Real fuzzy PID control of the UAV AR.Drone 2.0 for hovering under disturbances in known environments

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***Abstract*— The Indoor flights of UAV (Unmanned Aerial Vehicle) are susceptible to impacts of multiples obstacles and walls. The most basic controller that a drone requires in order to achieve indoor flight, is a controller that can maintain the drone flying in the same site, this is called hovering control. This paper presents a fuzzy PID controller for hovering. The control system to modify the gains of the parameters of the PID controllers in the x and y axes as a function of position and error in each axis, of a known environment. Flight tests were performed over an AR.Drone 2.0, comparing RMSE errors of hovering with classical PID and fuzzy PID under disturbances. The fuzzy PID controller reduced the average error from 11 cm to 8 cm in a 3 minutes test. This result is an improvement over previously published works.**

Keywords — AR.Drone, Control, PID, UAV.

I. Introduction

The use of UAV has developed strongly in the last years. Particularly, with the use of quadricopters or drones which are widely required, since, these are versatile in the flight and their costs have been declining due to the development of new technologies. In addition, the incorporation of cameras and the possibilities of stationary fligths makes them suitable to be used in a large number of applications such as: technical/visual inspection in hard to reach places, the evaluation of traffic flow in the streets [1], indoor surveillance, the topographic survey [2], the visual inspection in agriculture [3]-[4], among others.

While all these applications have been widely studied, researchers still have to deal with serious problems of control and navigation [5]; particularly, when a quadricopter is used in interior spaces without the aid of a GPS. In addition, some applications such as: indoor surveillance requires the drone to move on well-defined discrete trajectories and be able to maintaining a position for a while without much oscillation making a stationary flight at the point of destination with the lowest margin of error.

Those applications require a control system that ensures stability and rejection of disturbances. For that reason, the automatic control must be more robust than in outdoor applications, since a centimeter error could cause a collision against the walls, floor and/or obstacles.

To overcome the difficulties of control and navigation in indoor environment of quadricopters, researches have been focused on two large areas: the creation of vision algorithms for location and navigation without assistance of GPS and the study of systems of flight's stabilization. Regarding vision algorithms, the focus has been to follow the marks (landmarks) to achieve the landing and programmed movements [6]-[7], and create systems of location for an indoor navigation [8]. In relation to this, in [9] is presented a vision algorithm for a quadricopter's flight based on the detection of lines and edges for the classification of the type of environment and subsequent decision of the flight path using an AR.Drone.

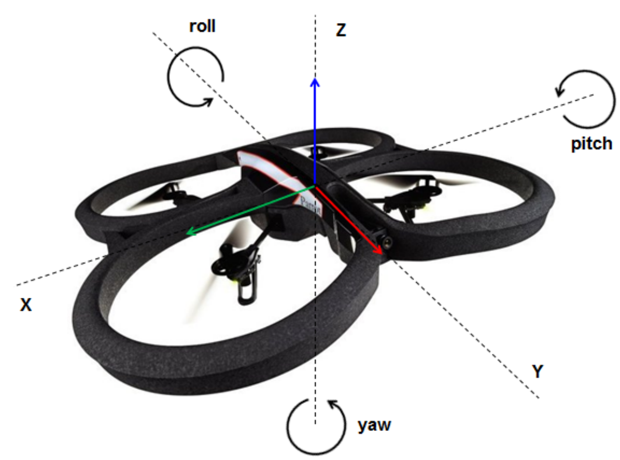

Fig. 1. Motion scheme of AR.Drone 2.0

Other works in this field are the research presented in [10] and [11]. The first developed a system based on the detection of Wall-Floor Features (WFFs), and the second work presented a location system and control based on SLAM (Simultaneous Localization and Mapping) and an automatic control algorithm LQG/LTR. Although an improvement has been achieved in the accuracy of the indoor location, even the noises are important and imply major challenges in the automatic control for trajectory tracking and hovering.

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With regard to flight stabilization systems is very common to use classic type PID controllers as the basis of the navigation system. These drivers are easy to deploy, and they work great in environments that allow flight errors without any risk, but are not satisfactory for flights in interiors and reduced spaces. However, in recent years there have been efforts to use automatic control algorithms more robust. For example, in [12] is presented a PID fuzzy for takeoff, landing and tracking trajectories of a quadricopter. Other authors in [13] and [14] presented control schemes by sliding modes in a quadricopter.

