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Fuzzy Logic Controller for Cooperative Tasks in Quadrotor Unmanned Aerial Vehicles (QUAVs)

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ABSTRACT

Studies on unmanned aerial vehicles (UAVs) such as quadrotors have increased over the years. One focus of research is the cooperation among these quadrotors in order to perform cooperative tasks. This paper proposes a fuzzy logic controller for a cooperative task done by two quadrotors and will be tested through simulations. The task to be performed is balancing and landing a certain payload onto a target destination. The fuzzy logic controller outputs the appropriate motor speeds of the rotors based on the yaw, pitch and roll angle as well as the positions of the quadrotors and the payload. The results show that the quadrotor was successful in balancing and landing the payload. Multiple testing shows that the system is robust with minimal error and that the system can adapt to varying load sizes.

KEYWORDS: UAV; quadrotor; fuzzy logic; controller; cooperative tasks

1 INTRODUCTION

A growing interest in unmanned aerial vehicles have been seen throughout the years due military, commercial, or entertainment purposes. Recent advancements include fleet (Kushleyev, et al., 2012), aggressive flight (Mellinger & Kumar, 2011) and cooperative tasks (Mellinger, et al., 2010) (Lindsey, et al., 2011). Quadrotors operate on nonlinear dynamics and many controllers have been designed for the position and attitude control (Bouabdallah & Siegwart, 2007). However, these quadrotors are found to use PID controllers most of the time (Passino & Yurkovich, 1997). Given that, a proposal to an alternative solution is significant.

Fuzzy logic is a form of computational intelligence first introduced in the 1960s. It is unique in a sense that it has the ability to represent subjective and linguistic information in to mathematical models (Ramot, et al., 2003) while simultaneously handling numerical data (Dadios & Williams, 1996). In general, fuzzy logic is the generalization of crisp knowledge into a two-value logic (Ramot, et al., 2003). It is currently used in many different household systems and other control applications.

This paper present a fuzzy logic controller to be used in quadrotor-unmanned aerial vehicles (QUAVs). Controllers in quadrotors are usually made to perform the altitude and attitude control for the system as it performs certain tasks in the xyz-axis. In this paper, the fuzzy logic controller will be used to control two quadrotors in the xyz-axis tasked to move and object cooperatively.

2 QUADROTOR MOTION

The quadrotor is a 4-rotor aerial vehicle that works by varying the rotation speed in each (Raza & Gueaieb, 2010). Adjacent motors rotate in the opposite direction to counteract rotational forces that are generated by the motors. There are three types of 4 basic types of quadrotor motion as described in the Figure 1. If all motor speeds are increased equally to a value greater than the equilibrium speed (or hovering speed), an altitude motion is observed as seen in Figure 1a. Decreasing and increasing the left and right motor speed will produce the roll angle of the quadrotor as seen in Figure 1b. Alternatively, in Figure 1c, performing the same action on the front and back motor will produce the pitch angle. The last type of quadrotor motion is achieved by increasing and decreasing the motor speed of the clockwise and counter-clockwise rotating pair of the quadrotor. This is the yaw motion as seen in Figure 1d.

The four basic types of motion are to be observed in the control of altitude and attitude of the quadrotor.

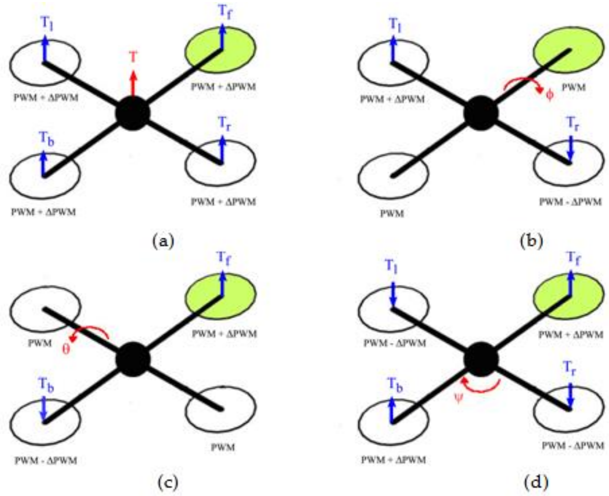

Figure 1. Basic Quadrotor Motion (Raza & Gueaieb, 2010)

3 SYSTEM OPERATION

The cooperative task to be tested and simulated in this paper is movement and landing of a certain payload from point to another. The starting position of the quadrotors and the payloads would be on the ground level or the xy-plane in the three-axis coordinate system. The initial task is to lift the payload to a certain height. After which, movement to the desired position and landing of the payload.

