Reconfigurable Multirotor Control Using Fractional-Order $PI^{\lambda}D^{\mu}$ Controller in the Presence of Uncertain Geometric Parameters

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***Abstract*— In this work, and for the first time, a Fractional Order Proportional Integral Derivative (FOPID) controller tuned by Particle Swarm Optimization (PSO) algorithm, is investigated to control and stabilize the attitude and position of a reconfigurable multirotor in the presence of uncertain geometric parameters. Furthermore, the variation of the structure parameters makes the flight stability and control of this aerial vehicle very challenging tasks differently to the classical drone. Our proposed control architecture considers the variable dynamic of this structure and calculates these changes on-line in the control loop.**

***Index Terms*— Reconfigurable multirotor, uncertain geometric parameters, Fractional Order Proportional Integral Derivative (FOPID).**

I. INTRODUCTION

A. *Related works and contribution*

Nowadays, reconfigurable drones can adapt to different flight conditions, missions and environments, due to their adaptable and variable shapes, unlike the classic drones [1] [2]. Nevertheless, by consulting the open sources of the literature, we find that few control approaches have been exploited by researchers to stabilize and control this type of UAVs.

Despite the rapid advancement in the control of the flying systems, PID controllers are still the majority used control algorithm in aeronautics [3] [4] [5] [6], due to their simplicity [7] [8] [9].

A Fractional Order Proportional Integral Derivative (FOPID) controller [10] [11] [12], is a generalization of the classic PID controller, where it was first used by Podlubny [13] in order to enhance the performance of the systems controlled by PID.

In [14], the auhtors have used a control strategy based mainly on a PID to control a quadrotor that can rotate its body in flight. Researchers in reference [15] have focused on the problem of optimizing the energy of a quadrotor with rotating arms, where the drone orientations are controlled by PID controllers. Bucki et *al.* in paper [16], have stabilized the attitude of a reconfigurable quadrotor that can fold and unfold its arms in flight. In work [17], a conventional PID was used to control the attitude of a quadrotor with variable shape. In the series of references [18] [19], a classic PID has been applied in order to control and stabilize extendable arm drones. Authors in [20] have exploited a PID controller to stabilize a special reconfigurable UAV in attitude. In reference [21], a cascade PD was used to deal with the uncertainties problem of a quadcopter UAV. In paper [22], the trajectory optimization of a reconfigurable Unmanned aerial–aquatic vehicle was investigated. In order to stabilize and control a reconfigurable drone in flight, a conventional PID was applied in paper [23].

The principal contribution of this work is to propose a simple Fractional Order Proportional Integral Derivative (FOPID) controller to control and stabilize the attitude and position of a reconfigurable multirotor in the presence of uncertain geometric parameters. The five parameters of the FOPID controller are tuned by Particle Swarm Optimization (PSO) algorithm to select the optimal ones for each flight configuration. In addition, the majority variables parameters related to the geometric structure are calculated instantly in the control loop.

II. MULTIOROTOR MODELING

In this part, we will briefly present the mathematical model that represents the dynamic of our reconfigurable multirotor, where the structural variations are taken into account [24] [25] [26].

The linear and the angular velocity vectors expressed in the mobile frame are represented respectively: $N^m = (u,v,w)^T \in \mathbb{R}^3$ and $P = (p,q,r) \in \mathbb{R}^3$.

The relation between the velocities and the external forces $\mathrm{F}^m = (f_x^m, f_y^m, f_z^m)^T \in \mathbb{R}^3$ and moments $\mathrm{T}^m = (\tau_x^m, \tau_y^m, \tau_z^m)^T \in \mathbb{R}^3$ is given by:

$$\begin{bmatrix} mI_{3\times3}(\alpha_i(t),\mathrm{d}_i(t)) & O_{3\times3} \\ O_{3\times3} & I_{3\times3}(\alpha_i(t),\mathrm{d}_i(t)) \end{bmatrix}\begin{bmatrix}\dot{N}^m \\ \dot{P}\end{bmatrix} + \begin{bmatrix} P\times mN^m \\ P\times I(\alpha_i(t),\mathrm{d}_i(t))P \end{bmatrix} = \begin{bmatrix}\mathrm{F}^m \\ \mathrm{T}^m\end{bmatrix} \tag{1}$$

III. MULTIROTOR CONTROL

The reconfigurable multirotor is considered as a series of structures (configurations), where each one is presented by its own parameters.

