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Automatic Landing Drone Using the Predictive Control Method

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Abstract

Due to the change in aerodynamic parameters, the problem of controlling the landing mode is much more complicated than that of high-altitude flight. Therefore, from this point of view, the problem requires the use of a control algorithm resistant to changing parameters. On the other hand, the presence of obstacles in the way of the UAV landing is another condition that should be considered in the design of the controller. Thus, it is necessary to use the predictive controller to solve the problem. This controller inherently has a high robust to model change. Also, if this controller is used in a restricted manner, it can be used to bypass obstacles in the path of movement during landing. The aim of this paper is to control the system for automatic landing by means of model-based predictive control. The reason for using the model-based predictive controller is the presence of obstacles in the path of movement and the fulfillment of the constraints in the environment to remove the obstacles. In the final result of the article, this controller is designed in such a way that the effect of external disturbances on the bird is minimized and the stability of the system is not jeopardized by the emergence of model uncertainties. Also, in this method, the effect caused by the delay of the external navigation system is taken into account in the closed loop system and the stability of the system is guaranteed. Finally, the design of the proposed controller for the model of a real unmanned UAV has been calculated and its performance simulation in the presence of obstacles, lateral and longitudinal wind has been presented.

Keywords: Automatic landing, Predictive Control, UAV, Obstacles.

1. Introduction

In the past years, UAVs have grown significantly in many fields and are very effective in many fields, such as the military field. These birds use a variety of control algorithms for flight phases. For example, in UAVs used for agriculture, the control process is done manually, while in military cases, the control algorithm is automatic and the flight of the bird is completely automatic. If we divide the flight path into different parts, the flight path at high altitude is much easier to control than taking off from the ground or landing on the ground. Therefore, a wide range of researches and articles are devoted to providing control methods for landing drones. This issue is very important and practical because it is possible that due to an error in the guidance and control system of the drone, the bird is required to make an emergency landing.

Automatic landing is one of the most complicated stages of flying drones. Although the landing phase constitutes approximately two to three percent of the total flight time; But a significant part of the accidents occurs in this phase. For this reason, the use of control algorithms with high performance and reliability is very important in this phase. Predictive model control is one of the modern control methods that has developed significantly in recent decades. The most industrial use of this method is in petrochemical processes; but in recent years, this method has been used a lot to guide and control flying devices.

Due to the change in aerodynamic parameters, the control problem of landing mode is much more complicated than that of high-altitude flight. Therefore, this issue requires the use of a control algorithm robust to changing parameters. On the other hand, the presence of obstacles in the way of the landing of the UAV is another condition that should be considered in the design of the controller. In other words, to reduce the risk of possible injuries to the bird, it is necessary to prevent it from colliding with the obstacles in the path of movement.

Thus, it is necessary to use the predictive controller to solve the problem. This controller inherently has high resistance to model change. Also, if this controller is used in a restricted manner, it can be used to bypass obstacles in the path of movement during landing.

Reference [7] has used the control of the forecast model to control the angle of the flight path in the approach phase. The used model is linear and single-input-single-output. This reference has shown that the control of the predictive model compared to the PID has improved overshoot and settling time. Also, in the control method of the previous model, the control effort in facing the turbulence has been reduced.

Reference [1] has used the predictive control of the nonlinear model to control an airplane. The gradient reduction method has been used for optimization. In order for the gradient reduction method to work well, a new criterion has been used to complete the optimization.

Reference [2] has used nonlinear predictive control to generate guidance commands in automatic landing. Pitch angle rate and roll angle are guidance commands. The algorithm of the predictive control gives an optimal control between the roll angle command and the pitch angle rate, and the outputs are generated by the optimal control and applied to the bird. Also, reference [3] has used the predictive control as a guidance loop. The control loops are located in the Piccolo autopilot hardware and follow the commands of the guidance loop.

Reference [4] has used predictive model control to design the guidance loop. To ensure the existence of the solution, the predictive control is initially initialized by the guidance algorithm L1, and then the optimization of the command of the guidance loop is performed with this initial solution. To get a better answer, the output of the steering loop is a roll command instead of a heading command.

