Aerial Object Following Using Visual Fuzzy Servoing

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Abstract

This article presents a visual servoing system to follow a 3D moving object by a Micro Unmanned Aerial Vehicle (MUAV). The presented control strategy is based only on the visual information given by an adaptive tracking method based on the color information. A visual fuzzy system has been developed for servoing the camera situated on a rotary wing MAUV, that also considers its own dynamics. This system is focused on continuously following of an aerial moving target object, maintaining it with a fixed safe distance and centered on the image plane. The algorithm is validated on real flights on outdoors scenarios, showing the robustness of the proposed systems against winds perturbations, illumination and weather changes among others. The obtained results indicate that the proposed algorithms is suitable for complex controls task, such object following and pursuit, flying in formation, as well as their use for indoor navigation

Keywords- Visual Servoing, UAV, Object Following, Fuzzy Logic, Fuzzy Control, Soft Computing.

1 Introduction

Our research interest focuses on developing computer vision techniques to provide UAVs with an additional source of information to perform visually guided tasks - this includes tracking and visual servoing, inspection, pursuit and flying in formation among others.

Different works have been done where a vision system in conjunction with range sensor were used for Object Following test. On [1] an omnidirectional visual systems is used as bearing sensor, while the distance to the target is measured using a range sensor, for control a robotic wheelchair on indoors. Others systems have been proposed only based on visual information for cooperative robotics [2]. Visual information also have been proposed on aerial robotics for flying in formation [3]. Several approaches also have been proposed for fixed wind UAV flying at constant altitude following circular paths, in order to pursuit a moving object on a ground planar surface [4],[5]. In the same way, several approaches have been proposed for rotary wind UAV following a terrestrial target [6], [7].

Visual servoing also has been successfully implemented on aerial vehicles. Pose-based methods, in which is necessary to estimate the 3D position, have been employed for applications like autonomous landing on moving objects [8] or on fixed place without location information [9], while image-based methods have been used for positioning [10], generally assuming a fixed distance to the object, reducing the complexity of the derived controlled and the necessity to estimate the reference depth.

The Soft Computing is getting more importance in the Robotics world in the last decade. These techniques are used for a sort of uses in this researcher field. One of the most used Soft Computing techniques and proposal is the Fuzzy Logic to create controllers. In contrast to conventional control, fuzzy logic control was initially introduced as a model-free control design method based on a representation of the knowledge and the reasoning process of a human operator. Fuzzy logic can capture the continuous nature of human decision processes and as such is a definite improvement over methods based on binary logic (which are widely used in industrial controllers). Hence, it is not surprising that practical applications of fuzzy control started to appear very quickly after the method had been introduced in publications. Some of those applications of Fuzzy control and UAV are: for visual servoing [11], for an autopilot using a Fuzzy PID control [12], an obstacle avoidance and path planning system [13] and to manage a team of UAVs [14].

This paper presents a Fuzzy Servoing strategy using a real time flying objects following method based only on visual information to generate commands in a Dynamic Look and Move control architecture. This work is based on our previous visual control architecture developed for UAVs [15]. Section 2 presents the flying object following problem statement. Section 3 explains how an adaptive color tracking method is used to identify and track the target object on the image plane. Then this information is passed to the Fuzzy controllers to obtain the commands to follow the flying objet from a safely distance as is presented on section 4. Section 5 shows the UAV architecture and the fuzzy visual servoing system. Finally, section 6 shows the test results of the proposed algorithm running onboard a UAV, validating our approach for an autonomous object flying following method based on visual information.

2 Problem statement

Considering a flying object T moving with an unknown trajectory on the world space $\mathbb{R}^3$, and a flying robot O with an attached fixed calibrated pinhole camera, both having an idealized flying dynamics. The control goal is to command the flying robot in order to track the target object, maintaining it always onto the camera FOV with a fixed separation distance. Taking into account the Figure 1 and considering the target object as a 3D spherical surface, it is projected on the camera image plane as a circular region that can be defined by its center of projection $\mathbf{x}_t = [x_t, y_t]^T$ and the circumference diameter $\o_t$. Because the target is an ideally spherical surface, the projection point ($\mathbf{x}_t$) can be considered as the image projection of target's sphere centroid with coordinates on the camera frame defines as $\mathbf{X}_{Tc} = [X_{Tc}, Y_{Tc}, Z_{Tc}]^T$. The detected circumference (with a diameter of $\o_t\, pixels$) on the image plane corresponds to the projections of the sphere perimeter (with a fixed diameter $\O_T$) that results of the intersection of the plane which normal is parallel to the vector defined by the camera optical centre and the sphere centroid, that divides the target in two hemispheres. The projected diameter also can be used to estimate the distance to the target, because it is inversely proportional to the distance from the camera to the object.