The transfer functions $G_{ci}(s)$, which represent our FOPID controllers (see Figure 1) are appeared in Equation 2 as:

$$\begin{aligned} G_{ci}(s) &= \tfrac{U_i(s)}{E_i(s)} \\ &= K_{Pj}(\alpha_i(t),\mathrm{d}_i(t)) + K_{Ij}(\alpha_i(t),\mathrm{d}_i(t))\tfrac{1}{s^{\lambda_j}} \\ &\quad + K_{Dj}(\alpha_i(t),\mathrm{d}_i(t))s^{\mu_j} \end{aligned} \tag{2}$$

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where K_{Pj}, K_{Ij}, K_{Dj}, λ_j and μ_j are variable positive parameters related to each flight configuration. $E_i(s)$ is the error, and $U_i(s)$ is controller's output. j, i=1, .., 4.

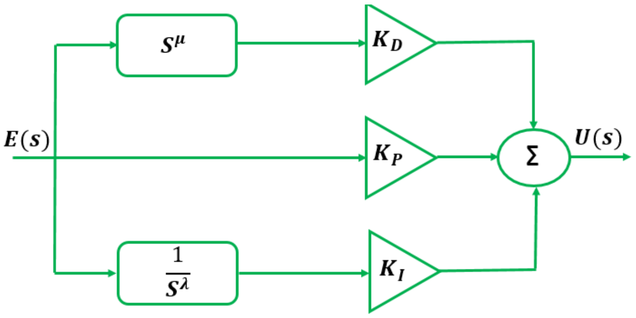

Fig. 1: FOPID block-diagram.

To assign the adequate controller gains for each structure, we have exploited a switching mechanism as shown in Figure 2. This mechanism works when it receives CoG, inertia, angles $\alpha_i(t)$ and lengths $\mathrm{d}_i(t)$ of the desired morphology to switch towards the appropriate gains.

The rotation and extension of the arms cause a variation of the arms by an angle α_i and by a distance d_i. These variations are sent to the switching mechanism block and to others blocks to update and calculate the structure parameters (see Figure 2).

The reference trajectories are provided by a Trajectory Generator Block (TGB) as shown in Figure 2. The attitude and translations of the drone are controlled by varying the position of the arms or by the angular speeds of the four rotors.

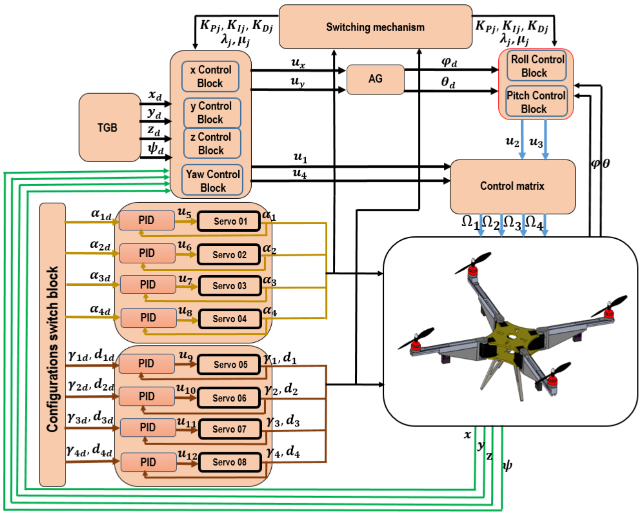

Fig. 2: Control architecture.

IV. SIMULATION RESULTS

1) Simulation scenario: From the initial point, the multirotor begins to rise vertically with the "x" configuration to cross a vertically narrow space. After 10 seconds of flight, it changes its structure to "Y" and takes aerial photos for 10 seconds. Then, it changes its structure to "T", in order to reach the next point. Afterwards, it changes to the last morphology "H", to pass through a horizontally narrow space.

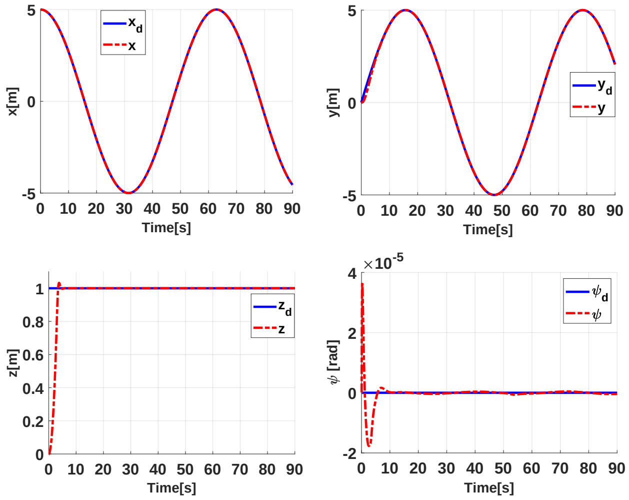

Fig. 3: Evolution of 3D trajectory.