Also, the need to have controllers capable of adapting to environment has developed the studies, such as [15] and [16] which proposed PID control schemes with auto-tuning for tracking trajectories. At the same area, in [17] is proposed a controller by modes sliders with adaptable parameters to cope with disturbances. Although these works are of great importance in the development of automatic control strategies. These works were done by simulation since there are not so many works that manage to implement strategies of robust control on real flights.

On the other hand Engel, et al., [18]-[19]-[20] conducted a navigation system based on PTAM/SLAM with the AR.Drone 2.0 for the estimation of the absolute scale of the visual map generated with a camera and inertial measurements, which significantly improved the accuracy of drone positioning. However, the rotors of a quadricopter generate disturbances that destabilize the flight [21]. This disturbances increase in indoor environments, even more in confined spaces, such as corridors or small rooms, so that the combination of a system of positioning [18] and an automatic control system capable of attenuating the disturbances are sufficient to carry out inland flights in a safe way.

In this research is used a UAV AR.Drone 2.0 of Parrot company whose characteristics and control system is described in [22]. In order to be able to move the UAV in discrete trajectories it was used a PTAM/SLAM system developed in [18], which is capable of generating a map in three dimensions of the scenario and estimating the position regarding this scenario using inertial measurements and a Kalman filter. Although this system works very well, the control system associated with the distances on the x, y, z axes is a classical PID control, because the great contribution in [18]-[19]-[20], was the localization algorithm. The errors of hovering of the Engel's system are increased when the drone is in the presence of walls, floor and obstacles, for what is necessary to improve this control system in order to perform discrete trajectories in reduced indoor spaces.

The main objective of this research is to propose a system of automatic control to attenuate the effect of disturbances generated in the hovering of a quadricopter, when this performs flights in known indoors environments. For that, a fuzzy PID controller is proposed for hovering, based on the system of localization and control proposed in [18], taking as the criterion for adjusting the control parameters the error and the distance in the x and y axes of a known scenario.

II. Methods and Materials

This section describes each part of the drone's control and navigation system. In addition, the experiments and the performance indices are detailed.

A. The UAV

The UAV used is the model AR.Drone 2.0 developed by the Parrot company. This UAV is a quadricopter of 52 cm side, with a weight of 400 g, which uses batteries of 2500 mAh to achieve a flight autonomy of 20 minutes. The movement of the AR.Drone in the three-dimensional space is done by changing the vertical velocity (Gaz) and three angular movements: pitch, roll and yaw (see Fig. 1), which are obtained by manipulating the individual speeds of the four engines.

This drone is equipped with a gyroscope, magnetometer and accelerometer three-axis, an ultrasonic altimeter, a barometer and two cameras [22], one pointing down and one pointing forward. The sensors provide the means of angles of pitch, roll, yaw, plus height, but it is possible access to more information from the UAV as speed of motors, percentage of the battery, etc. In addition, the drone is connected via a Wi-Fi bi-directional link to the Flight Control Center.

B. Flight control center (FCC)

The FCC is a computer where operate the routines of location and superior control of the drone. In this work, an Intel Core i7 Notebook with 8GB of RAM was used in which was installed the Linux Ubuntu as Operating System. Additionally, a framework for developing applications for robots was configured that provides the functionality of an operating system called ROS, by its abbreviations in english (Robot Operating System). ROS has two basic components: a component that corresponds to the operating system, which manages the messaging between different applications and the second component corresponds to a suite of packages provided by the contribution of users (which are organized in sets, or "stacks").

For this research the FCC was equipped with ROS Indigo Igloo versión. Also was installed the ardrone autonomy and tumardrone packages.

C. Location system

To facilitate control on quadricopters in indoor spaces, where GPS is not available, in [18] is developed a monitoring and mapping system to estimate their position, which is executed in the FCC. This system, which was replicated for its use, is composed of two elements: (a) monocular SLAM based on Parallel Tracking and Mapping and (b) an extended Kalman filter that allows to improve the estimation of the location and orientation of the mobile using sensors that complement the location obtained by the SLAM/PTAM methods applied to video coming from a camera installed aboard the drone. The automatic control routines were modified to achieve the correct operation of the application.