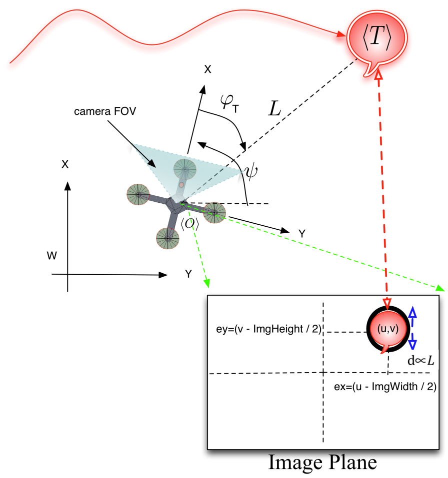
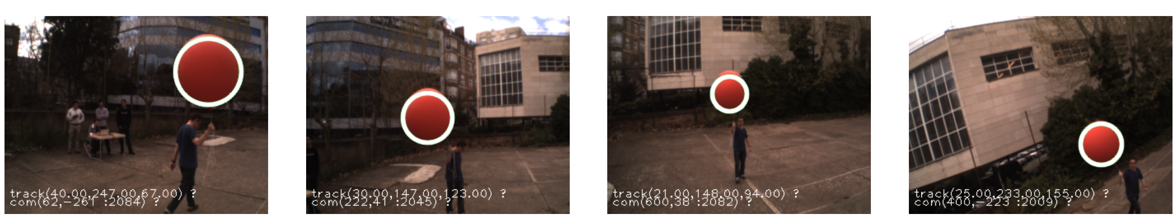


Figure 1: UAV object Following setup in 2D. The control goal is to follow a target object (T) with an unknown trajectory using only the pose ($(u,v)_t$) and projection diameter ($\o_t$) on the image plane. The objective is to maintain the Target centered on the image plane with fixed distance or a proportional projection diameter on the image

3 Detection Approach

Using cameras in outdoor environments is a challenging task. Sudden changes and inconsistencies with outdoor illumination cause changes in the apparent colour as perceived by a camera. Here, it is described the details of the tracking approach used for detect the target.

We approach the problem of tracking by exploiting the colour characteristic of the target. We define a basic colour to the target by assuming a simple coloured mark to it and tracking this mark. Therefore, we rely on a suitable and consistent colour representation that allows us to keep colour distributions derived from video image sequences approximately constant (in outdoor settings). However, this process is not always perfect, and changes still occur in colour distributions over time. An algorithm that has proven to deal with this issue by dynamically adapting to changes in probability distributions is the *Continuously Adaptive Mean Shift* [16] (CamShift). This algorithm is based in the *mean shift* originally introduced by Fukunaga and Hostetler [17].



(a) (b) (c) (d)

Figure 2: Camshift tracking of a colored red target on a image sequence. The white circle corresponds to the boundaries of the tracked colored area

The Camshift algorithm is used to track a defined color on an image sequence, obtaining for each frame the center of the color region and the the circumference that involves the tracked colored area. Figure 2 shows an example of a color tracked sequence using the Camshift tracked of a red object.

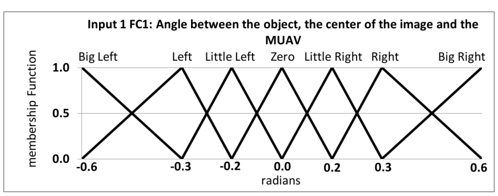
4 Fuzzy Controllers

This Section presents the implementation of two Mamdani Fuzzy controllers which based on the visual information previously described, generate yaw and pitch commands for the MUAV (velocity commands in degrees per secods and milimeters per seconds).

