THE PHILIPPINE-AMERICAN Academy of Science & Engineering

Fuzzy Logic Controller for Alignment Formation in Quadrotor Unmanned Aerial Vehicles (QUAVs)

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ABSTRACT

Swarming behavior implemented artificially is an emerging technology that researchers are trying to improve and develop. What makes them so interesting is that they exhibit formations that prove to be effective in performing a certain task/job. This can be seen in certain applications such as in a search and rescue robot swarm. In this paper, control for a single formation in a two-member Quadrotor unmanned aerial vehicle (QUAV) swarm is tackled. Specifically, the formation being focused on is the alignment of the two in a vertical fashion. However, it is a problem to maintain and stabilize their positions. For this paper, a Fuzzy Logic Controller is investigated to address this use. The controller would have the coordinates, roll, pitch, and yaw angles as inputs. The outputs of the controller would be the motor voltages corresponding to each motor speed. The results showed that the system was able to keep the angle and coordinates differences to a minimum level. As such, the two-member quadrotor swarm was able to exhibit the desired vertical alignment formation. The Fuzzy Logic Controller implementation in this system proved to be robust and effective.

KEYWORDS: QUAV; swarm technology; fuzzy logic; alignment control

1 INTRODUCTION

In the field of engineering research, quadrotor unmanned aerial vehicles (QUAVs) attract a lot of attention. They are often used as platforms in implementing various research purposes. This is so because of the wide range of applications from military operational employment down to civilian usage domains (Valavanis, 2007). Due to the increasing popularity of QUAVs, there is a need for research on performance improvements. They can also be used in multiple numbers; as in a swarm. Swarms behave in a way that they aggregate, or loosely speaking, follow a certain pattern/formation. This is a key aspect in any robotic system (Bandala, Vicerra, & Dadios, 2004).

In this paper, the formation taken into consideration would be the vertical alignment formation of a two-member quadrotor swarm. An alignment formation is desired when considering certain specific applications. This kind of formation could be an ideal test bed for a QUAV carrier station function system in which a carrier QUAV would be hosting another smaller QUAV on its top. However, design considerations must be made in dealing with QUAV operation and stabilization. Different methods have been implemented by researchers. Some of these include works by Phillips, et. al and Sugeno which made use of fuzzy logic (Phillips & Karr, 1996) (Sugeno, 1995), and also by San Martin, et al who made use of neural networks for UAV modelling (San Martin, Barrientes, Gutierrez, & del Cerro, 2006). Other modelling and stabilization researches have been made by several researchers (Saripalli, Montgomery, & Sukhtatme, 2003) (Sanchez & Velez, 2007) (Madani & Benallegue, 2006) (Pounds, Mahony, & Corke, 2007) (Labadille, 2007). For this paper, a Fuzzy Logic approach was used.

2 FUZZY LOGIC

Fuzzy logic extends the idea of digital logic. Digital logic focuses only on two extreme values whereas Fuzzy logic incorporates intermediate values. Basically, it is an approach in computational intelligence that aims to provide a system for emulating human decision-making. It is unique in the sense that it is able to mathematically represent subjective knowledge (Ramot, Friedman, Langholz, & Kandel, August 2003).

Fuzzy logic takes in crisp input values. These readings are crisp in the sense that they represent actual values of input parameters. They are then fuzzified using a certain rule-base. These fuzzy values are then in the range from 0 to 1. The fuzzy values coming from the rules based are then defuzzified back to crisp values as output/s of the fuzzy logic system.

The rule base would depend upon the fuzzy inputs based from the user-defined membership functions. These functions are shapes placed along the parameter x-axis that correspond to the degrees of extremity. For example, the membership functions may have 3 groups corresponding to levels of temperature: cold, lukewarm, and hot. The fuzzy logic approach manifests its peculiarity due to the intersection of these membership functions. Like in the previous example, an intersection of lukewarm and hot may yield a fuzzy output corresponding to warm.

3 METHODOLOGY

The paper would be presenting a Fuzzy Logic Controller for the stabilization of an Alignment Formation of a two-member Quadrotor Unmanned Aerial Vehicle swarm. Each QUAV would be equipped with this controller. As such, the discussions from here on would only consider one quadrotor. The Mamdani-type of Fuzzy Logic Controller would be utilized in this paper. The Fuzzy Logic Controller would compose of a two-stage cascaded fuzzy system blocks. The first block would have the 3-dimensional coordinates of the QUAV as the inputs. The output/s is/are considered as the motor speed weighting variable/s. This would then serve as input/s to the second block. The second block, aside from the output of the first block, would have three inputs corresponding to the UAV angles: roll, pitch, and yaw angles.

The roll angle corresponds to the sideways tilt of the UAV. The pitch angle refers to the "see-saw" motion. Lastly, the yaw angle refers to the spin/rotation of the UAV with respect to its vertical axis. These three angles determine the relative position of the QUAV with respect to the reference upright position.

