helicopter employ high-bandwidth digital flight-control systems to achieve greatly increased agility and disturbance rejection across a significantly widened operational flight envelope as compared with the older generation of helicopter [8].

Fig 2. Aircraft System Identification

An extensive development facility has been used in the NASA vertical/short take-off and landing (V/STOL) systems research helicopter (VSRA) project, which equipped a YAV-8B Harrier helicopter with a fly-by-wire research flight-control system.

6. SYSTEM IDENTIFICATION MODELING OF A MODEL-SCALE HELICOPTER

First-principle based modeling approach, considerable knowledge about rotorcraft flight dynamics is required to obtain the governing equations, and comprehensive flight validations and model refinements are necessary before sufficient accuracy is attained. Instead, in the helicopter community a modeling method based on system identification has been developed and successfully used with full-scale helicopters.

The yoke itself is attached to the rotor shaft over a teetering hinge in an under-swung configuration, reducing the Coriolis forces and the associated in-plane blade motion. The teetering motion is also restrained by an elastomer damper/spring [9]. This lag produces a moment about the helicopter's centre of gravity opposite to the rolling or pitching direction and proportional to the rolling or pitching rate. A smaller rotor has a smaller rotor time constant τ; therefore, for a given pitch or roll rate, it will lag less and thus produce less damping. The system identification steps to be performed for any given aircraft is shown in the figure 3.

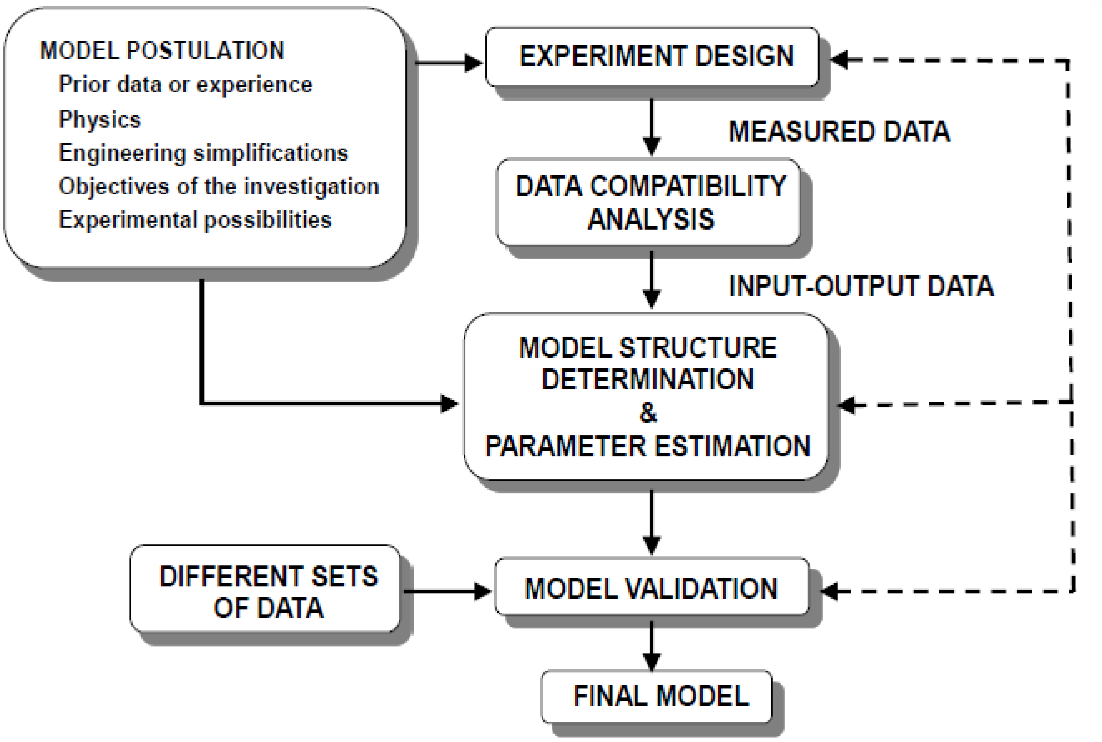

Fig 3. Steps involved in aircraft system identification

The compatibility of the flight data with the postulate of linear dynamics used for the modelling. While the accuracy of the state estimates depends on the instrumentation, the information content and compatibility depend on the execution of the flight experiments.

The stabilizer bar can be regarded as a secondary rotor, attached to the rotor shaft above the main rotor, through an unrestrained teetering hinge. The blades consist of two simple paddles.

The stabilizer bar receives cyclic inputs from the swashplate in a similar way as the main blades.

7. ELECTRO-MECHANICAL CONTROL LOADING SYSTEM FOR ROTARY WING HELICOPTER SIMULATORS

High-fidelity electro-mechanical Control Loading System (CLS) for a rotary wing helicopter simulator.

1. CLS is one of the major components of a flight simulator. It is used for providing realistic force feedback to pilots [10].
2. In a helicopter simulator, CLS has four control axes, which are cyclic (pitch and roll), collective and pedal [11].
3. A CLS contains multiple inner loops, one for each control axis.