The main issue in this research is the use of predictive model control method for UAV control. The estimation of control derivatives should be done online and the necessary correction coefficients should be applied online to the controller output. The process of doing this article is that first the automatic landing of UAV is defined and then the method and necessity of doing it is discussed. Next, the required equations are extracted and then the block diagram of the flight configuration in clear sky is made with Simulink software and the desired simulations are performed in MATLAB software and the outputs are presented.

2. Methodology

The automatic landing maneuver has three important phases: 1- approach phase, 2- glideslope phase and 3- flare phase.

The approach or alignment phase as shown in Figure 1 is usually the alignment phase where the UAV aligns with the runway. Once the UAV aligns with the runway, the flight phase is essentially level until the slope descent begins.

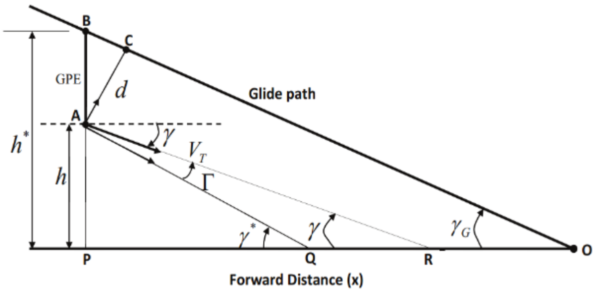

Figure 1. The approach or alignment phase

During the glideslope landing phase, the UAV must follow a fixed downhill reference trajectory. The usual reference angle γ_G is the desired glideslope angle along the glide path and is usually in the range of 2.5 to 3.5 degrees. The error between the flight path angle γ and the glideslope angle, γ_G, is shown as Γ and is calculated as:

$$\Gamma = \gamma - \gamma_G \tag{1}$$

The flight path angle error Γ is shown in Figure 1. The flight path error corresponds to the glide path error (GPE) shown in Figure 1.

The control diagram block in this phase can be seen in Figure 2

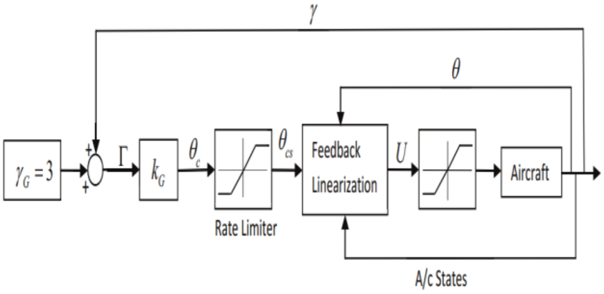

Figure 2. The control diagram block in glideslope phase

The flare starts from the starting point $h(0)$ or the flare height hf. During flare, the drone follows the path of the exponential function.

The block diagram of the flare autopilot is shown in Figure 3, where k_f and k_f are the gains of the flare controller and θ_c is the demand of the flare controller. A rate limiter is added to obtain θ_{cs}. This command value θ_{cs} is actually fed back to the linearizer controller. A tracker anti-windup loop has been added in the flare block diagram with increased k_b feedback. The anti-windup scheme reduces the rate of increase of integrated output. The flare controller is designed using the adjustment in such a way that the desired height and descent rate can be achieved at the same time

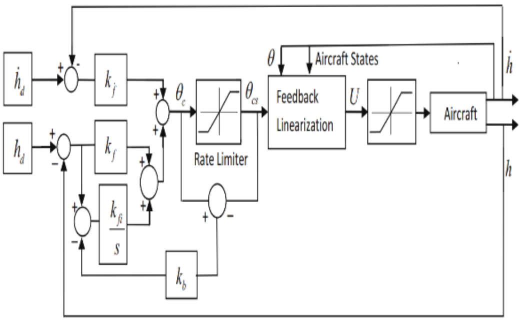

Figure 3. Block diagram of flare autopilot with anti-windup

3. Discussion and Results

In this section, the system simulation results in the landing phase for a real UAV are presented. In Figure 4, the step rate response for UAV flight in clear sky is shown.