Certain assumptions are made in the operation of the Fuzzy Logic Controller. First, it is assumed that the relative positions of each QUAV are known. Localization methods are not discussed in this paper. Also, it is assumed that the roll and pitch angles are kept within a certain domain such that the QUAV would not overturn. The roll and pitch angles would only be from -90 to 90 degrees while the yaw angle would only be from -180 to 180 degrees.

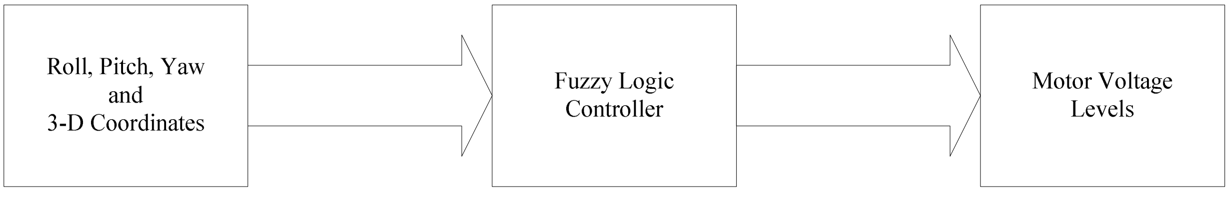

Figure 1: IPO Model of the Fuzzy Logic Controller

From Figure 1, the Fuzzy Logic Controller would have the roll, pitch, and yaw angles as well as the 3-D coordinates as the crisp inputs. The Fuzzy Logic Controller would be the one responsible for translating those values to the corresponding motor voltage levels of the four motors.

3.1 3-D Coordinate Inputs

The coordinates of the QUAV would determine the speed of the motors; therefore the proper voltage levels must be seen at the output of the Fuzzy Logic Controller. The domain space would be constrained from -50 to 50 units away in all three axes. The farther away the QUAV is from the origin, the faster is the speed of the motor. The more the QUAV is skewed to the –y-axis, the faster is the speed of the left side motors, while if skewed to the +y-axis, the faster the speed of the right side motors. The more the QUAV is towards the +x-axis, the faster the speed of the front motors, while if in the –x-axis, the faster the speed of the rear motors. The altitude control would be done by making the speed of all the four motors equal at all times. If the motor speed is made higher than the reference voltage level, the QUAV would ascend. On the other hand, if it is made less than the reference voltage level, the QUAV would descend.

There would be three membership functions for each axis corresponding to far, near, and centered. The design of the controller would be such that the output of the controller corresponding to the four motor voltages levels would already by the real/crisp values. This is done such that there would no longer be the need to defuzzify the outputs values.

The 3-D coordinates would be corresponding to the (x, y, z) coordinates set in a specified domain space. The crisp outputs would be three distinct levels corresponding to the speed of the motors: 1V, 5V, and 9V. The reference voltage level setting would be the intermediate value, 5V. The larger the output voltage, the faster is the speed of the motor. It is assumed that when the voltage outputs of the motors are at 5V (i.e. the reference voltage level), the QUAV has a resultant upward force just enough to compensate for the weight of the quadrotor. Any voltage setting higher than 5V would make the QUAV go up. On the other hand, any voltage less than 5V would make the QUAV go down.

3.2 Orientation Angle Inputs

The angles of the QUAV would also be a factor in determining the speed of the motors (i.e. the voltage levels). Similar to the first block, each input (i.e. angle) would also have three membership functions corresponding to angle values: negative, neutral, and positive. As with the first block, the output would also be crisp motor voltage levels corresponding to the speed of the motors: 1V, 5V, and 9V.

Table 1: Fuzzy Rule Base of the Second Block

roll	pitch	yaw	mot1	mot2	mot3	mot4
-	-	X	1	5	5	9
-	X	X	1	5	1	5
-	+	X	5	1	9	5
X	-	X	1	1	5	5
X	X	-	1	5	5	1
X	X	+	5	1	1	5
X	+	X	5	5	1	1
+	-	X	5	9	1	5
+	X	X	5	1	5	1
+	+	X	9	5	5	1

The proposed rule base has ten fuzzy rules. Table 1 shows the rule base of the second block Fuzzy Logic Controller. The "–" values there denote negative angle values while the "+" values mean positive angle values. The "X" values there mean don't care.

4 DATA AND RESULTS

The testing was done such that there are different cases of inputs. The outputs produced are simply based from the rule base that was proposed.