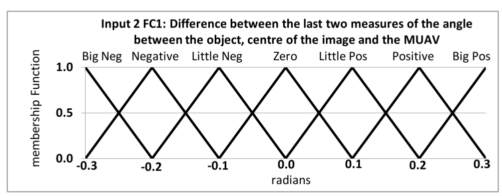
The Fuzzy controllers were implemented using the MOFS (*Miguel Olivares' Fuzzy Software*). This software was used, previously, to implement fuzzy Controllers with other different platforms like a wheelchair [18] or on an unmanned helicopter, where it was applied to control a pan and tilt visual platform onboard the UAV [19] and for the autonomous landing of the aircraft [9]. With this software, it is possible to define easily fuzzy controllers with the required number of inputs and select the type of membership functions, the defuzzification model and the inference operator, from a sort of methods. A more detailed explanation of this software can be found in [20].

For this work two fuzzy controllers were defined. All the variables of the two controllers are defined using triangular membership functions. The decision of this and the rest parts of the design of the controllers were made based on the excellent results obtained in the previously mention works.

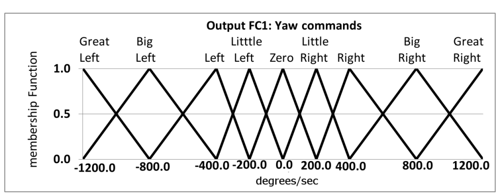
Both controllers have two inputs and one output. The desing of the controller of the yaw or heading of the MUAV is shown in Figure 3. The first input of this controller is the angle estimation, in radians, between the MUAV and the center of the image and the center of the object to follow (Figure 3(a)). The second input is the difference between the last angle estimation and the actual angle (Figure 3(b)). This controller sends velocity commands (degrees per seconds) for change the heading position of the aircraft (Figure 3(c)).



(a) First input. Estimation of the deviation of the object from the centre of the image capture from the MUAV.



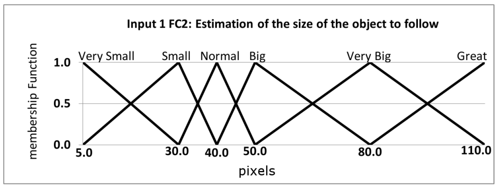
(b) Second input. Difference between the last two measures.



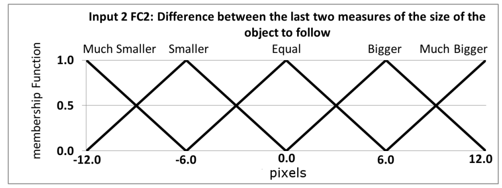
(c) Output. Velocity commands to change the heading of the MUAV

Figure 3: Definition of the Yaw controller.

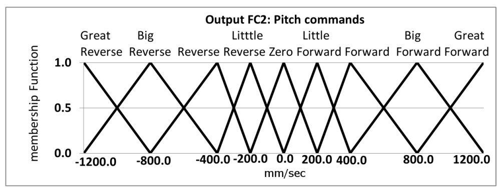
The second controller acts on the pitch state of the MUAV as is shown in Figure 4. The controller take the data about the size of the object, in pixels, to follow and estimate the distance. Using as the first input the actual size of the object (Figure 4(a)), and as the second one the difference between the last size measure and the actual one (Figure 4(b)). The ouput of the controller consists in velocity commands to go ahead, in the case that the object is far away (Figure 4(c)). Stay in the same position if the object is near at a predefined distance of segurity, or go back if it is very close to the MUAV.



(a) First input. Estimation of the distance between the object and the MUAV.



(b) Second input. Difference between the last two measures.



(c) Output. Velocity commands to keep the safe distance to the object.

Figure 4: Definition of the Pitch controller.

The defuzzification process is made using the product model of inference and the height weight defuzification model as is shown in the Eq. 1.

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

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5 UAV platfom

We performed experimental tests using a Pelican quadrotor [21] and a moving colored target. The testbed shown in Figure 5 has a low-level stability controller based on PID that uses information from GPS, IMU, pressure altimeter and magnetometer fused using a Kalman filter. This controller is embedded, closed, unmodifiable but gains are tunable. Onboard vision processing is achieved using a dual core Atom 1.6 GHz processor with 1 GB RAM, wireless interface and support for several types of USB cameras (mono or stereo). This computer runs Linux OS working in a multi-client wireless 802.11(a,b,g) ad-hoc network, allowing it to communicate with a ground station PC used for monitoring and supervision.

