Design of a Flight Stabilizer System Using a Hardware-in-the-loop Test Platform

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Abstract: In this paper a hardware-in-the-loop (HIL) test platform is used to design a flight stabilization system for unmanned aerial vehicles (UAV). Controllers are first designed and tested separately for lateral and longitudinal axes using numerical simulations, and later these controllers are merged on the HIL platform. It is observed that the resulting controller successfully stabilizes the aircraft to achieve straight and level flight.

Key words: UAV, Autopilot, PID controller, Hardware-in-the-loop, HIL, flight control, SISO, MIMO

1. INTRODUCTION

Aeronautics has recently gained great importance in both military and civil applications. The field of unmanned air vehicles (UAVs) is very broad, covering myriad missions and system types [1]. Autopilot systems are a major area of design for UAVs. These systems perform autonomous flights. A flight mission can be done without human input [2].

If an airplane is to remain in steady uniform flight, the resultant forces as well as the resultant moment about the center of gravity must both be equal to zero. An airplane satisfying this requirement is said to be in a state of equilibrium of flying at a trim condition [3].

In this paper we outline an approach based on a hardware-in-the-loop platform for building a stabilizing controller for UAVs. A suitable flight condition is designed by MATLAB/Simulink environment simulation to design a controller for UAVs. Flight control surfaces are selected as the inputs of the system to hold the UAV in this condition by trimming and linearizing using MATLAB's features. The next step is based on these trim points of the system, where nonlinear flight dynamical equations are linearized. There are several types of controller can be used for UAVs but PID controller is preferred and designed due its simplicity. Both manual calibration and MATLAB's automated design tools are used to determine the PID coefficients.

2. DESIGN STAGES

2.1. Controller Design

A general treatment of the stability and control of airplanes requires a study of the dynamics of flight [4]. Much useful information can be obtained, however, from a more limited view, in which we consider not the motion of the airplane, but only its equilibrium states. This is the approach in what is commonly known as static stability and control analysis [4].

Elevators and ailerons are flight control surfaces. Elevators are surfaces on the tailplane (the horizontal part of the tail assembly). While the entire tailplane surface helps stabilize the aircraft during flight, the elevators apply pitch by angling the trailing (rear) edge of the tailplane up or down.. Ailerons are surfaces on the outer, trailing edge of each wing. They angle in opposite directions to waggle the wings up and down or roll the aircraft about its nose-tail axis. If you apply stick left or right, one wing's aileron angles down and the other angles up. This rolls one wing up and forces the other wing down, effectively rolling the airplane [5].

2.1.1. Elevator-Theta Control

Elevator angle is given as an input to the Simulink model and theta angle is as an output. Firstly, Airlib library in MATLAB is used for the aircraft dynamic model. Cessna 172 flight model's aerodynamic derivatives are followed up. By using this aircraft model a Simulink stucture is established. It can be seen in Figure 1. Determining the cruise speed and altitude condition, trimming and linearization is obtained.

