Autonomous Quadcopter Design by Using Fuzzy Logic

Zekeriya HACIMUHAMMED and İbrahim SAVRAN

***Abstract*—** The purpose of this paper is to present an Automatic Flight Controller for quadcopters drone by using two-input-single-output (MISO) fuzzy system. The paper supposes that the manual flight control system of the drone is working by default, receives control commands from transmitter and sends speed commands to rotors depending on the computed PID or Fuzzy rules in the flight controller. It working on creating control commands instead of transmit-ter's commands, this will base on the attitude and the drone's velocity to enable the drone to take a route between two GPS point or more. The drone will takeoff and will turn to the right direction then go to the target position. The control system that have to compute along this route is three command (Throttle, Roll, Pitch).

***Keywords*—** Quadcopter; UVA; Flight Controller; Fuzzy system; Route; Drone.

I. Introduction

A quadrotor is a cross-shaped aerial vehicle that is capable of vertical take-off and landing. It has four motors, each mounted per corner equidistant from the centre. The synchronized rotational speed of all the motors is key to the control of the quadrotor [1]. Vertical motion results from the simultaneous increase or decrease of the rotational speeds of all the rotors. The motion along any direction on the lateral axis is obtained by decreasing the rotational speed of the rotors along the desired direction of motion, and increasing the speed of the rotors opposite to the desired direction of motion. Moment produced by rotation of rotors is used to initiate yaw [4]. For instance, clockwise yaw is initiated by simultaneously increasing the rotation speed of the rotors creating a clockwise moment, and decreasing the rotation speed of the rotors creating counterclockwise moment [1][2]. The motion of the quadrotor is described schematically in fig.1

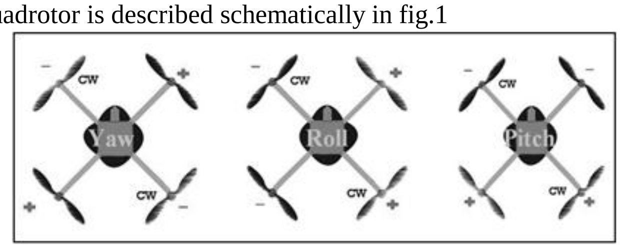

Fig. 1: Yaw Roll Pitch

Department of Computer engineering, Karadeniz Technical University, Trabzon, TURKEY

II. Manual Flight Control System

The quadcopter with manual flight control system work by receiving the control commands from RC transmitter as PWM pulse and then will convert from time (1000, 2000us) to suitable value range, in our case Throttle (0, 100), Pitch and Roll (-60, 60) and Yaw (-180,180) [3]. The flight controller compute the rotor's speed command depending on the actual angle of the drone was recived from MPU (Motion Processing Unite) and the desired angle was recived from RC transmitter using fuzzy rules or PID con-troller [2] as we show in fig .2, the Y, P, R values refer to the current quadcopter Yaw, Pitch, Roll angles. The rotors are abbreviated as FR, FL, BR, BL which refer "Front Right", "Front Left", "Back Right" and "Back Left" rotors respec-tively.

Manual flight controller uses stabilized mode for the flight, that means the angle of quadcopter equal to the angle of Sticks that set.

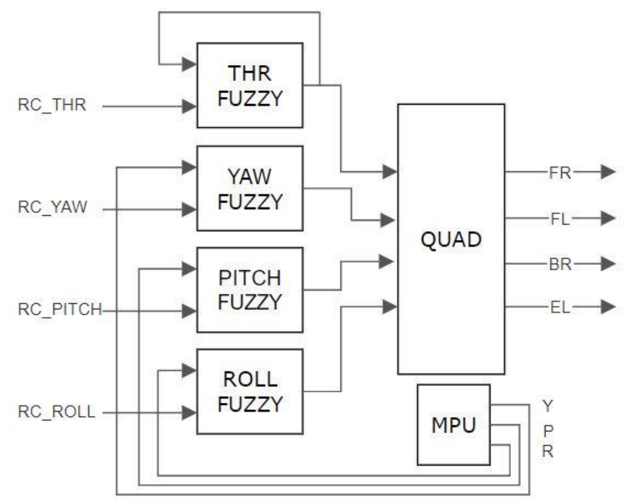

Fig. 2: Manual Flight Controller

III. Automatic Flight Control System

In this paper we assume that the manual flight controller is functioning. The goal is to generate the appropriate signals to enable the drone decide an optimum route automatically.