The fuzzy controllers developed previously are implemented on the Pelican UAV using a *dynamic look-and-move* servoing architecture as is presented on figure 6. In this scheme, the velocity references generated by the controller (running onboard aircraft) are used as a input references for the Pelican Low Level controlled. This low level controller, when is operated on position control, allows to get as input, velocity commands, as well as

Figure 5: CVG-UPM [22] Pelican QuadCopter testbed used for sense and avoid experiments

direct control actions. For this test, the velocity commands generated by the visual system are directly send as input velocities for the Autopilot. This autopilot also allow to independently control the *X, Y, Z* and *Yaw*. *Roll* and *Pitch* angles are no directly controlled by velocity command, but it is possible to control it by means of motor direct control. So, in this control architecture, and considering that the camera is looking forward, the quadrotor *X* and *Z* as well as the *yaw* angle will be controlled by the generated references ($V_{Xq} = V_{Zc}, V_{Zq} = V_{Yc}, \omega_{Zq} = \omega_{Yc}$) . The *Y* axis and $Pitch, Roll$ angles are controlled by the low level autopilot.

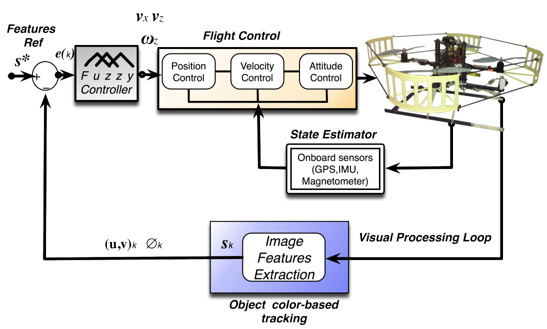


Figure 6: Object Following *Dynamic image-based look-and-move* system architecture.

6 Test and results

Several tests have been done which different balloons used as the target object (in order to reduce the complexity of an aerial moving object). These balloons are moved with a random trajectory on the 3D space. The visual system composed of the Camshift color tracked and the Fuzzy Controler running onboard the Pelican quadcopter (Figure 5) in a Intel Atom Board PC. The velocity commands are send to the low level autopilot through a serial interface. Figure 7 shows a external view of a Object following tests and the onboard images used for the fuzzy controller.

Here one of these flight-tests is presented. Figure 8 shows the trajectory that was made by the MUAV and some captions made by the onboard camera. This trajectory was reconstructed using the GPS data of the aircraft. In this case a red balloon was followed during almost two minutes.

The Figure 9(a) shows the estimation of the angle between the red balloon, the MUAV and the centre of

(a) (b)

Figure 7: Object Following test using a fuzzy controller on a Pelican quadrotor:(a) External view of the tests using a colored balloon. The balloon is manually moved with a random trajectory, (b). The onboard image captured, and the projected diameter on the image plane identified using the Camshift color tracked.

