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A Closed Loop Auto-tuned PID Aided UAV Motion Controller

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ABSTRACT: Unmanned aerial vehicle (UAV) safety and control is attracting attention increasingly in an attempt to improve the stability and manoeuvrability of UAVs. Three degrees of freedom UAV dynamic model (called planar vehicle model) is established. Based on theories of PID control and auto-tuned based-PID Controller, controller of UAV stability is designed by using the method of direct yaw rate control and the two different control strategies. The controllers were compared under in flight condition which is a random pitch, roll and yaw manoeuvre. By comparing and analyzing the control effect of the autotuned PID control and auto-tuned based-PID Controller, the result shows as follows: the two controllers improved the yaw rate to follow the reference yaw rate but, using the auto-tuned PID controller gave a better and closer path for the desired path of yaw rate compared to using of the non-auto-tuned PID controller.

KEYWORDS: Unmanned aerial vehicle, PID controller, YAW rate control, Simulink, Auto-tuning.

I. INTRODUCTION

The potential for utilizing automatic control theory to accomplish the heading control of automatically-steered bodies was first demonstrated using a simple PID controller as far back as the 1920's [1], [2]. Thanks to deployment of the global positioning system (GPS) in the 1970s, integration of the positional data from the GPS, into ship steering autopilots, forms the so-called track-keeping autopilots, making it possible to navigate automatically along prescribed routes with high precision [3]. According to the mathematical model, during the controller design process, we can classify the track-keeping autopilot design methods into two categories, the model-based approach and the model-free approach. The LQG optimal control [4], the H∞ control [5], and the IMC (Internal Model Control) [6] are typical model-based methods. The Close loop auto-tuned control [7] and the artificial neural (ANN) [8] belong to the model free approach. An extensive review of some of the more significant proposals is presented in [9].

The popularity of the PID controller can be attributed to its simple structure, well-understood principle and relative ease of implementation. PID controllers do have weakness; namely it is not easy at all to tune the controller gain coefficients. Typically, tuning of the controller gain coefficients is based more or less on a trial and error approach. The Ziegler-Nichols tuning method is a best known method providing a systematic approach to tuning of the gain coefficients [10]. The IMC method implicitly incorporates a model of the process being controlled into the deign considerations. Based on the IMC design configuration, the PID controller can be implemented as a model-based controller, and the controller gain coefficients can be expressed in terms of the process model parameters and a design parameter that characterizes the speed of response of the control system. Hence, the time-consuming process of tuning the PID gain coefficients is no more necessary.

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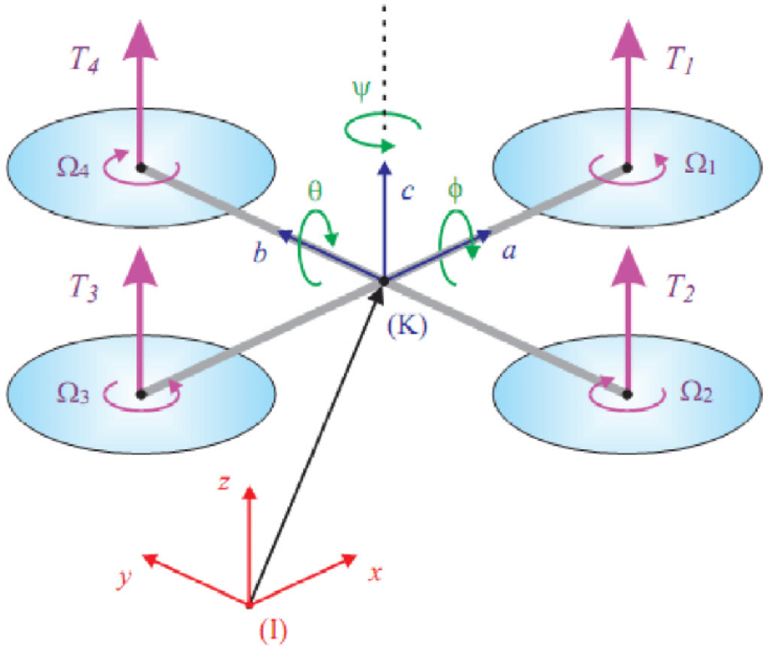