The quadcopter will takeoff first to achieve target height based on the readings from the Barometer sensor, then will go to a given destination with roll and pitch angles changing continuously based on the readings from GPS, after that the aircraft will land. In fig .3, T', P',and R'refer to the former values and the NT, NP, NR refer to the current values.

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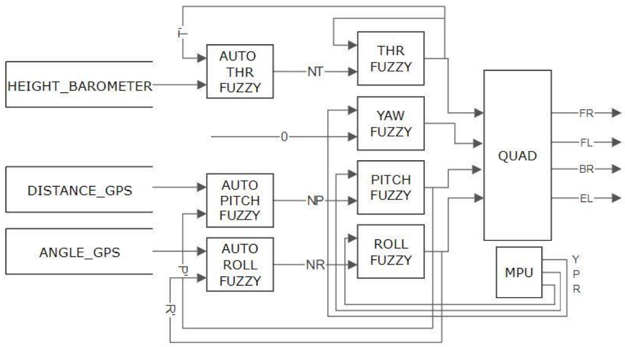

Fig. 3: Automatic Flight Controller

A. Fuzzy Takeoff Control Step

At this stage we define the fuzzy membership functions for the distance and throttle [8], where the throttle has value between 0 and 100 as shown in fig. 4, and the distance is equal to reference height minus the current position. The distance value ranges from negative to large positive as shown below in the fig. 5. The negative value is assigned when the quadcopter crosses the reference height [5].

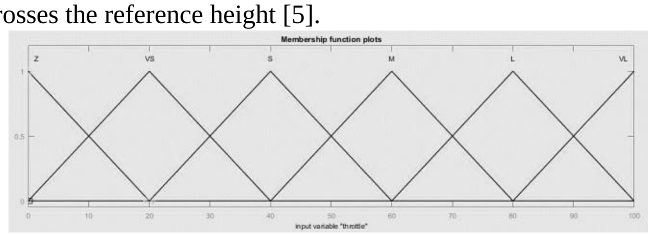

Fig. 4: Throttle

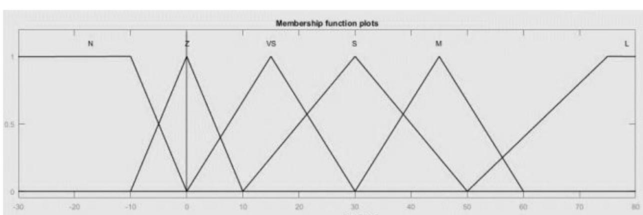

Fig. 5: Distance Membership Function

The output will be as new throttle based on the fuzzy rules that computed from the past throttle and distance.

The rules computed to make the new throttle has value related with every height, keep the current position when the distance become zero. Stay on when the distance is still greater than 0 and decrease when the distance become negative [5] as shown in the Table. 1. Membership functions are encoded as Z (Zero), VS (Very Small), S (Small), M (Medium), L (Large), VL (Very Large), N (Negative).

The plot of Nthrottle surface for the takeoff rules shown in fig. 6.

