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Fuzzy Logic Based Path Planning for Quadrotor

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ABSTRACT

Many researchers are now interested in quadrotors. It can be used in many applications such as military, search and rescue, surveillance, exploration and entertainment. The main problem of controlling the quadrotor is how it will go to a certain point without hitting an obstacle. The quadrotor should have a reliable controller that will manage the path planning to minimize the time of travel and at the same time avoiding an obstacle. This paper will use Fuzzy Logic approach for path planning of the quadrotor. Fuzzy Logic is a branch of artificial intelligence that deals with reasoning algorithms used to match human thinking and decision making in machines. This will serve as the brain of quadrotor to know the best path to travel in order to reach the destination point safely.

KEYWORDS: Fuzzy Logic, Quadrotor, Unmanned Aerial Vehicle (UAV), Obstacle Avoidance, Path Planning.

1 INTRODUCTION

Path planning of quadrotor is essential for accurate movement from one place to another. Using a quadrotor for exploration of unknown environments can be dangerous because there is a chance of hitting an unknown object. This can cause fatal damage to quadrotor and as a result, it cannot continue its mission. The energy used by a quadrotor can be wasted when there is no planned path of travel. As a proposed solution, Fuzzy Logic based path planning is introduced. The fuzzy logic controller will simplify the control mechanism of the quadrotor for efficient travel and collision free.

2 FUZZY LOGIC

Fuzzy logic was introduced by Lotfi A. Zadeh in 1965 (Zadeh, 1965). It is a computational model that is based on how humans think. The common idea about fuzzy logic is that it takes the inputs from the sensors which is a crisp value and transforms it into membership values ranging from 0 to 1. Fuzzy logic looks at the world in imprecise terms just similar to our brain when it takes information. The information is described in terms of fuzzy sets and made precisely through the definition of an associated membership function (Dadios et al.,1996). Fuzzy logic systems can process vague data and produce acceptable outputs without using very complex mathematical computations to control the robot movement (Dadios et al.,2012). Fuzzy logic requires knowledge in order to reason which is provided by a person who knows the process or machine (the expert). One of the most important components of fuzzy logic is membership function. Membership functions group input data into sets, such as temperatures that are too cold, motor speeds that are acceptable, distances that are too far, etc. The fuzzy controller assigns the input data a grade between 0 and 1 based on how well it fits into each membership function. The simplicity of fuzzy rule-based systems, ability to perform a wide variety tasks without complex computations and measurements make it widely popular among the scientists and researchers (Hong et al.,2012). Figure 1 shows the typical fuzzy logic system.

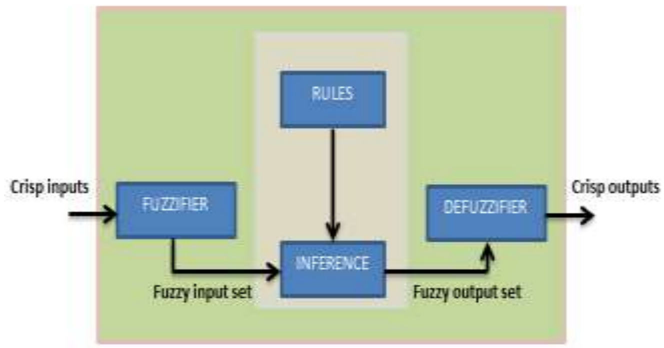

Figure 1: Fuzzy Logic System

The crisp inputs are the exact numeric values that are entered into the fuzzy logic system (Dadios et al., 2000). One of the most important components of every fuzzy system is the fuzzification (Zimmermann, 2001). Fuzzification refers to the process of converting crisp values into grades of membership using linguistic terms or labels of fuzzy sets (Sangyam et al.,2010). Many types of curves can be used, but triangular or trapezoidal shaped membership functions are the most common because they are easier to represent in embedded controllers (Simoes). Fuzzy rule base is the main part of fuzzy logic and composed of if-then rule. Inference engine will apply fuzzy rule base to output from fuzzification then it will provide an output and pass this output to defuzzification (Sangyam et al.,2010). The defuzzification process examines all of the rule outcomes after they have been logically added and then calculates a crisp value that will be the final output of the fuzzy controller.