D. The control and navigation system

The navigation system runs on both, the drone and in FCC. This can be divided schematically into several layers. The first and lowest is the central control found within the drone, whose task is to vary the speed of engines to achieve the pitch and roll angles and modify the yaw angular velocity. In addition, simultaneously modifying the speed of all the motors the speed of vertical ascent of the drone.

The second control layer is executed in FCC and is the responsible for generating angular and speed references that are sent to the drone to control the position in x, y, z axes, and angular velocity of yaw. A simplified control scheme is shown in Fig. 2, considering the first and second control layers.

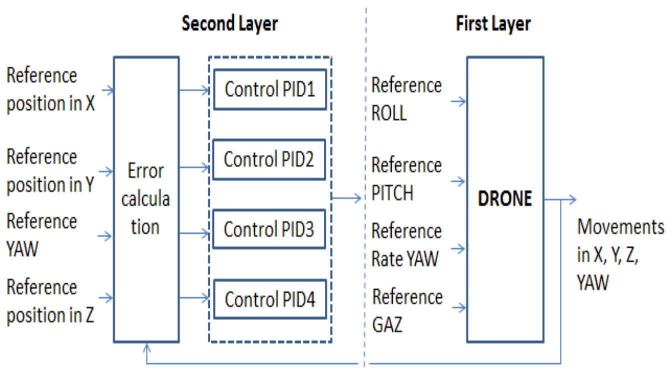

Fig. 2. Simplified control scheme of AR.Drone 2.0

In the second layer, the controllers are PID type of continuous time with limiters in the variables of output, whose input are the desired positions on the x, y, and z axes, and the yaw angle, in addition to the data delivered by the position estimator.

E. Scenario of the experiments

The scenario where the experiments were performed corresponds to a laboratory of the Department of Electrical Engineering of La Frontera University. The laboratory has a width of 4.72 m (x-axis as reference of the movement of the drone) and a length of 5.76 m. The physical resources that were used were: tables, chairs, objects and colored letters to ensure the correct operation of the positioning system so as to that flight errors were mostly caused by the behavior of the automatic control system and not by a malfunction of the PTAM / SLAM algorithms.

F. Error indicators

In each of the flight tests described in section III, it is quantified as a performance indicator the root of the mean square error RMSE in the x, y, and z axes, taking the information from the position estimator (1).

$$RMSE_j = \sqrt{\frac{1}{n} * \sum_{i=1}^{n} (\hat{y}_i - y_i)^2} \quad (1)$$

In (1), $\hat{y}_i$ is the position on the j-th axis calculated by the estimator of position, y_i is the last reference for the j-th axis, and n is the total number of measurements. Also, the sample rate is approximately 30 Hz.

Fig. 3. Laboratory, the experimental scenario

G. Classic PID Control

PID controllers are widely used in multiple systems because they are easy to implement and respond favorably to most of the requirements of automatic control in common system.

The automatic system control proposed in [18] controls the position variables of the x, y, z axes and velocity angular of yaw. In the case of x-axis and y-axis controllers are of type PD and are identical, these were used with their default values because when tested under without disturbances, similar errors are obtained in comparison with [18]. The control law of a controller PD has the following form:

$$u(t) = Kp * e(t) + Kd * \frac{d}{dt} e(t) \quad (2)$$

It is necessary to mention that the z axis and angular velocity of yaw were not modified.

H. Fuzzy PID Control

The automatic control routines of the system proposed in [18] were modified, those act on the second layer of control, to achieve the program of a PID control, the position on the x and y axes of the system of drone reference. Although the proposed control system is based on a control of the classic PD type is capable of modify in flight the control parameters Kp and Kd

of the axes x and y. The input parameters of this fuzzy control system are the position and position error of the drone for each coordinate axis. In this way the values of the control parameters are modified based on rules are shown graphically in the Fig. 4 and Fig. 5 by the membership functions.

Finally the effects of the position in each axis and the position error on the control parameters are weighted by (3). Where C_1 and C_2 are the factors of weighting for the effects of position and error of position respectively.