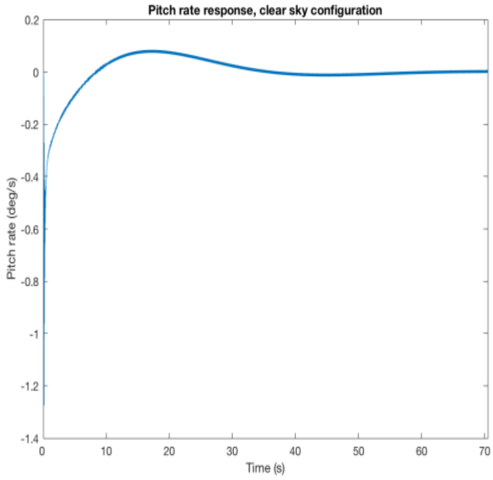

Figure 4. Step rate response for UAV flight in clear sky

As can be seen in the figure above, the pitch angle rate is well controlled. Also the response is very smooth. In the following, the height of the UAV for the initial values 7, 12 and 15 degrees and based on the predictive control can be seen in Figures 5, 6 and 7.

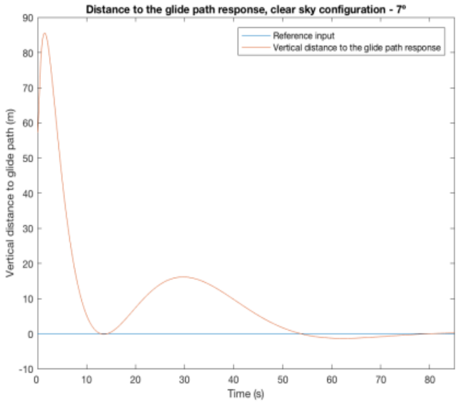

Figure 5. Distance to glide path response, clear sky flight, 7 degrees

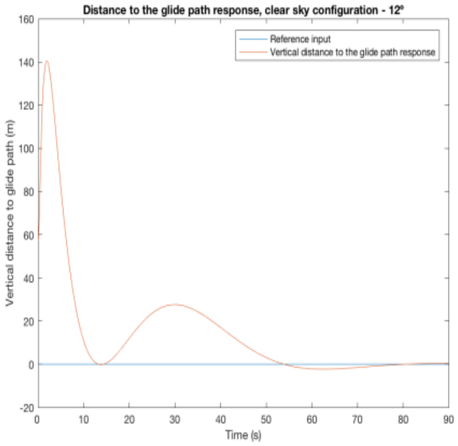

Figure 6. Distance to glide path response, clear sky flight, 12 degrees

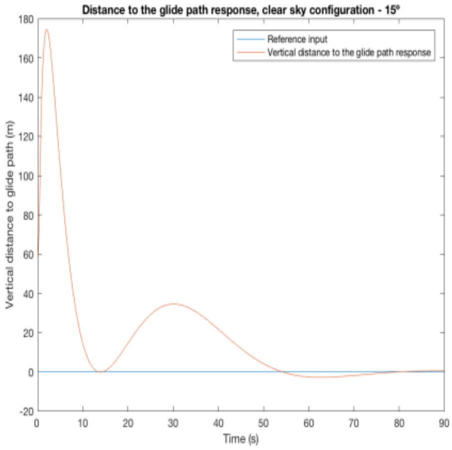

Figure 7. Distance to glide path response, clear sky flight, 15 degrees

The results of the above figures show that the UAV had good results at different initial angles using the predictive control method.

4. Conclusions

According to the cases mentioned in this research, the automatic landing system is always one of the most important and sensitive parts of the flight of a UAV. After completing its mission, the UAV should be able to safely return to the origin and prepare for the next missions. The first method is automatic landing by PID controller. This method is one of the most widely used automatic landing methods, but it is mostly used on systems whose dynamics are unknown, and in air vehicles with known dynamics, it is often less accurate. In this article, a method for designing a predictive control for the landing phase of drones was presented. This controller is designed in such a way that the effect of external disturbances on the bird is minimized and the stability of the system is not jeopardized by the emergence of model uncertainties. Also, in this method, the effect caused by the delay of the external navigation system is taken into account in the closed loop system and the stability of the system is guaranteed. Finally, the design of the proposed controller for a real unmanned bird model has been calculated and its performance simulation in the presence of obstacles, lateral and longitudinal wind has been presented.

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