PI-D Flight Controller for UAVs Autopilot Design

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Abstract– It is required for the autopilot flight-controller design of a fixed-wing Unmanned Aerial Vehicle (UAV) to track a predetermined path. In addition, it is required to be robust with respect to environmental disturbances especially wind, since its magnitude is comparable to the UAV speed. In this paper, the modified PID (PI-D) control algorithm is utilized to design an autopilot flight controller for the Aerosonde fixed-wing UAV.

Flight controllers based on the PI-D control algorithm are designed for controlling the altitude and the speed of the UAV. In order to verify the effectiveness and the robustness of this flight controller, it is compared with the genetically tuned traditional PID flight controller. The simulation results based on the Aerosonde UAV model confirm the effectiveness and robustness of the proposed modified PID flight controller. The simulation results show also the capability of the designed approach and its very satisfactory performance with good stability and robustness against external wind disturbance.

Keywords-- UAV, PID, PI-D, flight control.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) play important roles in critical missions. Nowadays, they are used in a growing number of civil applications beside their use within military applications. They are used for damage inspection after disasters, observation of volcanoes and for reconnaissance. This is because of its low cost and also to protect human crew in such dangerous missions [1,2]. An autopilot is used for flight control to track a reference path [3]. The autonomous controller has to guarantee the accuracy of the tracking path, and the robustness with respect to environmental disturbances and especially wind. Small UAVs are significantly sensitive to wind disturbance since its magnitude may be comparable to the UAVs speed [4]. The fixed-wing classification of UAV, in contrast to rotary wing or flapping wings, is similar to the typical aircraft design for manned operations. The flight performance of this aircraft is affected by the aerodynamic parameters as well as physical external conditions like altitude, wind, payload variation, and limited resources. The fixed-wing UAV dynamical model is nonlinear and strongly coupled. It is also affected by external disturbances like wind gusts. The controller must be robust against model uncertainties and external disturbances that are considered as a great challenge [3].

In recent years, considerable control design algorithms for UAV autopilots using modern control theory have been established. A large number of researches have been developed for onboard navigation and control systems. These have been achieved using nonlinear control, evolutionary algorithms, or optimization techniques. Despite their success, only a small number of implementations of these systems have been reported. It appears that there is not much enthusiasm to use them due to their complexity, nonlinear nature, and computation cost. On the other hand, PID autopilots have been successfully integrated as real-time control and online navigation systems for UAVs. This is not only due to their simple structure and easy implementation, but also because of their acceptable performances. However, for successful implementation of such controllers, and without requiring complex mathematical developments, parameters adjustment or tuning procedures are needed to achieve enhanced performance through the operating envelope [5].

In this paper, an autopilot is designed to control the longitudinal motion (altitude, and speed of Aerosonde UAV). In aircraft modeling phase, the aerodynamic forces (lift and drag) as well as the aircraft inertia are taken into account. A modified PI-D is utilized to design the flight controller of the autopilot. Another flight controller is designed to be compared with the modified PI-D controller. The second controller is a genetically tuned traditional PID flight controller. The autopilot performances have been studied with respect to each controller. A comparative study using simulation model of the Aerosonde UAV is held to decide which controller is the best in terms of performance analysis and robustness to external disturbances.

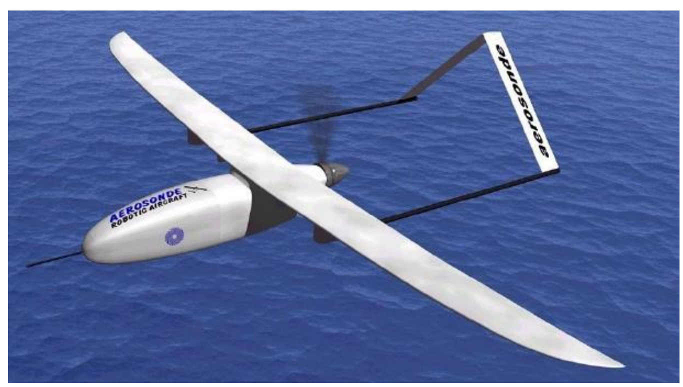

Fig. 1 Aerosonde UAV field.