3 QUADROTOR

Quadrotor became popular nowadays because of its many applications in different fields. It is a type of unmanned aerial vehicle (UAV) that is propelled by four motors. Two pairs of motors are rotating in a clockwise direction and counter-clockwise direction (Abeywardena et al.,2009). Control of lift and torque is done by varying the revolution per minute (rpm) of its four motors (Khan, 2014). Quadrotors has six degrees of freedom (DOF) so it can move in linear and angular direction (Ilhan & Karakose, 2013). When all rotors are rotating at same speed and the trust created exceeds its weight, it pushes the quadrotor to hover. If the front and back rotors are varied at same magnitude, forward and backward movement can be achieved. Left and right movement can be done by varying the speed of left and right rotors. Figure 2 shows the image of a real quadrotor.

Figure 2: Quadrotor

4 FUZZY LOGIC FOR PATH PLANNING

In order to apply fuzzy logic for path planning, it is assumed that the obstacles are detected by the ultra-sonic sensors that are mounted on quadrotors body. The sensors are assumed to detect a maximum distance of 4.5 meters. This sensors will output values and used it as the input of fuzzy logic controller (FLC).

4.1 Membership Function

This paper used trapezoidal and triangular membership function for simplicity. The FLC has two inputs such as distance and obstacle angle with respect to quadrotors direction of movement. The FLC has four outputs, these are motors rotational speed measured in revolution per minute (rpm). Positive angle denotes obstacle is in right side and negative angle denotes obstacle is in left side. Motor 1 is assigned as front motor of the quadrotor. Motor 2 & 4 are assigned as left motor and right motor respectively. Motor 3 is assigned as back motor of the quadrotor. Figure 3 shows the proposed orientation of the quadrotor while moving to a target.

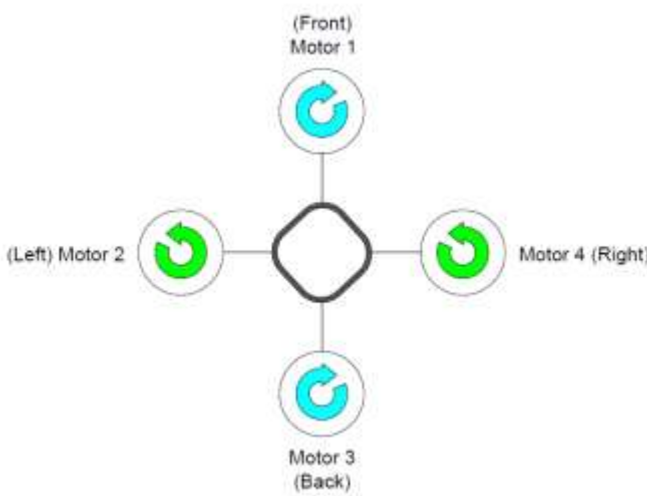

Figure 3: Quadrotor orientation

The fuzzy set distance is labeled { *Danger*, *Warning*, *Safe* }, obstacle angle is labeled { *(L)Large*, *(L)Medium*, *(L)Small*, *Zero*, *(R)Small*, *(R)Medium*, *(R)Large* } L means left and R means right, rotational speed of motor 1, motor 2, motor 3 and motor 4 are labeled { *VLS*, *SS*, *NS*, *FS*, *TS* }, which stands for *Very Low Speed, Slow Speed, Normal Speed, Fast Speed, and Top Speed* respectively. Figure 4 shows the membership function for input variable distance. Figure 5 shows the membership function for input variable obstacle angle. Figure 6,7,8, and 9 shows the output variable rotational speed of each motors.

