

Short Communication: Robust PID Controller for Quad-rotors

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In this Short Communication, the paper discussed is of A. Wahyudie, T. B. Susilo, and H. Noura, "Robust PID controller for quad-rotors", *Journal of Unmanned System Technology*, vol. 1, no. 1, pp. 14--19, May 2013.

This paper considers a stabilization problem for micro quad-rotors modeled as a nonlinear system according to its physical dynamics. Parameters of the resulting mathematical model are apparently highly coupled due to nonlinear dynamical nature of the micro quad-rotors. This nonlinear model is indeed to completely represent flight dynamics of the micro quad-rotors (see (1)). However, it may give rise to delicate analysis and synthesis if a particular linear control method is applied to address the stabilization problem. This concern has led the authors to simplify the nonlinear model based on a small-angle approach. Such an approach then allows the authors to confine their attention to only stabilizing the quad-rotors when performing hovering motion. It is important to note that despite its simplicity, the authors do not properly justify and explain their approach in sub-section II.A. Thus, the resulting simplified model, nevertheless, may be inappropriate in order to provide meaningful outcomes of their investigation.

For the hovering motion, the simplified model of the quad-rotors represents three rotational and one translational dynamics with respect to the Earth coordinate system (see (2)). The rotational and translational motions are then indicated by roll angle (ϕ), pitch angle (θ), yaw angle (ψ), and altitude/vertical displacement (z) of the quad-rotors, respectively. Upon the model simplification, the authors obtained the decoupled rotational and translational dynamical model of the quad-rotors with a rather simple nonlinearity in terms of θ and ϕ . This result is then used to construct a four-input-four-output augmented plant model, which includes actuator and sensor models, needed for designing a linear feedback controller for the quad-rotors (see Figure 2). Note that, however, the actuator model, which consists of an inverted movement matrix and linearized dynamic of the motor, is not well described. In this case, it is not elaborated in sub-section II.B about how the inverted movement matrix can be derived and about why this matrix is involved in the actuator model. Moreover, instead of a clear explanation about how a linear relationship between the propeller angular speed Ω and the

motor output voltage v is obtained via an experiment, a nonlinear equation is presented in sub-section II.C to which is not referred anywhere in the paper. Such a modeling process, unfortunately, does not provide thorough comprehension about how the actuator and sensor models can be combined with the simplified model in (2) in order to obtain the linear augmented plant model denoted by P in Section III.

In order to stabilize the hovering motion of the quad-rotors for a fixed altitude z , the authors proposed to use a set of proportional-integral-derivative (PID) controllers designed based on the augmented plant model P . This approach then results in three independent PID controllers as the dynamical model of attitude angles (ϕ, θ, ψ), which have been decoupled. The PID controllers are required to be robust against perturbation (unstructured uncertainties) Δ and to result in a small-gain control input u in order to fulfill hardware limitation. The uncertainties are then represented as an inverse additive perturbation (see Figure 3). In this case, the authors thus proposed to apply an H_∞ criterion to simultaneously satisfy those requirements (see (3) and (4)). Moreover, poles of the resulting closed-loop system are also required to reside within a particular region in an open left-half of the s -plane (see Figure 4). This additional requirement aims to provide the closed-loop system with specific time constant and damping ratio.

The application of the PID controller to the quad-rotors is simply motivated by the fact that the controller is commonly used for micro unmanned aerial vehicles. Despite its popularity and practicality, synthesizing the PID controller for each decoupled dynamics of the quad-rotors does not add any new information to enhance scientific knowledge in control engineering. This is due to the fact that many similar works have also been carried out by other researchers as mentioned in the introduction of the paper. It would be more useful and challenging if the authors could directly apply a multiple-input multiple-output PID controller, which may allow parameter coupling to some extent. Moreover, an advantageous claim over a robust H_∞ controller is inaccurate because the authors do not explicitly compare the order of the robust H_∞ controller with that of the PID controllers, which are of sixth order in total. Meanwhile, a particular reduced-order robust H_∞ controller may be designed to simultaneously stabilize the quad-rotors.

To find a suitable set of parameters for the PID controllers, the controller design problem is reformulated as a constrained optimization problem (see (5) and (6)). The authors then proposed to solve this problem using a population-based

optimization method referred to as the Genetic Algorithm (GA). This algorithm is a biology-inspired numerical algorithm based on an evolutionary mechanism, which follows a principle referred to as survival of the fittest. When applying the GA, an initial population of candidate solutions is randomly generated and undergoes a mutation-recombination-selection cycle prior to forming a new population based on the fitness of candidate solutions. Thus, each candidate solution is examined against fitness criteria formed based on constraints involved in the PID controller design (see Step 1 - Step 7 on page 17). A desired stabilizing (sub-) optimal solution is therefore the one that minimizes the H_∞ criterion while satisfying all constraints.

The proposed GA-based controller design algorithm is demonstrated through an example of designing the PID controllers for AscTec Pelican quad-rotors whose parameters were estimated using SolidWorks (see Figures 5 and 6). In order for interested readers to repeat or conduct similar numerical iterations, it will be useful if the authors can also provide the GA parameters used. The resulting PID controllers were then simulated for both nominal and perturbed plant models in order to perform attitude stabilization during the hovering motion (see Figure 7). The authors have indeed demonstrated the efficacy and merit of their algorithm and approach to address the attitude stabilization problem of the quad-rotors (see Figures 8 and 9). However, the model of the quad-rotors and the simulation results were not validated using experimental results, which are apparently not presented in the paper. In this case, although an experiment using the quad-rotors mounted on a testbed is mentioned in the paper, detail descriptions about how it was setup and how the PID controllers were implemented are also not provided. Moreover, instead of using SolidWorks, it is necessary to properly estimate the parameters of the quad-rotors based on a system identification method. Since many similar works have been done, it is recommended to provide a fair comparison between the results of this paper and those of others.

Eventually, this paper has presented interesting research outcomes, which may be enhanced by the authors and other researchers with similar interests in designing feedback control systems for unmanned aerial vehicles. All critical comments are expected to be constructive to achieve better results in future research directions.