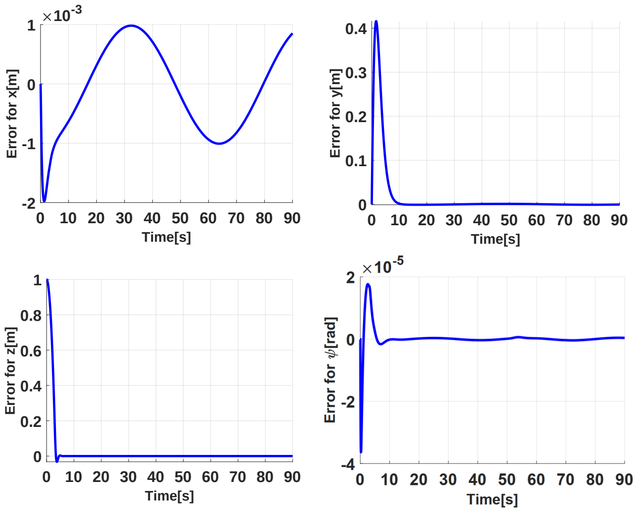

Fig. 4: Evolution of errors.

The parameters considered in simulation for the FOPID controllers are well selected using PSO algorithm (see Table I).

TABLE I: FOPID controller parameters of the five configurations.

	x	Y	T	YI	H
K_{Pj}	13.56	10.89	12.51	12.23	9.12
K_{Ij}	3.02	6.73	8.12	4.22	5.10
K_{Dj}	2.22	4.66	5.04	6.11	5.61
λ_j	0.18	0.78	0.33	0.15	0.11
μ_j	0.91	0.16	0.88	0.36	0.95

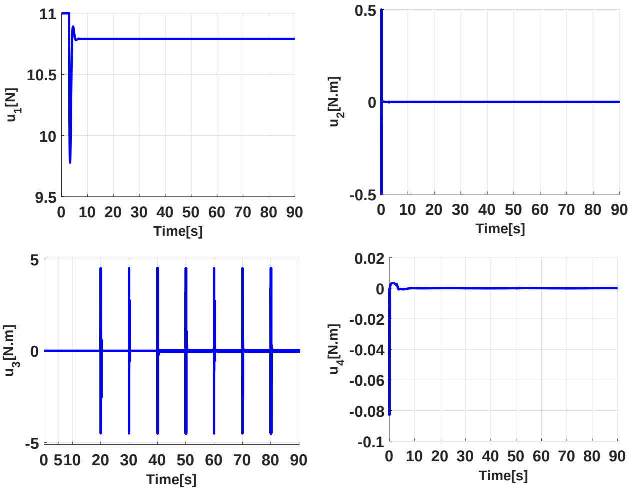

Fig. 5: Evolution of control signals.

A. *Interpretation of the simulation results*

From Figure 3, we note that the evolution curves of the x and y positions track the reference trajectories with some deviations, which is represented by their errors in Figure 4. Furthermore, the altitude z follows the desired trajectory z_d with a small overshoot of $0.04m$ at the start. It starts from $z = 0$ up to $1m$ (see Figure 3), where its error is canceled after 6 seconds (see Figure 4) and its control signal u_1 is at its maximum in the beginning before to stabilize around a constant value (see Figure 5).

The change of the control signal u_3 is due to the change of shape during flight and the trajectory y_d. For the yaw angle ψ, there is a very slight deviation in the system response as displayed in Figure 3. This is illustrated by the cancellation of the error in Figure 4 and by the very low values of the u_4 control in Figure 5.

The simulations carried out have shown that, the FOPID controller has given acceptable results in the face of uncertain geometric parameters of the reconfigurable multirotor.

V. CONCLUSION

In this paper, we have introduced a FOPID controller to stabilize and control the attitude and position of a reconfigurable multirotor in the presence of uncertain geometric parameters. This aerial vehicle changes its aerial configuration depending on the requirement tasks. Furthermore, the majority of variable parameters were calculated instantly in the control loop. From the simulation results, we can conclude that, the applied control strategy has achieved its objective.

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