TABLE I
TAKEOFF RULES TABLE FOR NEW THROTTLE

THR *DIST*	**Z**	**VS**	**S**	**M**	**L**	**VL**
N	Z	Z	VS	S	M	L
Z	Z	VS	S	M	L	VL
VS	VS	S	M	L	VL	VL
S	VS	S	M	L	VL	VL
M	VS	M	M	VL	VL	VL
L	VS	M	L	VL	VL	VL

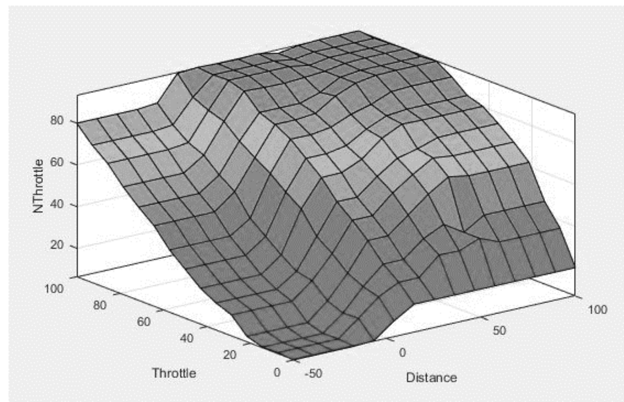

Fig. 6: Plot of Takeoff Rules

B. Fuzzy Landing Control Step

As takeoff phase we define the fuzzy membership functions for the distance and throttle, the throttle has same range and same membership functions but the distance value equals to now height sub the ground reference value and will not be have a negative value because the ground will be at distance value 0 as shown in fig. 7.

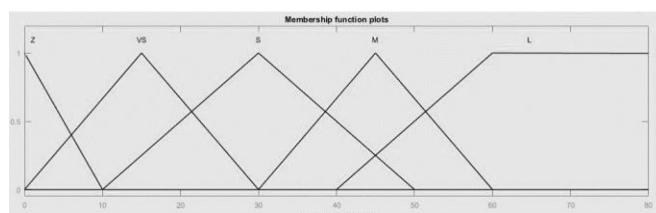

Fig. 7: Distance Membership Functions in Landing Phase

When we look to the table 2, we see that when the quadcopter is not close to the ground and at the same time the throttle is near to zero, the throttle will be increased. Fig. 8 shows the plot of Nthrottle surface for the landing rules.

TABLE II
LANDING RULES TABLE FOR NEW THROTTLE

THR DIST	**Z**	**VS**	**S**	**M**	**L**	**VL**
Z	Z	Z	Z	Z	VS	VS
VS	VS	Z	VS	VS	VS	S
S	VS	VS	VS	S	M	L
M	S	VS	VS	S	M	M
L	S	VS	VS	S	M	L

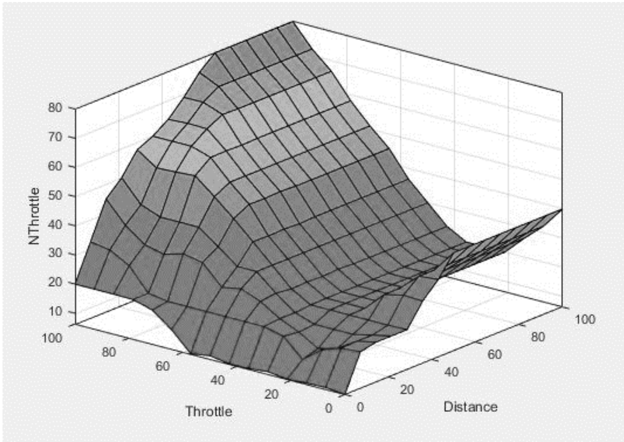

Fig. 8: Plot of landing Rules for current Throttle

C. Route Determination

Deciding a route between two spatial points, human mind intrinsically controls the aircraft as follows:

• To change the velocity, our mind checks the current speed and the distance simultaneously.

• To update the rotation angle our mind compares the angle between the quadcopter direction and the target position.

For that, the work is to make quadcopter a smart drone by adding the control rules based on the necessary parameter (**speed**, **distance**, **angle**, **direction**) [7].