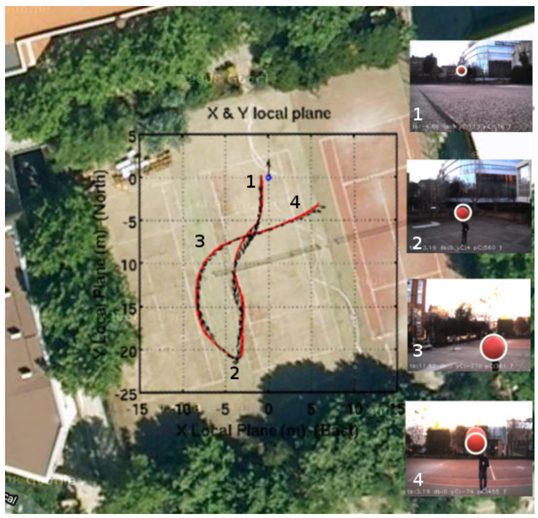


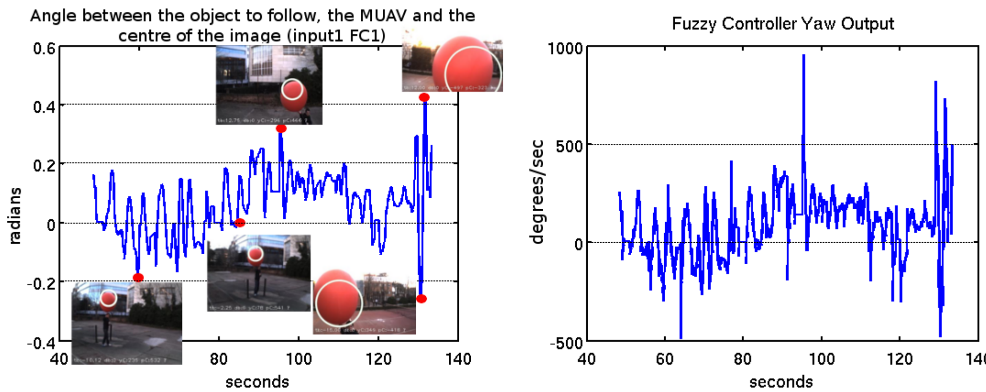
Figure 8: Trajectory of the Pelican-MUAV during an object following test.

the image. This measure is obtained by the visual algorithm in radians, and was introduced to the first fuzzy controller as the first input. The difference between the last measure of this angle and the actual one is introduced as the second input. As is shown in this Figure, the controller keep the object in the centre of the image, despite the effects of the wind and the random trajectory. Some captions of the most critical moments are include in the Figure.

In Figure 9(b) is shown the output values of the yaw controller of the MUAV.

Figure 10(a) shown the measure of the balloon during the test. The size of the balloon gives the information to the controller to go ahead, when the object it is far away or to go back when is so near. Some captions of the most representing movements are include in this Figure. The first picture represents the begin of the test, in where the four rotors were started. The second one shows the normal situation in where the object has the predefined size. To test the reverse movements of the aircraft, the balloon was moved against the MUAV, that is shoed on the third. The fourth picture shows how the MUAV was recovered from the previous situation.

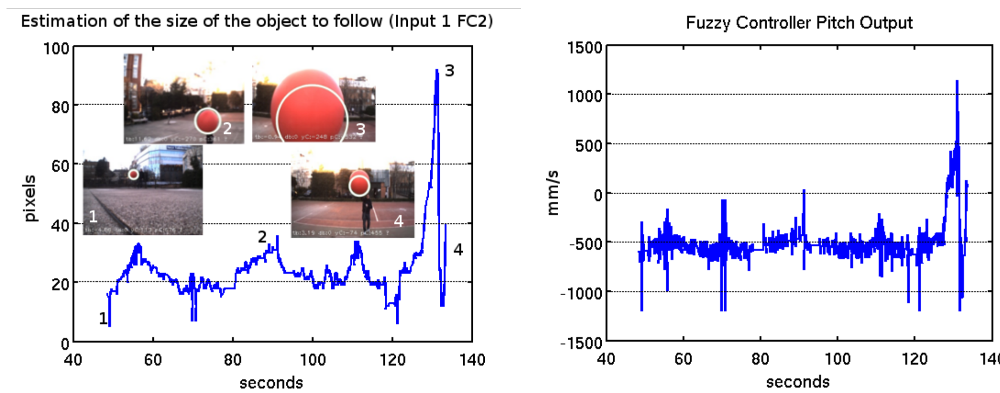
Figure 10(b) shows the response of the Pitch controller to follow the object from a safe distance.



(a) Measure of the angle between the MUAV, the object to follow and the centre of the image.

(b) Output of the Yaw Fuzzy Controller.

Figure 9: Measures for the orientation of the MUAV and response of the Yaw controller.



(a) Measure of the size of the red balloon during all the test.

(b) Output of the Pitch Fuzzy Controller.

Figure 10: Measures for the orientation of the MUAV and response of the Yaw controller.

7 Conclusion

In this paper a Fuzzy visual servoing system for flying object following have been presented. The visual information is provided by an adaptive color tracking algorithm based on CamShift. The fuzzy controllers acts on the yaw and the pitch of a Micro-UAV, in order to keep the aircraft from a safe distance to the object to follow and mantain it in the centre of the image.

Real tests on outdoors scenarios have been made to validate the proposed method and the fuzzy controllers. The excellent results of these tests have demonstrated the robustness against the weather, wind and light variations of the visual algorithm. The proposed visual algorithm is based on color detection and could be used to detects objects with another color and different shape, not just red balloons. Also, these results prove the excellent behavior of the fuzzy controllers performing the following action of the target objective from a safe distance.

In the future works, a height control of the MUAV is in the initial phase. Also, the uses of this algorithm and controller for an obstacles avoidance tasks with fixed objects and other MUAVs have to be done.

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