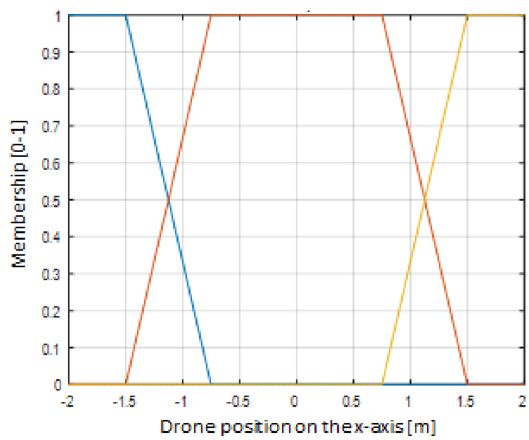

Fig. 4. Position membership function

The self-tuning capability of the proposed controller increases the overall accuracy of the control so that errors of hovering are mitigated in the worst conditions of flights close to walls and are smaller than those produced with the classic PID.

The tuning of the parameters Kp and Kd for the control fuzzy PID was achieved in preliminary tests, on flights close to the walls of the stage. In this way, the ranges of values of the parameters used in the controller are [0.5-1.0], [0.32-0.37] for Kp and Kd respectively. The characteristic of the fuzzy PID controller is to be able to generate a more flexible automatic control and incorporates extra information on the operation of the controller, in this case, the knowledge of scenario and position error of the flight.

$$K_n = C_1 * f_p(x(t)) + C_2 * f_p(e(t)) \tag{3}$$

III. Flight Testing

Flight tests are divided into two groups:

a) Classic PID control: Corresponds to 2 flights at 1.0 m and 0.5 m in height. On each flight hovering was performed in 5 positions, to the center, 90 cm to the left, 150 cm to the left, 90 cm to the right and 150 cm to the right. Each position was held for 3 minutes. The most distant flights of the center, correspond to positions close to the walls where the drone is 60 cm ± 5 cm from the wall since the scenery is 4.72 m wide.

b) Fuzzy PID control: Corresponds to 2 flights at 1.0 m and 0.5 m in height. On each flight hovering was carried out at same 5 positions as flight tests with PID control classic, keeping also for 3 minutes each position.

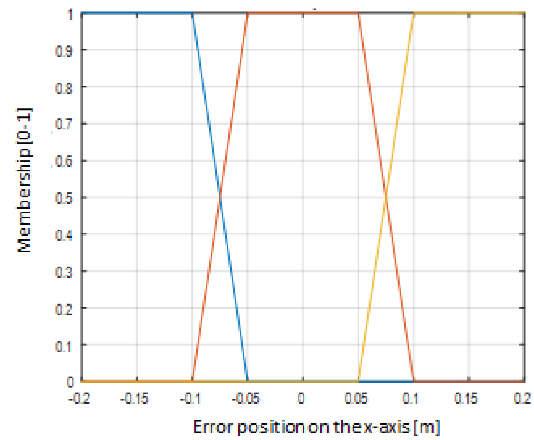

Fig. 5. Error position membership function

IV. Results

The results of flights are shown in Fig 6. corresponding to the use of the classical PID at 1 m and 0.5 m height seen from the x, z axis. In red the nearest hovering to the walls, in green the hovering to 90 cm of the center and in blue hovering to the center of the stage.

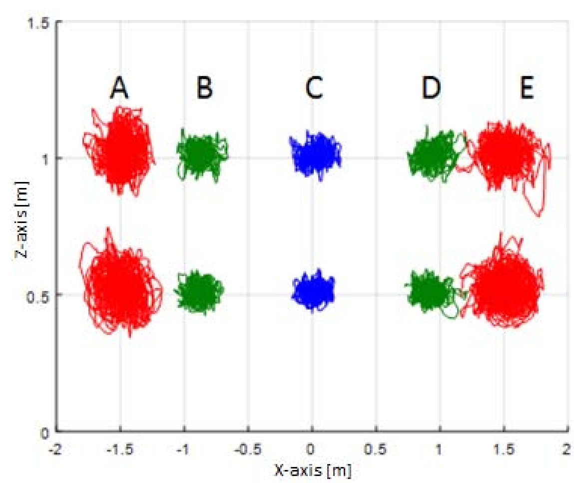

Fig. 6. Classic PID flight tests

It can be seen in Fig 6. that the drone presented many problems to maintain the position in the flights close to the walls. But in positions B and D at 90 cm of the center there were not great differences with respect to the center, since the drone is still kept at a sufficient distance, so as not to be disturbed by the blasts of air produced by it rotors.

