Non-symmetric membership function for Fuzzy-based visual servoing onboard a UAV

M. A. Olivares-Méndez* and P. Campoy and C. Martínez and I. F. Mondragón B.

Computer Vision Group, DISAM, Universidad Politécnica de Madrid, Madrid, Spain

**E-mail: miguelangel.olivares@upm.es*

www.disam.upm.es/colibri

This paper presents the definition of non-symmetric membership function for Fuzzy controllers applied to a pan & tilt vision platform onboard an Unmanned Aerial Vehicle. This improvement allows the controllers to have a more adaptive behavior to the non-linearities presented in an UAV. This implementation allows the UAV to follow objects in the environment by using Lucas-Kanade visual tracker, in spite of the aircraft vibrations, the movements of the objects and the aircraft. update has been tested in real flights with an unmanned helicopter of the Computer Vision Group at the UPM, with very successful results, attaining a considerable reduction of the error during the tracking tests.

Keywords: Unmanned Aerial Vehicles, Non-Symmetric membership function, Fuzzy Control, Visual servoing, pan-tilt visual platform.

1. Introduction

The unmanned aerial vehicle (UAV) has made its way quickly and decisively to the forefront of aviation technology. Opportunities exist in a broadening number of fields for the application of UAV systems as the components of these systems become increasingly lighter and more powerful. UAVs provide a cheap and safe alternative against to manned systems and often provide a far greater magnitude of capability.

Visual sensing can provide a source of data for relative position estimation, situation awareness, and a UAV's interaction with the physical world. It probably represents a preferable technology for these purposes than either GPS or INS. In several UAV projects, computer vision plays the most important role in the environmental sensing accomplished by UAVs. Some applications of vision for UAVs include, obstacle avoidance[1] , the works of Rathinam et al.[2] and Campoy[3] for inspection and monitoring of oil-gas pipelines, roads, bridges, power generation grids, and other civilian tasks, the uses of natural landmarks for navigation and safe landing[4] , or the works of Mondragón with an omnidirectional camera for attitude estimation of UAVs[5] , among others.

A VTOL-UAV (Vertical Take Off and Landing) has more non-linearities than a fixed winds UAV, because it can change its position with a fast movements, and can remain in hover position for a long time, being affected, just, by the perturbations of the environment. The objective of this work is to develop an active visual-based system for object tracking on real-time onboard the UAV, by modeling the non-linearities states of this kind of UAV. For tracking objects the well known Lucas-Kanade-Tomasi tracker has been used[6] ,[7] . This visual-based object tracking is implemented using a pan & tilt vision platform controlled by Fuzzy controllers. A non-symmetric membership function implementation using the MOFS (Miguel Olivares' Fuzzy Software) has been used for the definition of the input and output variables of the Fuzzy controllers, in order to fit in a better way to the high nonlinear system, improving the results of previous works[8] and[9] with better results and follow objects during flights, in which the velocity commands are increased and more position changes are made.

For a better comprehension, the paper is divided in the following sections. In Section 2 we show a description about the UAV used in this work. Section 3 will show the *Miguel Olivares' Fuzzy Software* definition and the configuration of the different fuzzy controllers. The presentation of some results obtained for this work are shown in the Section 4 and finally, we present the conclusions and future works in Section 5.

2. UAV System Description

The Colibri project has three totally operative UAV platforms. One electric helicopter, and two gas powered helicopters. The COLIBRI testbeds,[3] are equipped with an xscale-based flight computer augmented with sensors (GPS, IMU, Magnetometer, fused with a Kalman filter for state estimation). For this work, the UAV system used was an electric SR20 of "Rotomotion", shown in Fig. 1. It includes a two axis pan-tilt video-platform powered by two servo-motors, with an action range of 180 degrees.

For the control of the platform we send position commands to the servos through the helicopter controller, based on the visual information acquired. To perform image processing, it has a VIA nano-ITX 1.5 GHz onboard computer with 1 Gb RAM-DDR2.

Fig. 1. COLIBRI III Electric helicopter.