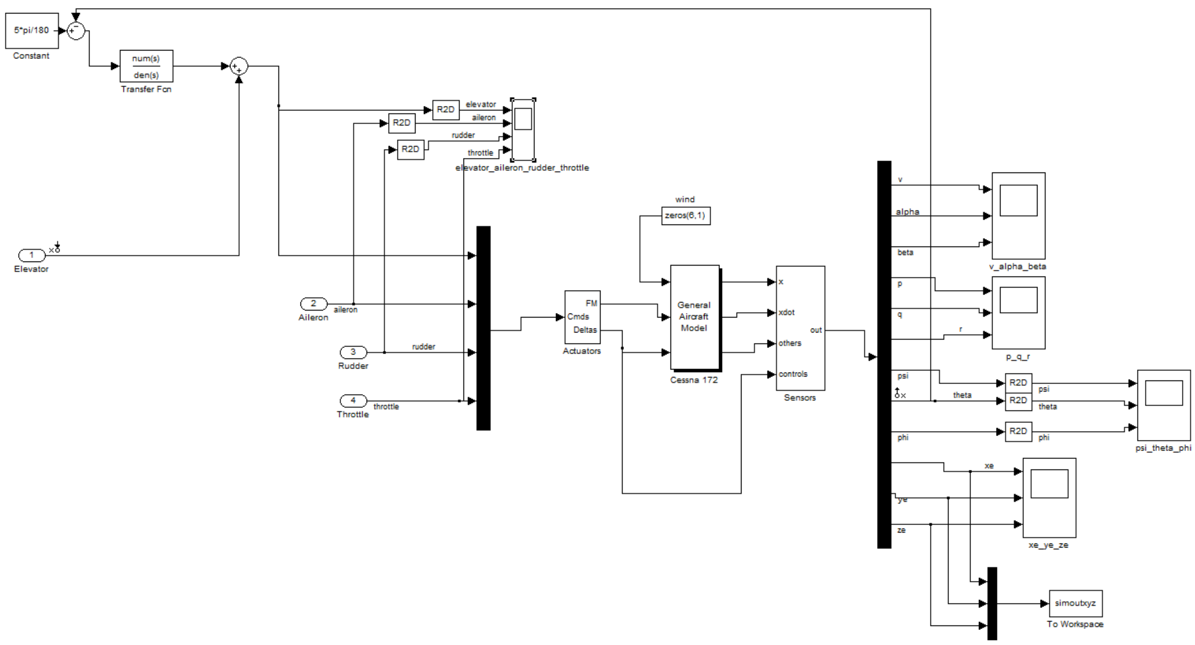


Figure-1 The Simulink Model for SISO system.

After linearization based on the operation point and system's minimal implementation is calculated, first step was designing the PID controller by MATLAB sisotool.

Closed loop step response provided by PID controller and the input which is applied are shown in Figure 2. Also it can be seen the input is reasonable.

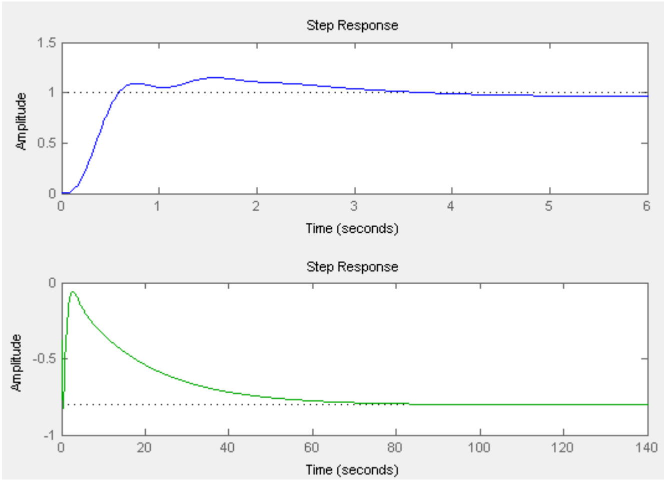


Figure-2 Theta output and Elevator input step responses for the PID controller

PID control structure is built for supported flight mode applied to the Simulink model's input which is the change of the elevator angle is shown in the Figure 3. The output of the system theta angle is shown in the Figure 4. Designed controller's impact of the other angles can be seen in the Figure 4. It can be seen that the psi and phi angles are not affected from the controller and remained around zero.

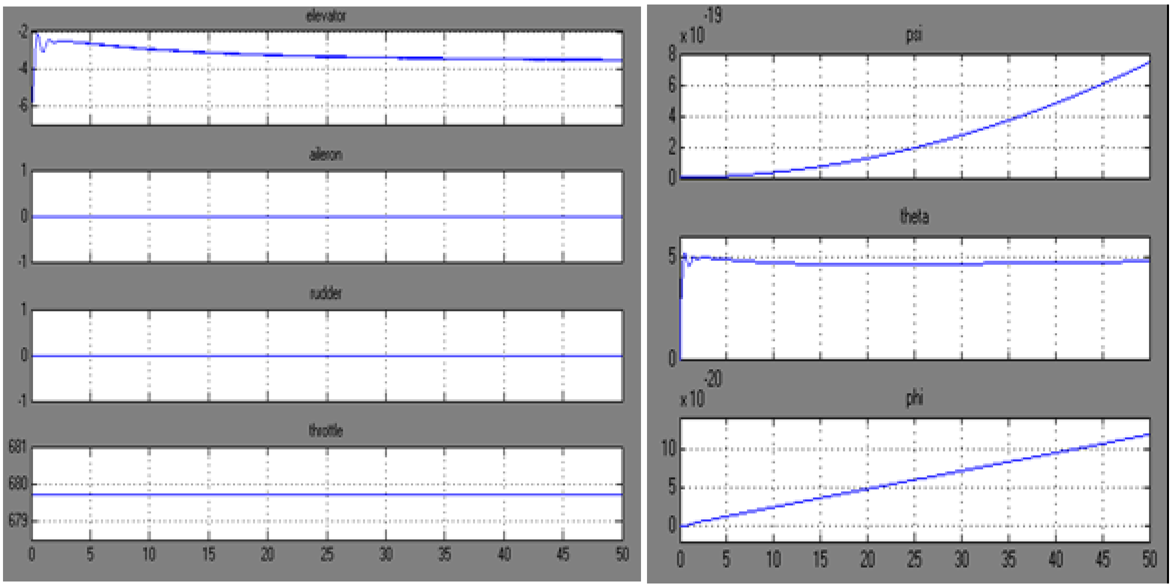


Figure-3 and 4. Changes of elevator, aileron, rudder and throttle as results of the applied controller. Changes of psi, theta and phi as results of the applied controller.