II. AEROSONDE UAV MODEL

The Aerosonde UAV system is modeled by simulating a number of test flights, using the standard configuration of MATLAB and the Aerosim Aeronautical Simulation Block Set [6], which provides a complete set of tools for rapid development of detailed six-degree-of-freedom nonlinear generic manned/unmanned aerial vehicle models. A model which is called Aerosonde UAV is used as a test air vehicle [7]. The basic characteristics of Aerosonde UAV shown in Figure 1 are listed in Table 1[8]. The great flexibility of the Aerosonde, combined with a sophisticated command and control system, enables deployment command from virtually any location.

TABLE I
AEROSONDE UAV SPECIFICATIONS.

Aerosonde UAV Specifications	
Weight	27-30 lb
Wing span	2.9 m
Engine	24 cc, 1.2 kw
Flight	Fully autonomous
Maximum speed	30-40 m/s
Cruise speed	20-30 m/s
Altitude range	Up to 20,000 ft
payload	1 kg

The Aerosonde UAV's flight dynamics model available in the AeroSim® toolbox Figure 2, a 6-DOF dynamics model, was used in this study. The model provides a representation of the Aerosonde characteristics.

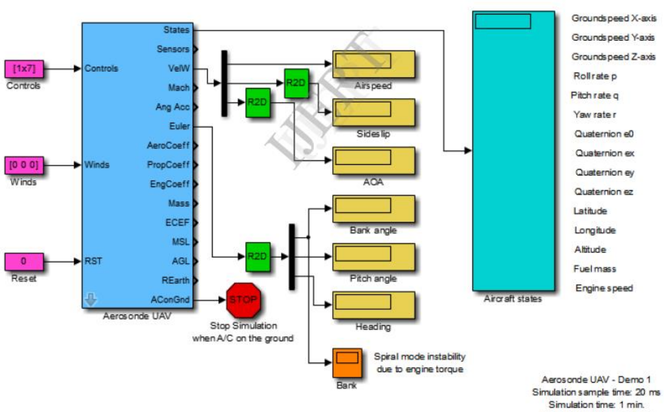

Fig. 2 Aerosonde UAV MATLAB simulation model.

The model receives three types of inputs; aircraft controls, background wind velocities, and the reset integrator. The aircraft controls are the flaps (the Aerosonde has no flaps so this value is set to zero), elevator, aileron, rudder positions, throttle, mixture, and ignition initial values. Based on these input values, the model outputs the aircrafts states, sensor readings, velocities, positions (Euler angles), body roll rates, as well as other important data regarding the aircraft state.

III. AUTOPILOT DESIGN

In this section, we briefly describe the autopilot design. As shown in Figure 3, the inputs to the longitudinal autopilot are commanded altitude, h^c and commanded velocity, V^c [12,13]. The outputs are the elevator deflection, δ_e, and the throttle command, δ_t. The Altitude Hold autopilot converts altitude error into a commanded pitch angle θ^c. The Pitch Attitude Hold autopilot converts pitch attitude error into a commanded pitch rate q^c. The Pitch Rate Hold autopilot converts pitch rate error to elevator command δ_e. The Velocity Hold autopilot converts velocity error to throttle command δ_t.

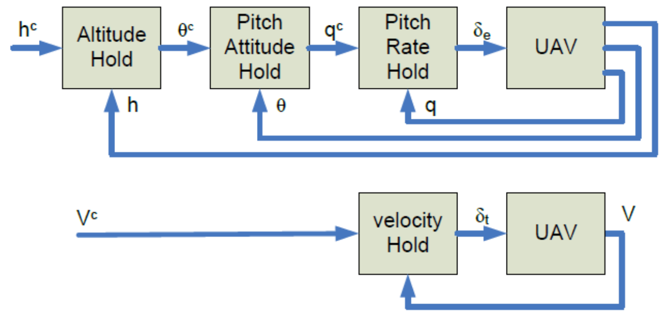

Fig. 3Autopilot for Longitudinal Motion.

The lateral autopilot is shown in Figure 4. The input command to the lateral autopilot is the commanded heading, ψ^c. The output is the aileron command δ_a. The Heading Hold autopilot converts heading error to roll attitude command, ϕ^c. The Roll Attitude Hold autopilot converts roll angle error to roll rate command, p^c. The Roll Rate Hold autopilot converts the roll rate error to aileron command, δ_a.