Table I, shows that RMSE errors in flights not near the walls of the stage with the PID control classic arrive at 9 cm on the x-axis, 7 cm on the y-axis, and 3 cm on the z-axis. These values are consistent with the values published by Engel et al. However, errors in flights near the walls are larger, reaching 11 cm in the x-axis. While these average values are acceptable, Fig. 6 shows that the maximum errors in flights close to the walls can reach 30 cm.

TABLE I. CLASSIC PID CONTROLLER ERRORS

Eje	Altura	RMSE [m]				
		A	*B*	*C*	*D*	*E*
Eje x	1.0[m]	0.092	0.079	0.072	0.089	0.106
Eje y		0.062	0.066	0.044	0.058	0.051
Eje z		0.063	0.034	0.028	0.035	0.045
Eje x	0.5[m]	0.106	0.065	0.063	0.065	0.118
Eje y		0.056	0.054	0.041	0.043	0.060
Eje z		0.066	0.028	0.026	0.028	0.057

On the other hand, Fig. 7 shows the results of the flights corresponding to the use of fuzzy PID at 1 m and 0.5 m height.

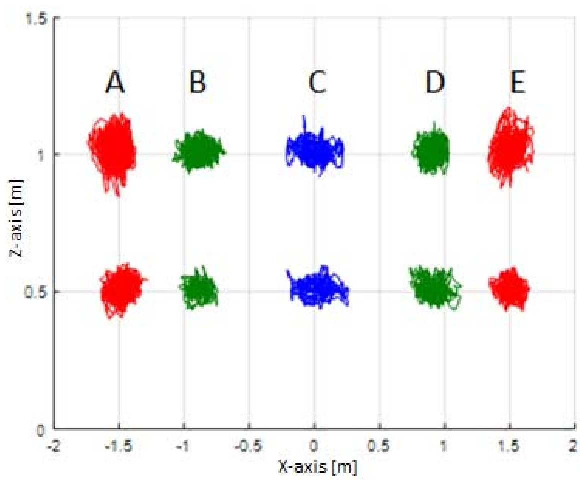

Fig. 7. Fuzzy PID flight tests

TABLA II. FUZZY PID CONTROLLER ERRORS

Eje	Altura	RMSE [m]				
		A	*B*	*C*	*D*	*E*
Eje x	1.0[m]	0.079	0.075	0.064	0.057	0.055
Eje y		0.047	0.048	0.045	0.042	0.037
Eje z		0.030	0.030	0.048	0.036	0.042
Eje x	0.5[m]	0.065	0.059	0.089	0.073	0.051
Eje y		0.043	0.048	0.060	0.043	0.033
Eje z		0.032	0.025	0.028	0.032	0.028

In Fig. 7 highlights the improvement in hovering of the flights closer to the walls, regarding to Fig. 6. This is possible since from the 75 cm of the center in the x-axis there is a strong influence on the tuning of the parameters of control Kp and Kd due to the position in which the drone (see Fig. 4).

This effect is added to the influence on the control parameters that occurs when the drone has position errors in the axes x and y greater than 5 cm (see Fig.5).

The Table II shows RMSE errors in flights performed using the Fuzzy PID control. It should be noted that errors at x are less than 8 cm at worst of the cases and 5 cm for the y-axis. That is an improvement over the classic PID controller.

CONCLUSIONS

In this research, the localization and control system proposed in [18] was implemented, obtaining errors of similar hovering for flights far to the walls of the scenario where the air gusts produced by the rotors of the drone did not succeed in destabilizing it. In addition, was implemented a real fuzzy PID control system based on position and error of position of the drone with respect to the axes x and y able to adjust the parameters Kp and Kd for these axes. That was achieved to mitigate the effect of disturbances on flights close to the walls of a known scenario.

Future work is intended to advance development of the tuning methodologies of the controllers and validate the methodology proposed in a real indoor surveillance application.

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