Figure 2 shows the system block diagram for the proposed fuzzy logic controller for the cooperating quadrotors. The fuzzy logic controller will use the current motor speed, current and desired position as well as the roll, pitch and yaw angles of the quadrotor as the fuzzy inputs. The output of the fuzzy logic controller would be the motor speeds for the two quadrotors used. These outputs will be used as feedback to serve as the new fuzzy inputs.

Since the system will be tested in simulations, additional inputs for the controller will be added such as the payload weight and target payload position. The quadrotors itself will be considered weightless and the load weight would depend on the payload weight distribution between the quadrotors over a fixed length of wire as seen in Figure 3. When the quadrotors remain at the same altitude and equidistant to the payload, weight distribution would remain equal.

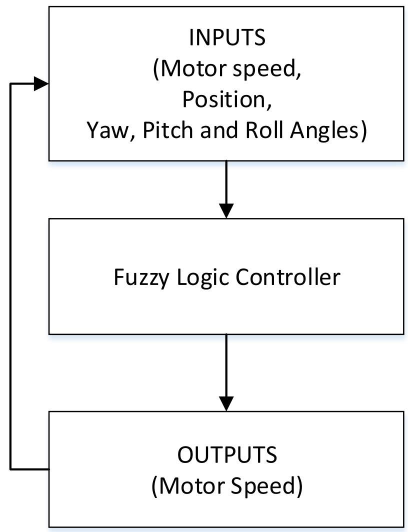

Figure 2. System Block Diagram

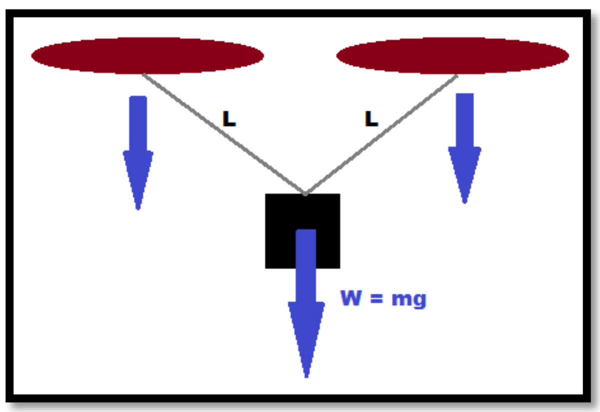

Figure 3. Weight distribution

Other assumptions to be made for the testing of the system would be the required total motor speed in order to lift a certain weight. The motor speed to be used in the testing would be in terms of duty cycle from 0 – 100. The total assumed motor speed would just be the arithmetic sum of the individual motor and this will be correlated to the total weight capacity of each individual quadrotor as seen in Table 1.

The initial testing of the system would include these parameters:
1. Initial Payload Position: (1, 1, 0)
2. Initial Quadrotor Position: (1, 0, 0) and (1, 2, 0)
3. Total Payload Weight: 4 kg
4. Target payload destination: (5, 5, 0)

TABLE 1. MOTOR SPEED TO WEIGHT CAPACITY

TOTAL MOTOR SPEED	WEIGHT CAPACITY
0	0kg
100	1kg
200	2kg
300	3kg
400	4kg

4 FUZZY LOGIC CONTROLLER

4.1 Fuzzy Control Block Diagram

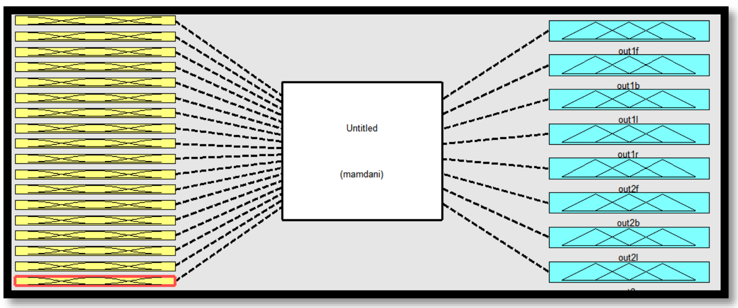

Figure 4. Fuzzy Logic Block Diagram

Figure 4 shows the block diagram of the fuzzy logic controller to be used. It will be made to receive 16 inputs corresponding to the speed of the 4 motors, the yaw, roll and pitch angles, the distance to the destination and the angle of the destination with respect to the position of the quadrotor and the x-axis. The distance and the angle from the destination will be computed separately before being fed to the fuzzy logic controller.