Figure 1: 6- degree of freedom UAV (Quadcopter) motion

Close loop auto-tuned logic controllers may be considered nonlinear PID controller whose parameters can be determined on-line based on the error signals and their time derivatives or differences [11]. During the past few years, Close loop auto-tuned control has been successfully applied in many practical areas and Close loop auto-tuned systems have proven to be superior in performance to some conventional systems especially where the plants are poorly modeled or have nonlinear dynamics [12]. A ship autopilot based on the combination of Close loop auto-tuned logic control (FLC) and linear control (PID control) has been proposed that has the advantages of both the PID and FLC control methodologies: ease of construction and adaptively to parameter variations and strong environmental effects [13]. Specifically, 5 sets of predetermined PID controllers were assigned to the size of the error signals and their derivatives.

The explicit expression of the PID controller gain coefficients in terms of the process parameters and the IMC design parameters is adopted in this paper in determining the universe of discourse of the proposed Close loop auto-tuned PID controller gains, which are defined as the Close loop auto-tuned outputs. The heading deviation and the rate of heading deviation are treated as Close loop auto-tuned inputs. The adopted line-of-sight (LOS) guidance law uses the positioning information provided from RTK-GPS in computing the heading deviation angle. A sequence of course-changing maneuvers are conducted to achieve the track-keeping mission. Computer simulations are carried out to examine the feasibility of the proposed approach and a small board-based track-keeping experiments were carried to demonstrate the practical use of the proposed close loop auto-tuned PID autopilot.

II. PID CONTROLLER MODEL ARCHITECTURE

The top model consists of the following subsystems and model references:

I. **Ground Control Station**: Used to control and monitor the aircraft while in flight.

II. **External Sensors - Lidar & Camera**: Used to connect to a previously-designed scenario or a photorealistic simulation environment. These produce Lidar readings from the environment as the aircraft flies through it.

III. **On Board Computer:** Used to implement algorithms meant to run in an onboard computer independent from the Autopilot

IV. **Multirotor:** Includes a low-fidelity and mid-fidelity mode, as well as a flight controller including its guidance logic.

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The model's design data is contained in a Simulink data dictionary in the data folder (uavPackageDeliveryDataDict.sldd). Additionally, the model uses Implement Variations in Separate Hierarchy Using Variant Subsystems to manage different configurations of the model. Variables placed in the base workspace configure these variants without the need to modify the data dictionary.

A. PID Controller Autotuning

This paper, uses the Closed-Loop PID Auto-tuner block from Simulink Control Design™ software to tune eight controllers used in the attitude and position control of a UAV. Here, in this work, we use many ways to tune controllers, including manual tuning and empirical calculations. By using the Closed-Loop PID Autotuner, we set up the control system ahead of time and then perform tuning of all eight loops with a one-click process. This makes the entire tuning process repeatable and easily adjustable for future tuning. In this work, we use a six degree-of-freedom model of a UAV in Simulink. However, we can also use the Closed-Loop PID Autotuner on hardware to perform the same process using a real UAV such as drone. Most other tuning techniques are difficult to implement on actual UAVs, can take a long time, and are not easily repeatable.

By using the Closed-Loop PID Autotuner for tuning the controllers in this paper, we do not need to have advanced knowledge of control tuning techniques.