D. Fuzzy Pitch Control

To create a fuzzy membership for pitch control the pitch value will be between -60 and +60. -60 pitch value mean negative very large speed NVL which makes the quadcopter go to backward direction. Zero value mean zero speed and +60 very high forward speed. The membership functions for pitch control is shown in the fig.9.

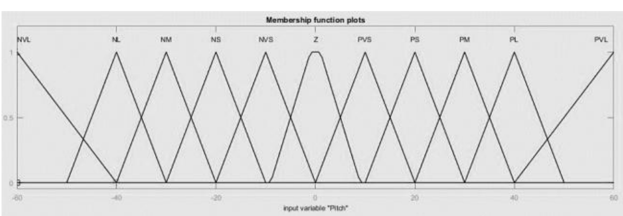

Fig. 9: Pitch membership function

Another parameter must used to compute the new pitch value is the distance between the current position and the target. The distance parameter is in range between negative large to positive large value and the quadcopter can move all directions [6] (please see fig. 10).

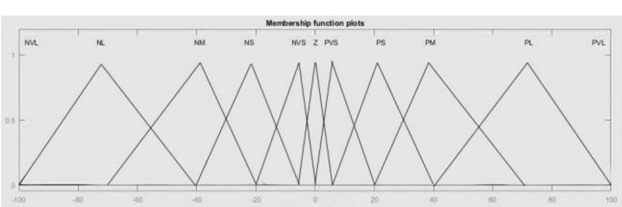

Fig. 10: Distance membership function

Pitch control system determines the distance sign by nearest zero angle to the quadcopter direction as shown in fig. 11. That means when the angle between the quadcopter direction and target position is in the range (0 to 90) or (0 to -90) the direction is forward otherwise backward direction [4].

At this way the quadcopter :

- Will not rotate to back if the target position is behind it, instead of that it will go backward direction.
- When across the target position will go back without turn (as Brakes).

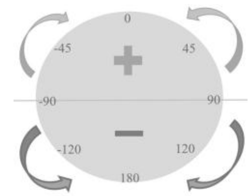

Fig. 11: Wanted dirction

The output will be a new pitch angle as output of the rules based on distance and past pitch angle as:

• The new pitch will increase when the distance is big and decrease when being small as shown in plot surface fig.12.

• Another think show in the rules table. 3 is when the quadcopter is going in a direction and the distance is zero the new pitch be a same speed but in the other way [9].

Where NVL (Negative Very Large), PVL (Positive Very Large).

TABLE III
PITCH RULES TABLE FOR NEW PITCH

PITCH / DIST	NVL	NL	NM	NS	NVS	Z	PVS	PS	PM	PL	PVL
NVL	NVL	NVL	NVL	NVL	NM	NM	NM	NM	NM	NM	NM
NL	NL	NL	NL	NL	NM	NM	NM	NL	NM	NM	NM
NM	NM	NM	NM	NM	NS	NS	NS	NL	NM	NM	NM
NS	NVS	NVS	NS	NS	NS	NS	NM	NM	NM	NL	NL
NVS	Z	NVS	NVS	NVS	NVS	NVS	NS	NM	NM	NL	NL
Z	PVL	PL	PM	PS	PVS	Z	NVS	NS	NM	NL	NVL
PVS	PL	PL	PM	PS	PVS	PVS	PVS	PVS	PVS	PVS	Z
PS	PL	PL	PL	PM	PM	PM	PS	PS	PS	PVS	VS
PM	PM	PM	PL	PL	PS	PS	PS	PM	PM	PM	PM
PL	PM	PM	PM	PL	PM	PM	PM	PL	PL	PL	PL
PVL	PM	PM	PM	PL	PM	PM	PM	PVL	PVL	PVL	PVL