3. Visual servoing using Fuzzy controllers

3.1. *Fuzzy Software Implementation*

The MOFS has been designed by the definition of one class for each part of the fuzzy-logic environment (variables, rules, membership functions and defuzzification modes) in order to facilitates the future updates and to make easier work with it. Currently, three different kind of membership functions have been implemented, those are the pyramidal, the trapezoidal and the gaussian. Furthermore, the two inference models for the fuzzification that have been implemented are the maximum and the product. Additionally, for the defuzzification phase the Height weight method is used. More details about the structure of this software can be found in.[10]

There are some differences between this fuzzy software and others. One is the learning algorithm based on the idea of the synaptic weights of the neurons, but for this work this improvement is not used, in[11] and[12] is possible to see how it works. Another characteristic of this software is the possibility of defining non-symmetric membership functions for each fuzzy variable. This idea consist in the definition of different sizes for the different parts of the membership function as is shown in the central part graphics in Figure 2. With this improvement, the system has a more adaptive response to the non-linear model of this system that represent the helicopter movements and the different perturbations of the environment that can affect the UAV. It must be considered that the helicopter can change it position with fast movements (more than 0.4 m/s) or slow movements (less than 0.4 m/s) in position and orientation, and also, it can remain in hover position for a long time, being affected (its position) just for the environment perturbations. Some of these different changes of the helicopter will be explain with figures in the next sub-section.

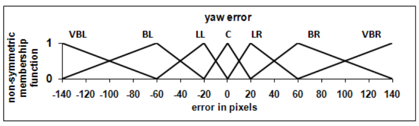
The definition of the different sub-sets of each variable is based on the result of more than 20 different tests. Those tests have been made in the laboratory and onboard the UAV in real flights.

3.2. *Fuzzy Controllers*

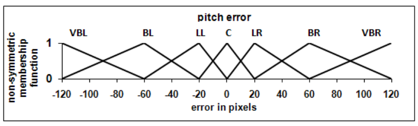
To develop the visual servoing task in a vision pan & tilt platform onboard the UAV, two fuzzy controllers have been implemented using the MOFS. They are working in parallel, one for the pan axis of the vision platform and the other one for the tilt axis. The purpose of this implementation is to keep in the center of the image the tracking object, in spite of the helicopter vibrations and the movements of the object and the UAV. The two controllers are design using triangular membership functions, the product inference model for the fuzzification, and the Height Weight operation method for the defuzzification of the output (Eq. 1).

$$y = \frac{\sum_{l=1}^{M} \overline{y}^l \prod \left(\mu_{B'}(\overline{y}^l)\right)}{\sum_{l=1}^{M} \prod \left(\mu_{B'}(\overline{y}^l)\right)} \quad (1)$$

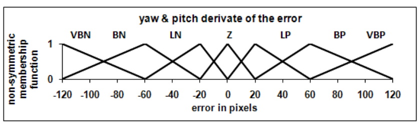
In Fig. 2(a) and 2(b) are shown the first input of each controller and in Fig. 2(c) the second input of them. The Fig. 2(d) shows the definition of the output for each controller. In those figures, it is possible to notice the definition of the non-symmetric membership functions.



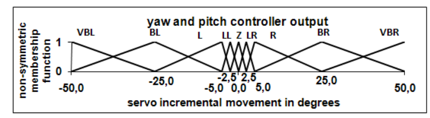
(a) First input variable of the Yaw controller.



(b) First input Variable of the Pitch controller.



(c) Second input of the Yaw and Pitch Controllers.



(d) Output of the Yaw and Pitch Controllers.

Fig. 2. Input and Output Variables for the Pitch and Yaw controllers.

The next Table shows the meaning of the acronyms used for the definition of the fuzzy sets of each variables.

Acronyms	Meaning
VBL	Very Big error to the Left
BL	Big error to the Left
L	Left
LL	Little to the Left
C	Center
LR	Little to the Right
R	Right
BR	Big error to the Right
VBR	Very Big error to the Right
VBN	Very Big Negative
BN	Big Negative
LN	Little Negative
Z	Zero
LP	Little Positive
BP	Big Positive
VBP	Very Big Positive

4. Experiments

In this section we present a result of the performance of the two controllers using the new defined membership functions on a real test onboard the UAV. Here, a real flight test was carried out. In figure 3, it is shown a 3D reconstruction of the flight using the GPS and the IMU data.