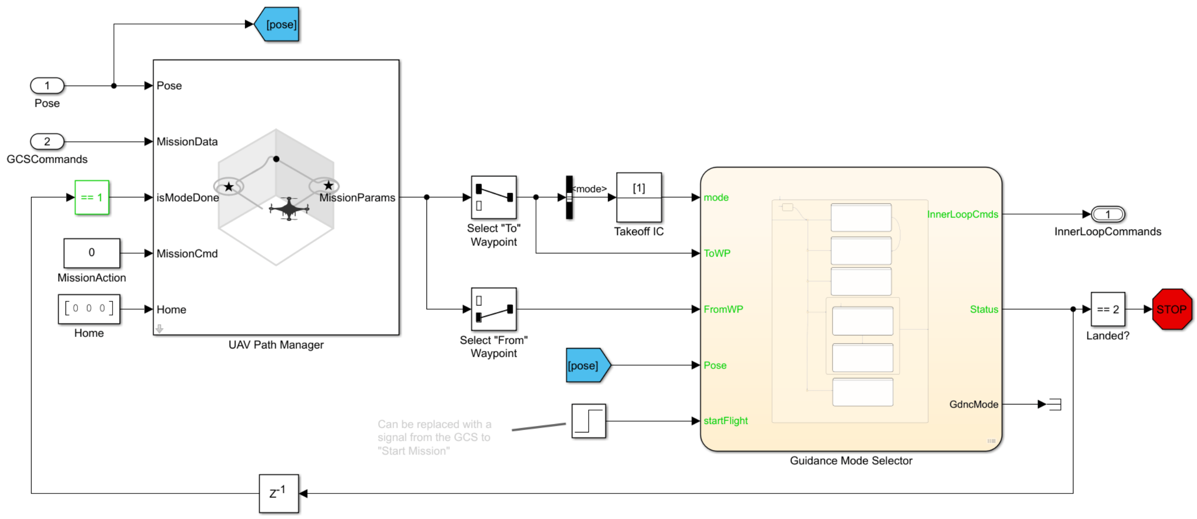

Figure 2: Simulink block diagram of the proposed YAW rate control system

B. Modify UAV Package Delivery Model for PID Autotuning

To facilitate PID autotuning, the original UAV package delivery model is modified with these changes:

- Hover mode added to the Full Guidance Logic subsystem
- Third Mission variant added to the Ground Control Station subsystem
- Four Closed-Loop PID Autotuner blocks added to the Attitude Controller and Position Controller subsystems in the High Fidelity Model
- PID Controllers in the Attitude Controller and Position Controller subsystems Controller Parameters Source changed from internal to external
- Data Store Memory blocks added to the Multirotor subsystem
- Default controller gains changed
- To Workspace added to root level model

These changes allow for the multirotor to take off and remain at a fixed altitude while autotuning takes place and to update the gains of the PID Controllers, all in a single simulation.

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III. RESULT AND DISCUSSION

The Closed-Loop PID Autotuner blocks inject perturbation signals to the output of each of the eight existing PID Controllers. The autotuners then use the feedback signals and the output of the PID Controllers in order to perform the autotuning process.