The fuzzy logic controller will employ a Mamdani-Type Fuzzy Inference which is the most commonly seen fuzzy method employed. This type of fuzzy inference method expected the output membership to be fuzzy sets. The fuzzy output then undergoes defuzzification to obtain the crisp outputs.

4.2 Fuzzy Membership Functions

Figure 5 shows the fuzzy membership function for each individual motor speed of the quadrotor. Since the payload weight for each quadrotor is to be maintained a 2kg each. The fuzzy membership “steady” would be kept at about 50 duty cycle each which would correspond to the established weight capacity.

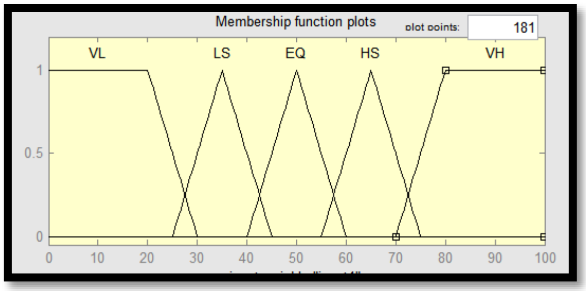

Figure 5. Motor speed membership function.

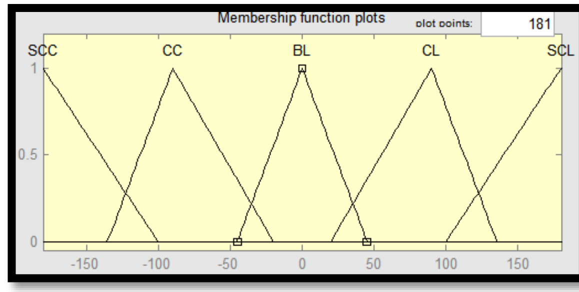

Figure 6. Yaw angle membership function

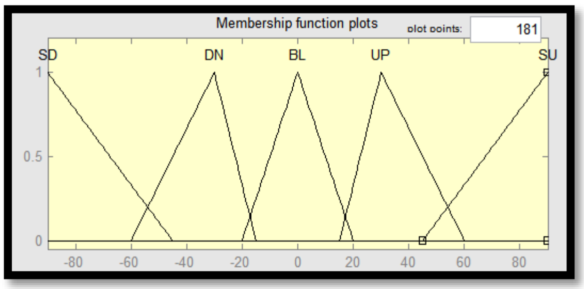

Figure 7. Roll angle Membership function

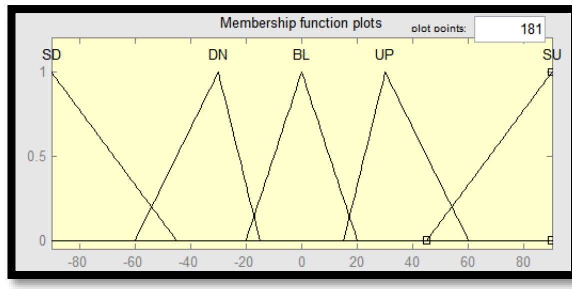

Figure 8. Pitch angle Membership function

Figures 6, 7, and 8 shows the yaw, roll, and pitch angle membership functions. These angles describe the current motion of the quadrotors. All the membership functions are subdivided nto 5 categories which will serve as the fuzzy inputs. The yaw angle functions are limited to -180 to 180 degrees since any further increase would allow it to be expressed in a smaller angle. The roll and pitch angle membership functions are similar since roll and pitch are essentially the same but on different axes of movement. Measurements in these angles would be limited to -90 to 90 degrees. This is because of the fact that if we increase the roll and pitch angle to a value greater than 90 degrees, it would mean that the quadrotor is angle upside down.