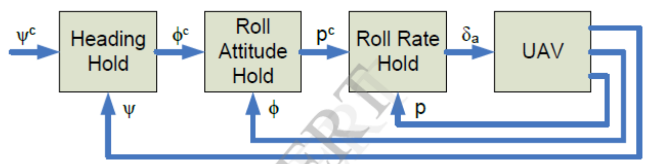

Fig. 4Autopilot for Lateral Motion.

The longitudinal autopilot is realized using two control loops (altitude and velocity), whereas the lateral autopilot is realized using only one control loop (heading angle).

IV. CONTROL DESIGN

The main control objective is to obtain directional control in order to follow a desired trajectory even in the presence of unknown crosswind. Modified PID (PI-D) flight controller is designed for the autopilot. This controller is compared with genetically tuned traditional PID. The simulation results are studied from performance and robustness points of view to show the effectiveness of each controller. Due to their simple structure, robust performance, reliability, and ease of understanding, PID controllers are the most commonly used controllers in industrial process control [9]. The transfer function of a PID controller has the form given in (1).

$$G(s) = K_P + \frac{K_I}{s} + K_D s \qquad (1)$$

where: K_P, K_I, and K_D are the proportional, integral, and derivative gains respectively. The parameters of the PID controller can be manipulated to produce various response curves from a given process. Finding optimum adjustments of a controller for a given process is not trivial. The most well-known tuning method is Ziegler-Nichols tuning method. Ziegler-Nichols tuning method produces rules or determining values of the PID parameters based on the transient response characteristics of a given plant. To enhance the capabilities of traditional PID tuning techniques, several methods have been developed.

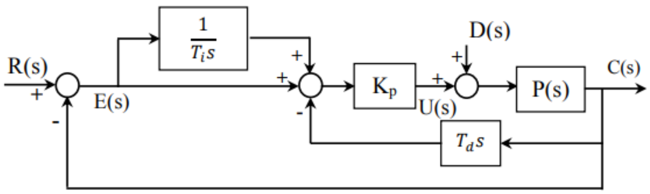

Fig. 5 PI-D Control Configuration.

In this paper, the PI-D control approach is utilized. To show its effectiveness it is compared with genetically tuned traditional PID controller. For genetically tuned PID, a multi objective function is used to minimize the mean square value of the error between the desired input and the system output, minimize the overshoot, and also minimize the coupling between the system outputs. Figure 5 show the block diagram of the modified PID (PI-D) controller.

V. SIMULATION RESULTS

PI-D controller is designed for the Aerosonde UAV autopilot. To show its effectiveness; PI-D flight controller for longitudinal autopilot is compared with the genetically tuned PID flight controller. The simulation results based on the full nonlinear model are studied from performance and robustness points of view. This nonlinear model takes into consideration the complexity of the aerodynamic forces/torques. Furthermore, the controllers and observers were developed in Matlab/Simulink with a sampling time of 0.02s, using the Runge-Kutta solver. Finally, disturbances represented by wind in the X-Y plane are taken into consideration to verifying robustness of each controller.

First, the two control loops are considered as in Figure 3. One is for the altitude, and the other is for the speed. There is a coupling between them should be taken into consideration. A desired altitude and speed have to be tracked by the Aerosonde UAV autopilot. The response of the autopilot of the longitudinal motion of the UAV is plotted in Figure 6.

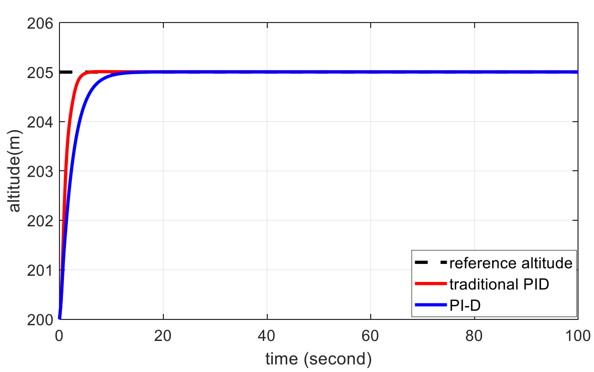

Fig. 6 Altitude Response of Autopilot.

The figure shows that the genetically tuned traditional PID produces less rise time and settling time. The speed response is shown in Figure 7. The two flight control approaches approximately produce the same response.