2.1.2 Aileron Phi Controller

Aileron is the control surface which operates the rolling of the UAV. This surface is the input of the MATLAB model. The output is the phi angle which is the rolling angle.

After linearization based on the operation point and obtained system's minimal implementation and PID controller's transfer function is calculated by MATLAB sisotool. Derivative filter is used to create a more resistant against noises and more realistic D parameter.

Closed loop step response provided by PID controller and the input which is applied are shown in Figure 5. Also it can be seen the input and output are reasonable.

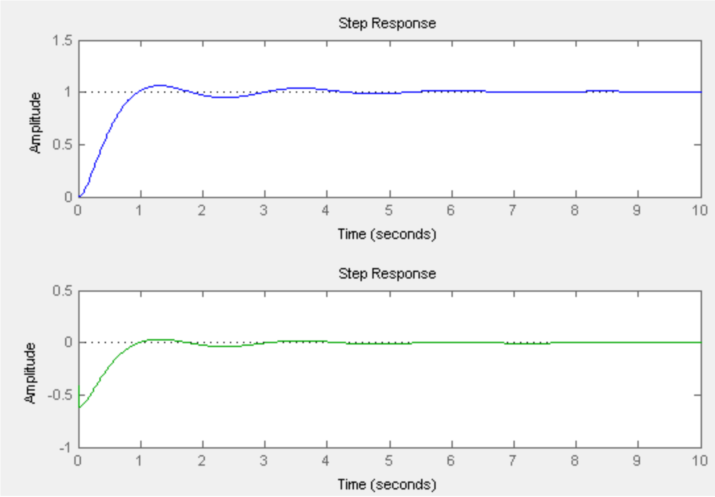


Figure-5 Phi output and Aileron input step responses for the PID controller

PID control structure is built for supported flight mode applied to the Simulink model's input which is the change of the aileron angle is shown in the Figure 6. The output of the system phi angle is shown in the Figure 7. Response settles without overshoot and around 3 seconds. Designed controller's impact of the other angles can be seen in the Figure 6 and 7. When the UAV roll over to its side the theta angle should change a bit because of the flight dynamics cross impacts. Besides UAV will trun in time which means psi angle will change. If these cross angles are undesirable, for instance if UAV's rolling over without changing theta is desired, two controllers (elevator-theta and aileron-phi) should be used together or multiple input multiple output controller should be designed.