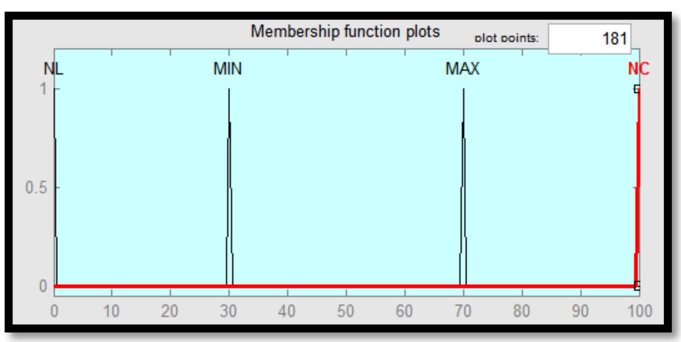

Figure 9. Fuzzy Output Membership Functions

Figure 9 shows the fuzzy output membership function to be used by the fuzzy logic controller. The output will have four possible outcomes that will determine the PWM signal in duty cycle to be fed to the motor. All 8 motors will be generated an output. These will then be fed back to the input to serve as feedback and the next instance input.

A summary of the membership functions is seen below.

For the motors:

- VL = very low speed
- LS = low speed
- EQ = equilibrium speed
- HS = high speed
- VH = very high speed

For the yaw angle:

- SCC = severe counter clockwise
- CC = counter clockwise
- BL = balanced
- CL = clockwise
- SCL = severe clockwise

For the pitch and roll angle:

- SD = severe down
- DN = down
- BL = balanced
- UP = up
- SU = severe up

For the distance:

- NR = near
- MD= medium
- FR = far

4.3 Fuzzy Rules

The fuzzy logic controller will have a set of rules to govern its response with respect to the fuzzy inputs. An example of the set fuzzy rules are

IF all motors = VL and all angles = BL and distance = FR
THEN
Motor1_Front = MAX
Motor1_Back= MAX
Motor1_Left = MAX
Motor1_Right = MAX
Motor2_Front = MAX
Motor2_Back = MAX
Motor2_Left = MAX
Motor2_Right = MAX

This action generates thrust upwards to provide lift for the quadrotors and the payload. Since there are a lot of inputs, a lot of rules are also to be generated. Figure 10 below shows some of the fuzzy rules generated in the MATLAB fuzzy toolbox.

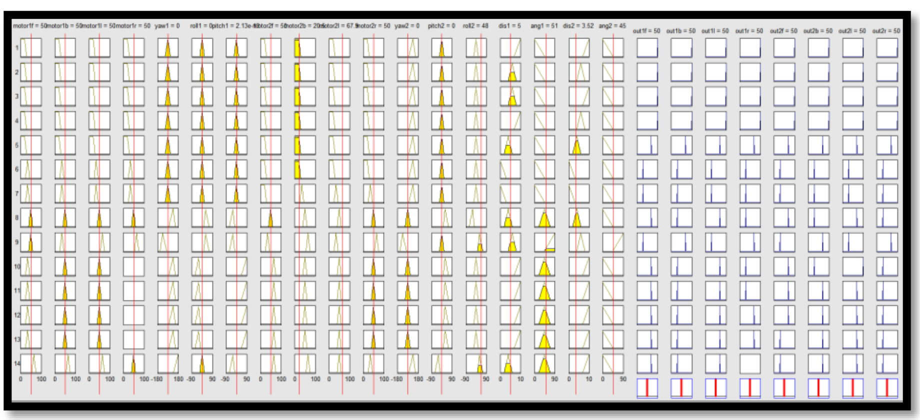

Figure 10. Fuzzy Rules

5 DATA AND RESULTS

The testing was conducted using simulations only. The test done was to move a 4kg object between two points using the cooperative quadrotors. The initial point for the payload was (1,1, 0) and the final destination was (5, 5, 5). The initial quadrotor positions assigned were (1, 0, 0) and (1, 2, 0). The fuzzy logic controller was started upon minimum lift from the quadrotors.

Figure 11 shows the results of the simulation test conducted. This plots the path taken by the payload. The blue path represents the ideal path to be taken by the payload while the red path is the actual path taken. The actual path taken deviates a bit from the ideal path. Calculating the average deviation from the ideal path, we get an average deviation of 0.124 units from the ideal path. This deviation is not too large to be of significance in the final output of the fuzzy logic controller. This shows that the fuzzy logic controller is effective and only needs further tweaking in the fuzzy membership functions in order to further reduce deviations in the output.