In this figure, it is possible to see the trajectory of the UAV during the tracking task. In order to increase the difficulty of the test, the selection of the object to track was made during the flight from the start point (as is shown in Figure 3). At first, some rapid movements were made in the three axis (Figures 4(a), 4(b) and 4(c), before frame 180-200), making big changes to the different angles of the helicopter, as shown in Figures 4(d), 4(e), and 4(f). Then, a side movement with an increasing velocity was made (from 0.0m/s to more than 1m/s), as is shown in Figure 4(c), from frame 180 to frame 300. Later, a rapid descend with a maximum of 1m/s was made, which is possible to see from frame 300 to frame 450 at the figure 4(a) and 4(d). The manual landing affected with big changes in all the angles when the helicopter was next to the floor. The test finalizes with the vibrations of the helicopter when it was in contact with the terrain at the End Point.

This flight is faster than the presented in the previous work, in order to increase the difficulty of the action to follow the tracked object.

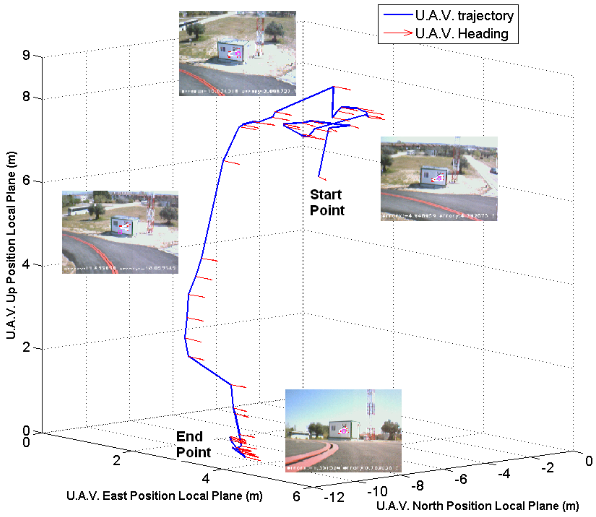
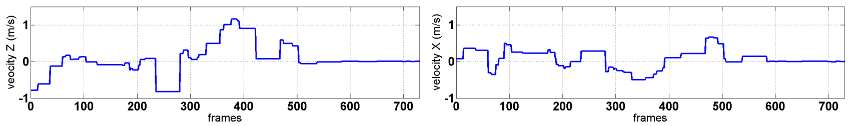
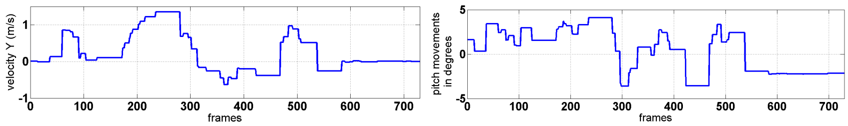


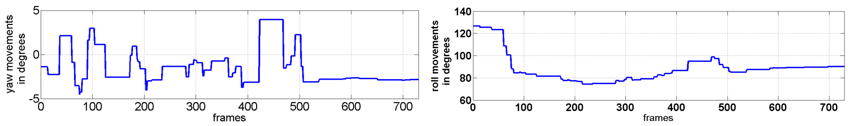
Fig. 3. 3D flight reconstruction using the GPS and the IMU data from the UAV. Where, the 'X' axis represents the NORTH axis of the surface of the tangent of the earth, the 'Y' axis represents the EAST axis of the earth, the 'Z' is the altitude of the helicopter and the red arrows show the pitch angle of the helicopter.



(a) Velocity changes in Z axis (altitude). (b) Velocity changes in X axis (Forward).



(c) Velocity changes in Y axis (Side). (d) Pitch angles changes.



(e) Yaw angles changes. (f) Roll angles changes.

Fig. 4. Changes of the UAV in velocity and in degrees.