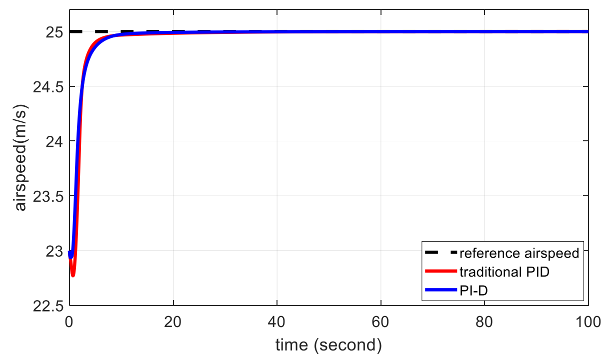

Fig. 7 Speed Response of Autopilot.

A reference altitude with fixed speed is tracked as shown in Figure 8. The both autopilot controllers show approximately identical responses for altitude tracking with constant speed.

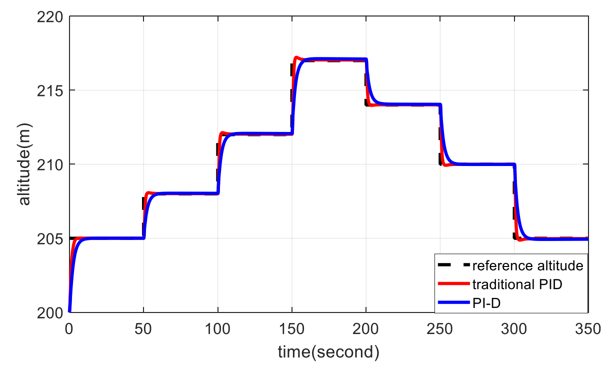

Fig. 8 Altitude Track with Fixed Speed.

Now, the effect of cross wind disturbance in X-Y plane is studied. The UAV is subjected to crosswind disturbance in the X-Y plane from the beginning of normal operation. A desired altitude and speed have to be tracked by the Aerosonde UAV autopilot. It should be noted that; when the wind speed is low, the both controllers for the autopilot behave in similar way and the disturbance rejection is achieved. As the wind speed increases, the autopilot response differs according to the controller robustness.

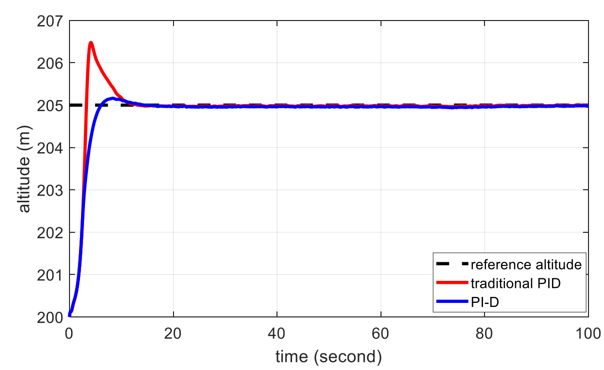

Fig. 9 Altitude Response of Autopilot in Windy Environment.

Figure 9 demonstrates that the autopilot based on the PI-D flight control approach produces better performance than the autopilot based on traditional PID flight control approach.

VI. Conclusion

A PI-D flight control is designed for Aerosonde autopilot as a fixed wing UAV. This controller is compared with genetically tuned PID controller. The comparison based on simulation results obtained from Aerosonde UAV model. The tracking performance of a predetermined path and the robustness to external disturbances are taken into consideration as criteria for comparison. Longitudinal autopilot motions are considered. The longitudinal autopilot has two control loops one for the altitude and the other for the speed.

The simulation results show approximately similar autopilot performances when the UAV is not subjected to any external disturbances. The external disturbances and especially the wind affect the autopilot controller. This is confirmed by the simulation results. For longitudinal autopilot, disturbance rejection is achieved for all controllers when the UAV is subjected to relatively small speed values.

When the external wind speed increases, the PI-D flight controller shows robust performance. The traditional PID flight controller fails to cope with this external wind speed after certain speed limit.

From the simulation results obtained based on the Aerosonde UAV simulation model, the autopilot controlled using any of the discussed controllers show acceptable results when the UAV is not subjected to any external wind disturbance. The autopilot controlled by PI-D achieves an excellent performance when dealing with external wind disturbances.

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