Table 2: Sample Inputs and Outputs of the Controller

roll	pitch	yaw	mot1	mot2	mot3	mot3
-90	-90	-180	1	3	3	5
-90	-90	0	1	3	3	7
-90	-90	180	3	3	3	7
-90	0	-180	1	5	3	3
-90	0	0	1	5	1	5
-90	0	180	3	3	1	5
-90	90	-180	3	3	5	3
-90	90	0	3	3	5	3
-90	90	180	3	3	5	3
0	-90	-180	1	3	5	3
0	-90	0	1	1	5	5
0	-90	180	3	1	3	5
0	0	-180	1	5	5	1
0	0	0	5	5	5	5
0	0	180	5	1	1	5
0	90	-180	3	5	3	1
0	90	0	5	5	1	1
0	90	180	5	3	1	3
90	-90	-180	3	5	3	3
90	-90	0	3	5	3	3
90	-90	180	3	5	3	3
90	0	-180	3	3	5	1
90	0	0	5	1	5	1
90	0	180	5	1	3	3
90	90	-180	5	3	3	1
90	90	0	7	3	3	1
90	90	180	7	3	3	3

Table 2 shows a set of inputs applied to the controller. The outputs shown are the corresponding crisp voltage levels for each for each of the four motors. Notice that the discrete voltage levels proposed are 1V, 5V, and 9V. However, intermediate voltage levels can be seen. This is due to the fact the controller compensates for cases in which two or more rules are satisfied.

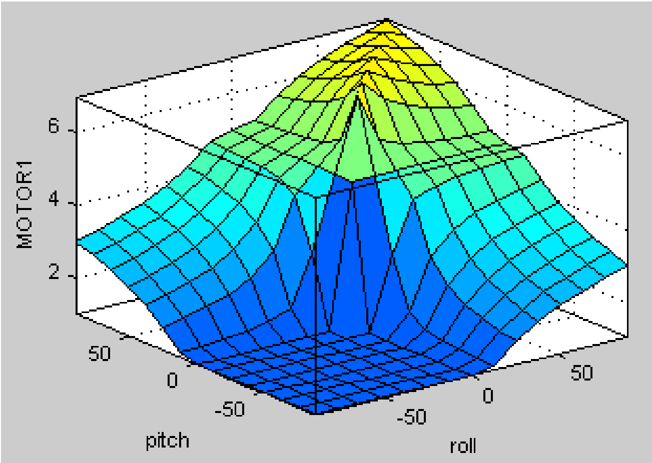

Figure 2: Motor 1 Pitch/Roll Voltage Response

Figure 2 shows the output of Motor 1 given a parameter sweep of the pitch and roll angles. The output skews to the 1st quadrant since the instance there would have the QUAV tilted in that direction. As such, the voltage level there would mean a compensation force to keep the QUAV in an upright position. The response of Motor 4 yielded a similar response.

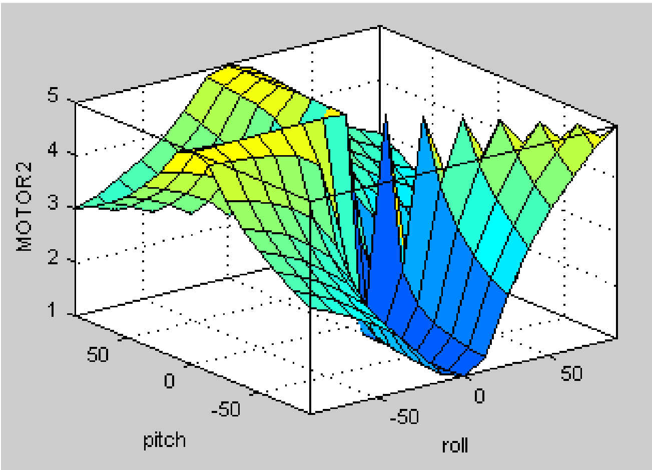

Figure 3: Motor 2 Pitch/Roll Voltage Response

Figure 3 shows the output of Motor 2 given a parameter sweep of the pitch and roll angles. The output skews to the 4th quadrant since the instance there would have the QUAV tilted in that direction. There should be compensation force to keep the QUAV in an upright position. There is an irregularity in the 2nd quadrant due to the yaw angle compensation to maintain the proper spin of the QUAV. The response of Motor 3 also yielded a similar response.

5 CONCLUSION

The Fuzzy Logic Controller was able to show crisp outputs for the four motors given a set of input orientation angles and coordinates. The controller was able to compromise between fuzzy rules such that the discrete crisp outputs set by the user were adjusted. A properly developed test bed may be used to further investigate the performance of the Fuzzy Logic Controller.

An improvement could be done on the proper integration of the two stages of the Fuzzy Logic Controller. Also, the fuzzy rule base could have been more complete when considering other cases of the inputs. More fuzzy rules set would mean more accurate crisp outputs values sent out by the Fuzzy Logic Controller. Another recommendation would be to integrate with the system an actual localization technique to realistically map the coordinates of each quadrotor.

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