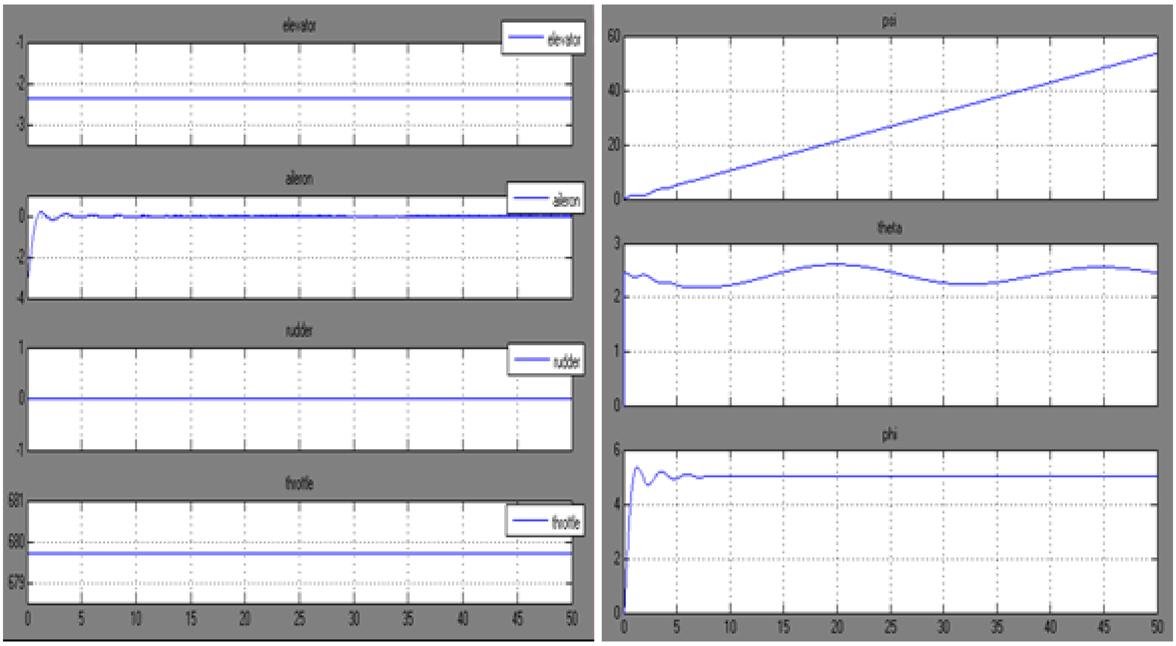


Figure-6 and 7 Changes of elevator, aileron, rudder and throttle as results of the applied controller. Changes of psi, theta and phi as results of the applied controller.

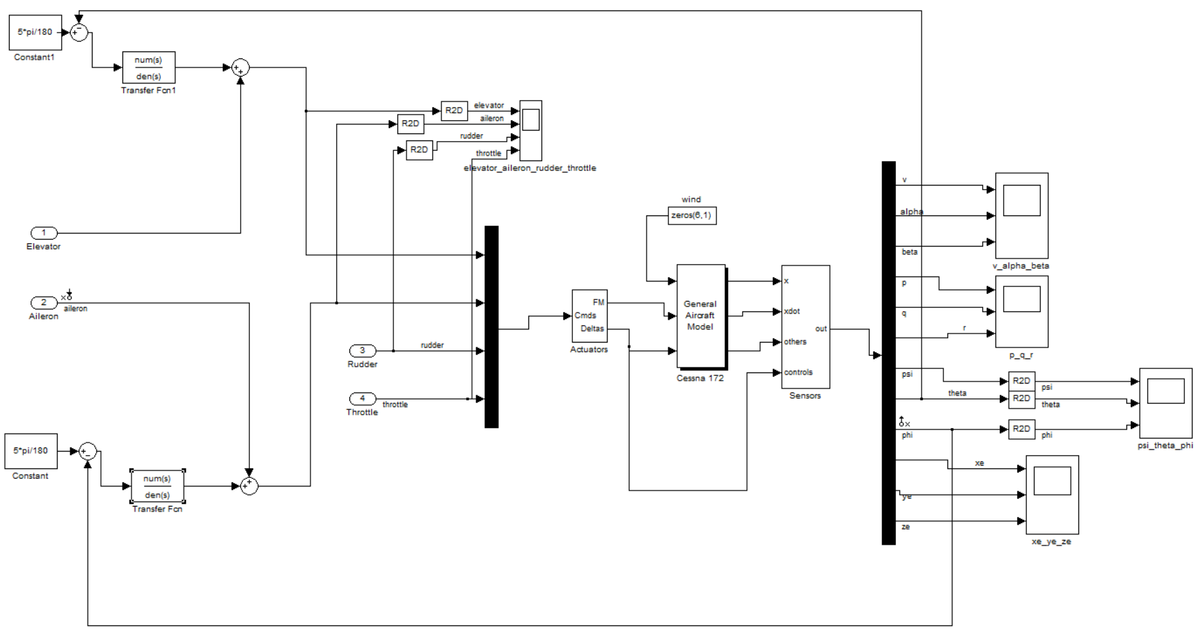


Figure- 8 The Simulink Model for MIMO system.

It is needed to be checked as if the elevator-theta and aileron-phi single input single output system controllers are working together. For this reason, both SISO system controllers are implemented at the same time. It can be seen in the Figure 8 in the Simulink model, elevator and aileron are as inputs and theta and phi angles are as outputs. It turned out that results were remain the same as the single input and single output systems. The corresponding figures could not be included here due to space limitations but they were exactly the same outcomes as in Figure 3-4 and Figure 6-7.