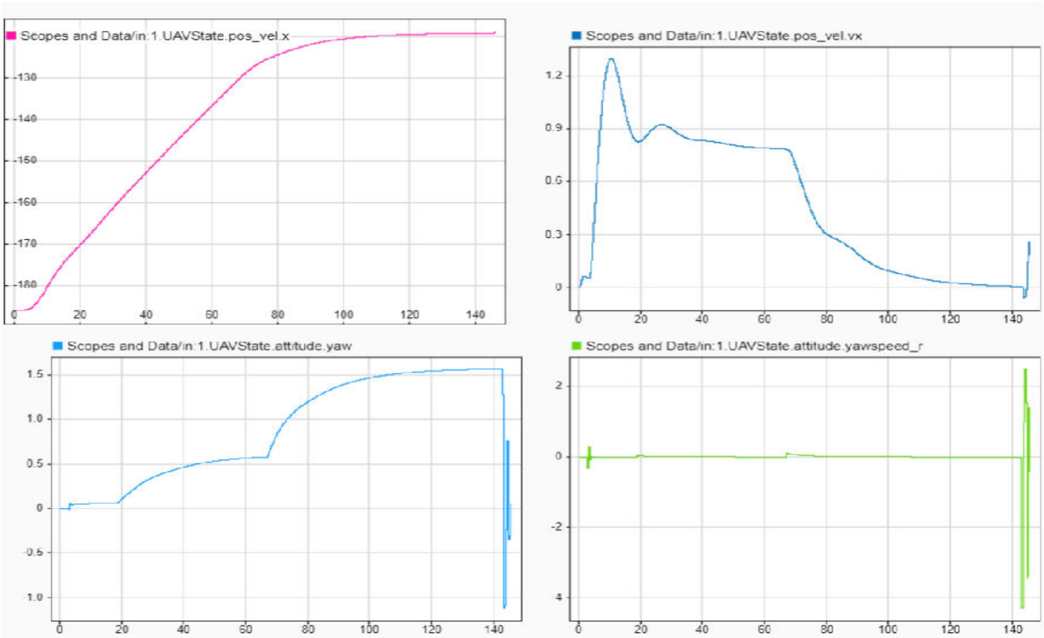

Figure 3: Output yaw and yaw speed with velocity in x direction before auto tuning of the PID Controller

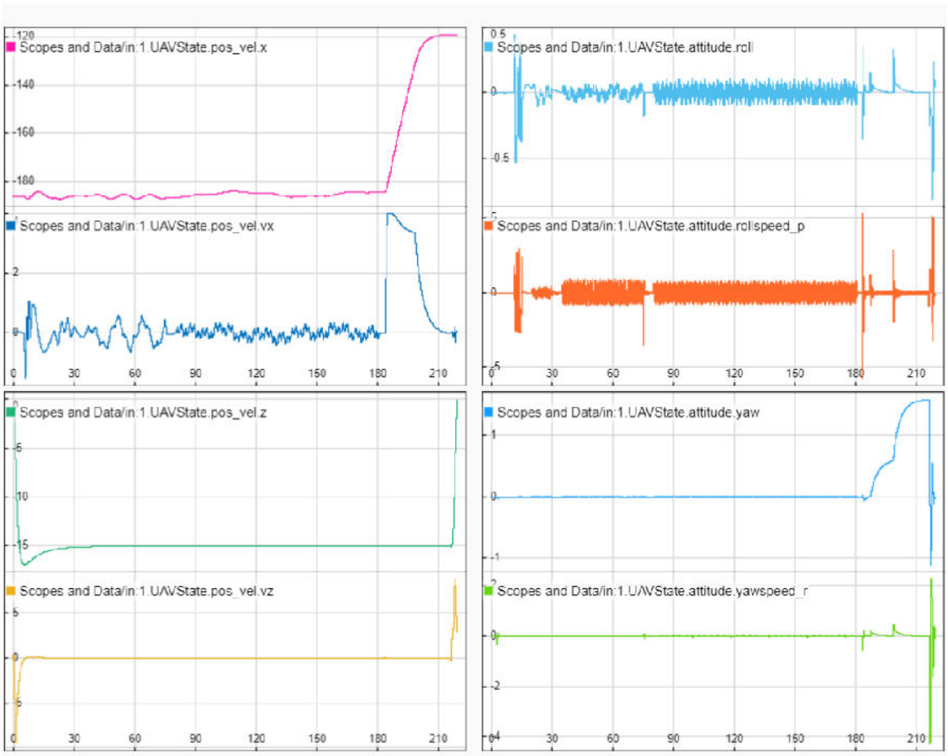

Figure 4: Output yaw and yaw speed with velocity in Z direction after auto tuning of the PID controller.

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With the exception of the innermost control loops, pitch and roll rate, the two axes being controlled are decoupled from each other. For example, the x velocity and the y velocity loops are decoupled from each other. This allows you to tune these two loops simultaneously which reduces the overall time to perform autotuning. For the pitch rate and roll rate loops, tune the control loops sequentially because they are coupled. Figure 3 represents the Output yaw and yaw speed with velocity in x direction before auto tuning of the PID Controller whereas figure 4 represents the Output yaw and yaw speed with velocity in Z direction after auto tuning of the PID controller.

IV. CONCLUSION

The proposed closed loop auto-tuned PID track-keeping autopilot is characterized by its simple structure; specifically, only a small number of operational set is required in defining the membership functions. Moreover, the explicit relationship between the PID gain coefficients and the speed of response design parameter of the adopted IMC design facilitates determination of the interval of universe of discourse of the closed loop auto-tuned PID gain coefficients. Successful computer simulations and a series of small UAV-based track-keeping simulation experiments indicate the feasibility and practical use of the proposed approach.