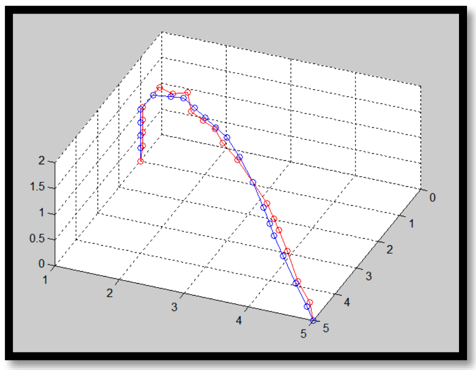

Figure 11. Test Reuslts

Table 2 shows the table of values generated by the trajectory of the quadrotor. These are expressed in xyz-coordinate positions and takes measurements over the course of the simulation. Most deviations occurred in the x-value and some in the y-value. The z-value was kept to a height of 2 as the maximum height of the payload.

TABLE 2. RESULTS OF SIMULATIONS

X-value	Y-value	Z-value	X-value	Y-value	Z-value
1	1	0	2.8	2.75	2
0.9	1	0.25	3.2	3	2
0.9	1	0.5	3.4	3.3	1.85
0.9	1	0.75	3.6	3.6	1.6
0.9	1	1	3.7	3.85	1.3
1	1.2928	1.5	3.8	4	1.1
1.607	1.707	1.8	3.9	4.1	0.95
1.8	2	2	4.1	4.3	0.7
2.4	2.25	2	4.5	4.6	0.4
2.6	2.5	2	4.7	4.85	0.15
			5	5	0

6 CONCLUSION

In conclusion, this paper presented a fuzzy controller for quadrotors performing cooperative tasks. The fuzzy logic controller receives input from multiple factors such as the current motor speed, yaw, pitch, and roll angle, distance from the destination, as well as the angle to the destination. This then outputs duty cycle motor speeds for both quadrotors in order to determine the motion for each quadrotor.

The results show that the fuzzy logic controller successfully delivers the payload to the target destination. A small deviation in the location, about 0.124 units away from the ideal path, is seen, however, this will not contribute too much significance in the output and is in and acceptable range.

For future research, the fuzzy logic controller may include the kinematics of the quadrotor and apply it to multiple quadrotors. Also, different cooperative tasks may be simulated.

REFERENCES

Bouabdallah, S., & Siegwart, R. (2007). Design and Control of a Miniature Quadrotor. In *Advances in Unmanned Aerial Vehicles* (pp. 171-210). Springer.

Dadios, E. P., & Williams, D. J. (1996). Multiple Fuzzy Logic Systems: A controller for the Flexible Pole-Cart Balancing Problem. *IEEE International Conference on Robotics and Automations.* Minneapolis, MI.

Kushleyev, A., Mellinger, D., Powers, C., & Kumar, V. (2012). Towards a swarm of agile micro quadrotors. *Proceedings of Robotics: Science and Systems, RSS.*

Lindsey, Q., Mellinger, D., & Kumar, V. (2011). Construction of Cubic Structures with Quadrotor Teams. *Proceedings of Robotics: Science and Systems (RSS).* Los Angeles, CA, USA.

Mellinger, D., & Kumar, V. (2011). Minimum Snap Trajectory Generation and Control for Quadrotors. *2011 IEEE International Conference on Robotics and Automation.* Shanghai, China.

Mellinger, D., Shomin, M., Michael, N., & Kumar, V. (2010). Cooperative Grasping and Transport using Multiple Quarotors. *Proceedings of the International Symposium on Distributed Autonomous Robotic Systems.*

Passino, K. M., & Yurkovich, S. (1997). *Fuzzy Control.* Addison Wesley Publishing Company.

Ramot, D., Friedman, M., Langholz, G., & Kandel, A. (August 2003). Complex Fuzzy Logic. *IEEE Trans. Fuzzy Syst. , Vol. 11*(No. 4), 450-461.

Raza, S. A., & Gueaieb, W. (2010). Intelligent Flight Control of an Autonomous Quadrotor. In *Motion Control* (pp. 245-264).