3. TEST PLATFORM

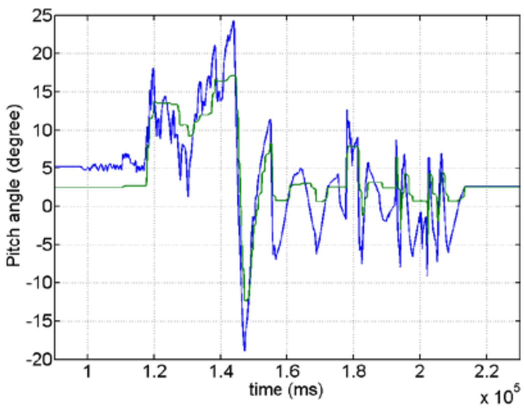
State space matrixes are gathered with calculations which explained before aren't always suitable for controlling UAVs. It's needed to be sure that simulation results are good enough to take a flight test with the designed autopilot. To achieve this pre-flight tests which are done by flight simulation are used. Hardware-in-the-loop simulation technique is used in this project as flight simulation. HIL simulation is chosen because actual autopilot and its inertial measurement unit (IMU) can be integrated with simulation.

This HIL simulation technique needs simulation software and a platform that use to integrate real values to simulation. For simulation software Xplane is chosen because this program let user review and transfer data to any other UDP enabled application and it has various types of plane models. Also the autopilot is designed for Cessna 172 is included in this software. And a platform which performs two axis movements (roll, pitch) to integrate autopilot's IMU is used. Ardupilot mega 2.0 is used as autopilot. Because Ardupilot has its own microcontroller, 6 DOF IMU and barometer, it is chosen. Also it is easy to program Ardupilot. The communication application is used to run all of these in order.

Figure-9 HIL Test Platform and Xplane Simulations

HIL simulation performs as follows. Plane fly in the Xplane generate roll and pitch angle values. These values send to UDP port and communication application read listens to Xplane's UDP send data port, captures datasets, distinguishes headers from data and sends angle bytes to the platform's microcontroller unit over serial port. Platform's microcontroller reads these values as reference values for pitch axis PID and yaw axis PID. Platform output and PID inputs are obtained by reading encoders which are connected to motors' shafts. Then each PID controller calculates their output and drives related motors which are individually connected to separate control surfaces. That surface is placed to desired angle. Therefore autopilot can be put over this platform and can operate on its own. Also transmitter and receiver are needed to give command to autopilot. Autopilot calculates new values for aileron and elevator according to given command and send them to serial port. The communication applications read them and convert them to messages Xplane can understand and write to UDP port which Xplane is listening. Xplane reads these values and actuates elevator and aileron according to these values. And plane state is changed based on these changes, new angle values are occurred.

Stabilizer is the first step of designing autopilot to test it at stabilizing mode. Reliable autopilot matrixes have been chosen after tests are made. Selected autopilot's results are shown in Figure 10 and 11.



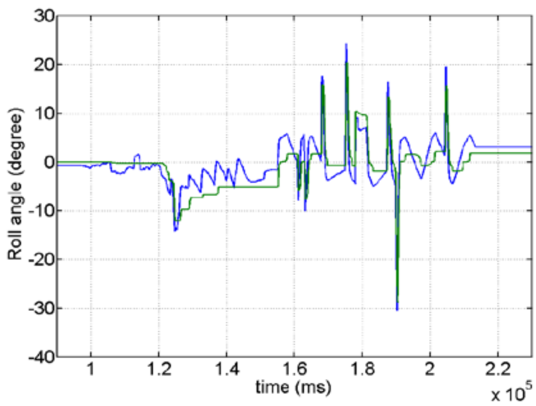


Figure-10 and 11 Pitch (left side) and Roll (right side) Axes Stabilization Results

In Figure 10 and 11 the autopilot created runs in stabilizer mode. In this mode it is possible to do maneuvers like rolls and loops but if the sticks were released then autopilot will level the plane. It can be seen that the plane is levelled when maneuvers were done in the Figure 11. Maneuvers were done for pitch angle at 12th to 14th seconds of simulations and levelled at around 17th seconds. Maneuver was done for roll angle around 16th second of simulation and levelled around 17th second then another maneuver was done around 19th second of simulation and levelled around 2 seconds of simulations. Other times stabilizer mode of autopilot was not been active.

4. CONCLUSION AND THE FUTURE WORK

In this paper we outlined the design of elevator and aileron stabilizer for UAVs and using data obtained from Xplane simulation. These data are processed by a system identification process utilizing MATLAB and a dynamically model of the aileron and elevator behaviors are obtained. These models are used to construct PID controllers for these surfaces and hardware in the loop simulations using a custom 3 degree of freedom moving platform confirm that the designed controllers successfully.

In future work surface loss scenarios are considered and to eliminate the impact of these losses controllers will be developed based on this study.

5. ACKNOWLEDGEMENTS

The authors would like to thank the Scientific and Technological Research Council of Turkey (TÜBİTAK) for supporting this work under project number 113E581.

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