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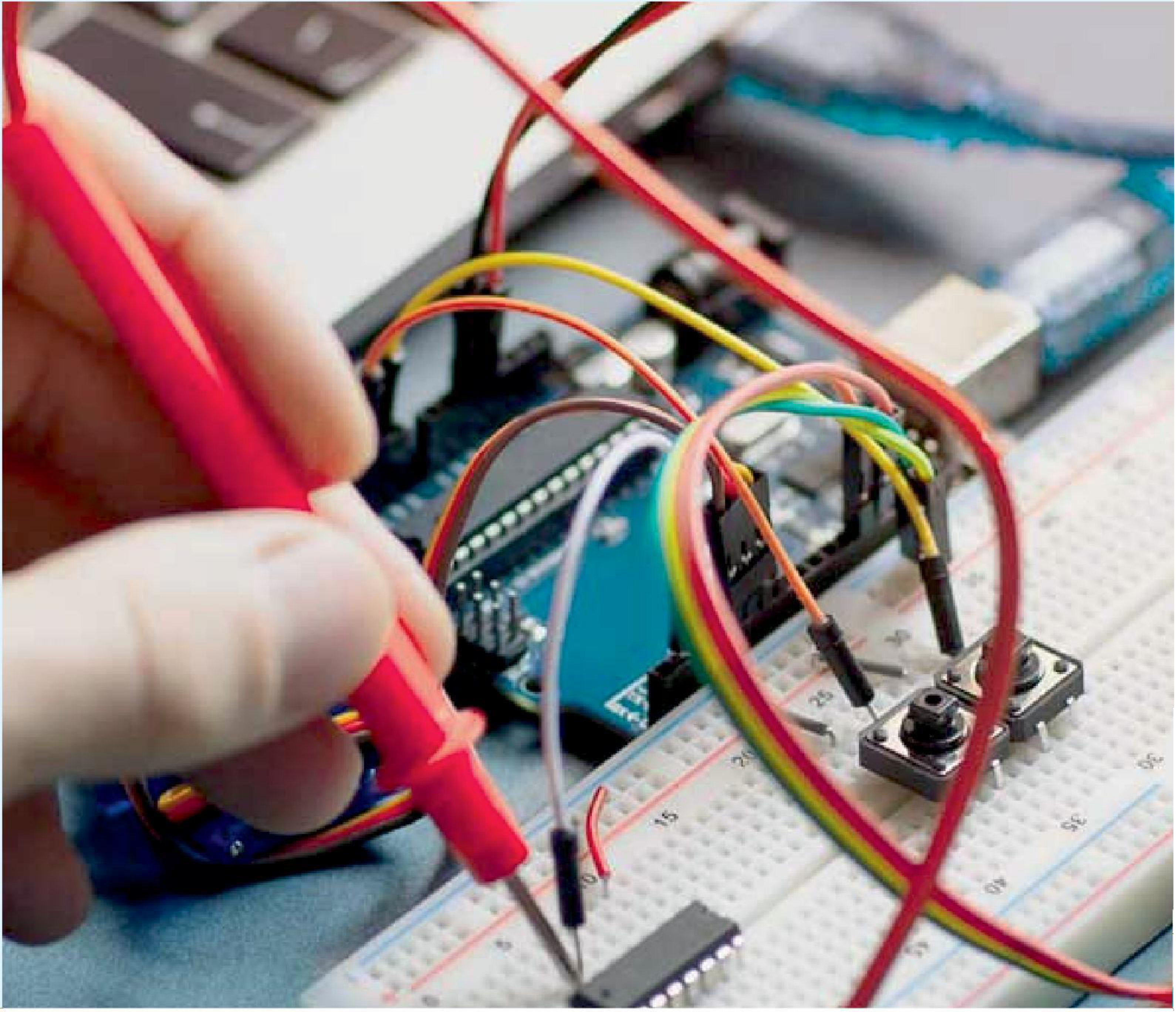

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