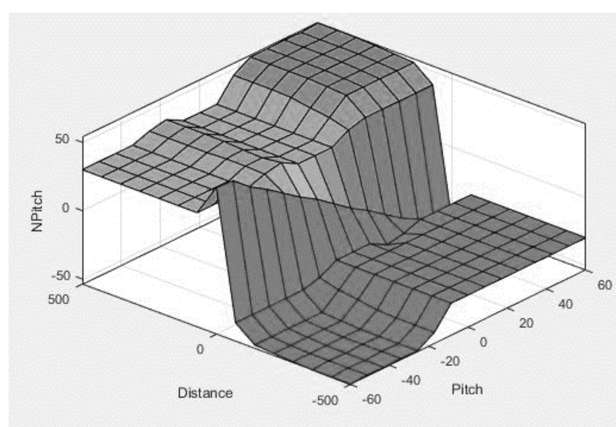

Fig. 12: Pitch plot surface

E. Fuzzy Roll Control Step

As pitch, the roll angle value will define between the -60 and +60 degree like fig. 9 but for roll, the second parameter is the angle between the quadcopter direction and 0 (forward state) and 180 (backward state) we can take another look to fig. 11 and see that the angle must be from -180 to 180 degree and the member function for it shown at fig.13.

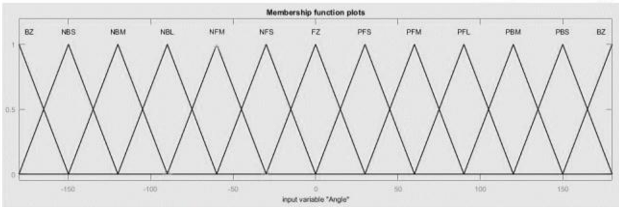

Fig. 13: Angle between quad direction and the target

The rules that applied from past roll and the angle their main goal is to make the angle zero, when the angle large the roll will be large too, the rules shown in the table. 4 below [6] where the negative value of roll means ccw rotate direction [9].

TABLE IV
ROLL RULES TABLE FOR NEW ROLL

	ANGLE / *ROOL*	BZ	NBS	NBM	NBL	NFM	NFS	FZ	PFS	PFM	PFL	PBM	PBS	BZ
	NEL	EL	VL	Z	NEL	EL	EL	EL	VL	Z	NEL	EL	EL	EL
CCW	***NVL***	VL	L	VS	NEL	EL	EL	VL	L	VS	NEL	EL	EL	VL
	NL	L	M	S	NEL	EL	EL	L	M	S	NEL	EL	EL	L
	NM	M	S	M	NEL	EL	VL	M	S	M	NEL	EL	VL	M
	NS	S	NVS	M	NEL	VL	L	S	NVS	M	NEL	VL	L	S
	NVS	VS	NVS	M	NEL	VL	M	VS	NVS	M	NEL	VL	M	VS
	Z	Z	NVS	L	NEL	L	VS	Z	NVS	L	NEL	L	VS	Z
CW	***VS***	NVS	NM	VL	NEL	M	VS	NVS	NM	VL	NEL	M	VS	NVS
	S	NS	NL	VL	NEL	M	VS	NS	NL	VL	NEL	M	VS	NS
	M	NM	NVL	EL	NEL	M	NS	NM	NVL	EL	NEL	M	NS	NM
	L	NL	NEL	EL	NEL	S	NM	NL	NEL	EL	NEL	S	NM	NL
	VL	NVL	NEL	EL	NEL	VS	NL	NVL	NEL	EL	NEL	VS	NL	NVL
	EL	NEL	NEL	EL	NEL	Z	NVL	NEL	NEL	EL	NEL	Z	NVL	NEL

IV. Conclusion

When we produce the control commands instead the transmitter we can convert every quadcopter to auto quadcopter (drone) whatever the internal system because we can convert the new (throttle, pitch, roll) values to range between 1000 to 2000 the same range as transmitter's commands, in the other hand as above we can build the complete system. In this paper, the fuzzy control system for quadcopter airplane is proposed by computing rules between the velocity and attitude, it has high performance and reaches to accurate results.

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