   Inner loops convert the computed forces into actual mechanical forces by generating drive signals to the CLS actuators, based on the force exerted by the pilot and what the pilot should feel.
4. CLS actuators and sensors are placed at the back of the platform.
5. Control loading part is implemented entirely on MATLAB/Simulink, using the real-time capabilities of the xPC-Target toolbox.
6. The simulator has two high-end computers named Host PC and Control Loading PC.
7. The Control Loading PC runs a real-time kernel
8. The connection between the Control Loading PC and the motor drivers is over a high-speed digital interface, which is Ethernet for Control Automation.

8. CONTROL LOADING SYSTEM

An electric control loading system for helicopter simulation was analysed and modelled to find a linear state space mathematical model and state feedback. A linear state space mathematical model and state feedback appear to provide satisfactory means for controlling an electric control loading system can be adjusted to simulate a wide variety of real helicopter by altering input and output gains at the force analog computer when helicopter parameters are changed.

Fig 4. A complete helicopter simulator setup with control loading system

Control systems in real helicopter which convert column, wheel, and pedal motions into control surface deflections. In addition to the pilot input, such systems provide force cues to the pilot, which assist him/her in assessing the extent and rate of controlled manoeuvres. The aspect of a real helicopter control system which concerns these cues is called control loading system. The control loading system in a helicopter simulator must be capable of accurately reproducing force cues typical of the real helicopter. The control loading system in a helicopter simulator must be capable of accurately reproducing force cues typical of the real helicopter. A helicopter simulator with control loading system is shown in figure 4.

A helicopter simulator control loading system includes systems which provide force cues in the elevator, aileron, and rudder control modes; however, only an elevator system is considered here. In a helicopter, the pilot exerts a force on the control column to deflect a control surface. Between the flight control and the control surface is a system of cables, pulleys, bell cranks, boosters, feel springs, dampers etc.

The principal components of most simulator control loading systems in current use are the force analog computer, which generates an electrical signal corresponding to the force require for these controls to give these realistic cues, the actual helicopter control in the cockpit, with the control connected to an electric cylinder by a linkage system that approximates part of the helicopter's push-rod system, The servo electric cylinders must simulate the forces that would have been produced by the remainder of the helicopter's control system, force transducer, to give an electrical signal corresponding to the force applied to the manually-operable controls of a helicopter simulator, position transducer and DC power etc.

The working principle is as following: when the pilot moves the control column, the position and force of the electric cylinder is changed. Force analog computer calculates the computed force according to the actual electric cylinder position and the flight parameter that affect the control system simulation in accord with simulated flight conditions. Then error signal between the computed force and the actual force is given, and then the electric cylinder controller drives the electric cylinder to make the generated force track the demanded force [12]. This is the force that a pilot trainee should sense at this particular control position.

9. STATE SPACE ANALYSIS AND OPTIMAL CONTROL FOR HELICOPTER SIMULATOR PITCH ELECTRIC CONTROL LOADING SYSTEM

The aspect of a real helicopter control system which concerns these cues is called control loading system.

The control loading system in a helicopter simulator must be capable of accurately reproducing force cues typical of the real helicopter. A Simulink model with state space implementation of control loading system is shown in figure 5.

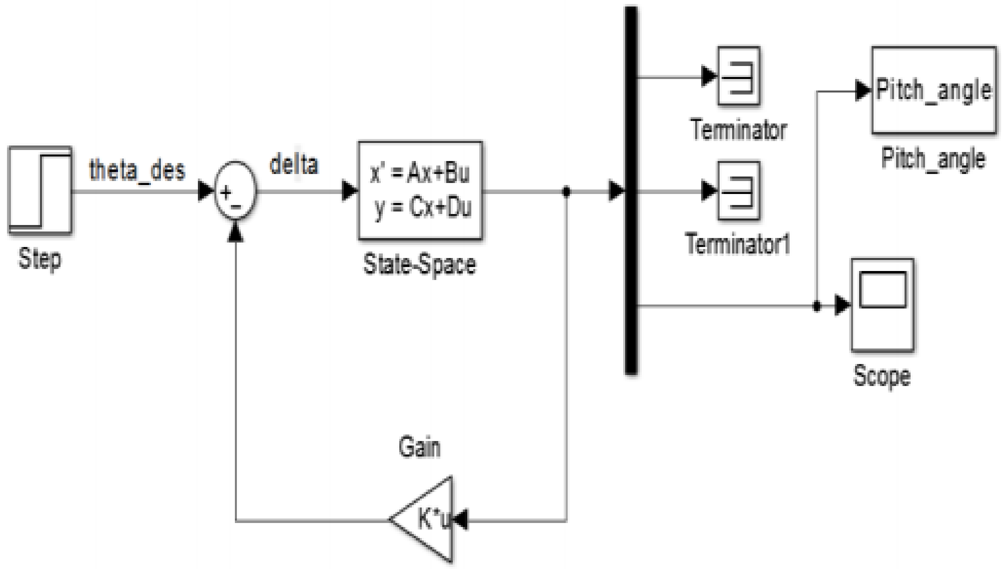

Fig 5. State Space model of CLS actuator using Simulink

A helicopter simulator control loading system includes systems which provide force cues in the elevator, aileron, and rudder control modes [13]. The force analog computer runs a drive logic to control a servo electric cylinder that drive a pitch control loading system for creating realistic force cue.

10. CONCLUSIONS

This paper gives a summary about the control loading system and its performance measures. With the help of pole placement, bode plot, frequency response and other plotting techniques, we can conclude whether the chosen system is stable or not. By doing so the system can perform in a very efficient manner.

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