In figure 5, it is possible to see the error in the two axis. Also, it is possible to see that there are not peaks of error during the flight, obtaining a very good response of the controller. Furthermore, the results show the correct control tracking besides the increase of the movements and velocities in comparison with previous work. Thus, based in these results, and on the behavior of the controllers, it is possible to say that the improvements in the membership functions have a successful behavior to overcome the vibrations problems and the high non-linearity of the VTOL-UAV.

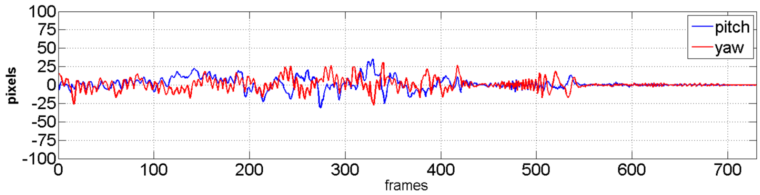


Fig. 5. Error between center of the image and center of the object to track.

5. Conclusions and Future Works

This work presents fuzzy controllers with non-symmetric membership functions in the definition of the input variables. These controllers are used for following objects by controlling a pan and tilt video platform on board a UAV. A Lucas-Kanade-Tomassi tracker is used. The controllers have an excellent behavior following the objects, obtaining better results than the previous results obtained without the non-symmetric membership function definition. The uses of the pan and tilt visual platform give to the helicopter freedom of movements, as well as, a faster response when following moving objects, being the other implementations of visual servoing on UAV (without pan and tilt platform) more limited and slower than the platform servos response. The principal and immediate future work is to implement controllers for all the possible movements of the UAV (Forward, Side, altitude and heading) using velocity or position commands, to make a total control of the UAV and platform, in order to following objects without any restriction. It is possible to view the test videos and more on[13] .

Acknowledgments

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References

1. Z. He, R. Iyer and P. Chandler, Vision-based uav flight control and obstacle avoidance, in *American Control Conference, 2006*, June 2006.
2. S. Rathinam, Z. Kim, A. Soghikian and R. Sengupta, Vision based following of locally linear structures using an unmanned aerial vehicle, in *Decision and Control, 2005 and 2005 European Control Conference. CDC-ECC '05. 44th IEEE Conference on*, Dec. 2005.
3. P. Campoy, J. Correa, I. Mondragon, C. Martinez, M. Olivares, L. Mejias and J. Artieda, *Journal of Intelligent and Robotic Systems* (2008).
4. A. Cesetti, E. Frontoni, A. Mancini, P. Zingaretti and S. Longhi, *J. Intell. Robotics Syst.* **57**, 233 (2010).
5. I. F. Mondragón, P. Campoy, C. Martinez and M. Olivares, *Robotics and Autonomous Systems* **In Press, Corrected Proof** (2010).
6. B. D. Lucas and T. Kanade, An iterative image registration technique with an application to stereo vision (ijcai), in *Proceedings of the 7th International Joint Conference on Artificial Intelligence (IJCAI '81)*, April 1981.
7. C. Tomasi and T. Kanade, *Detection and Tracking of Point Features*, tech. rep., International Journal of Computer Vision (1991).
8. M. Olivares-Mendez, P. Campoy, C. Martinez and I. Mondragon, *Eurofuse workshop 09, Preference modelling and decision analysis* (Sept. 2009).
9. M. Olivares-Mendez, P. Campoy, C. Martinez and I. Mondragon, A pan-tilt camera fuzzy vision controller on an unmanned aerial vehicle, in *Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on*, Oct. 2009.
10. I. F. Mondragón, M. A. Olivares-Mendez, P. Campoy and C. Martinez, *Autonomous Robots* **In Press, Corrected Proof** (2010).
11. M. Olivares and J. Madrigal, *Intelligent Signal Processing, 2007. WISP 2007. IEEE International Symposium on* , 1(Oct. 2007).
12. M. Olivares, P. Campoy, J. Correa, C. Martinez and I. Mondragon, Fuzzy control system navigation using priority areas, in *Proceedings of the 8th International FLINS Conference*, (Madrid,Spain, 2008).
13. COLIBRI, Universidad Politécnica de Madrid. Computer Vision Group. COLIBRI Project http://www.disam.upm.es/colibri, (2009).