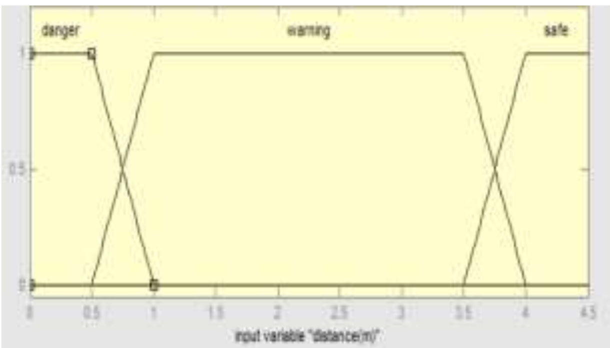

Figure 4: Membership function for distance (m)

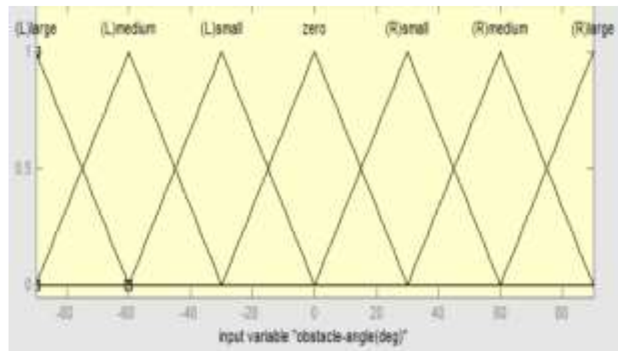

Figure 5: Membership function for obstacle angle (deg)

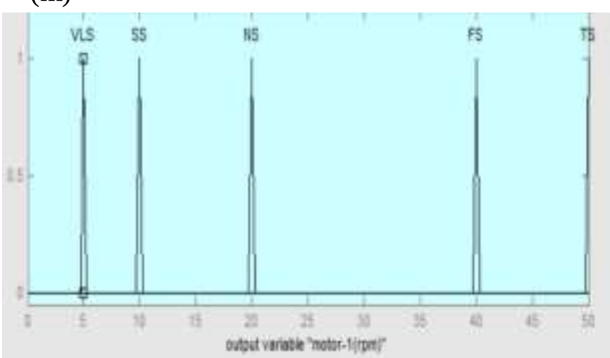

Figure 6: Membership function for motor 1 (rpm)

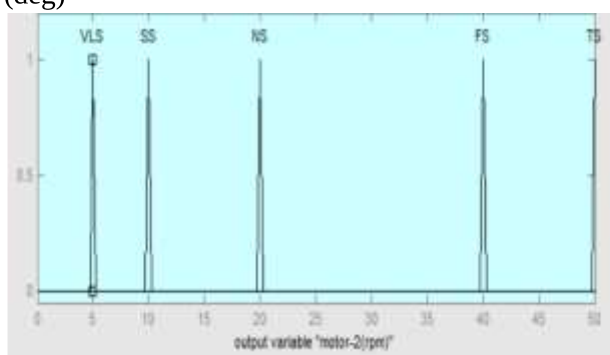

Figure 7: Membership function for motor 2 (rpm)

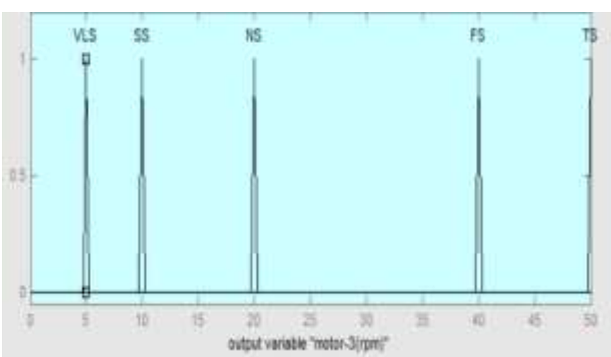

Figure 8: Membership function for motor 3 (rpm)

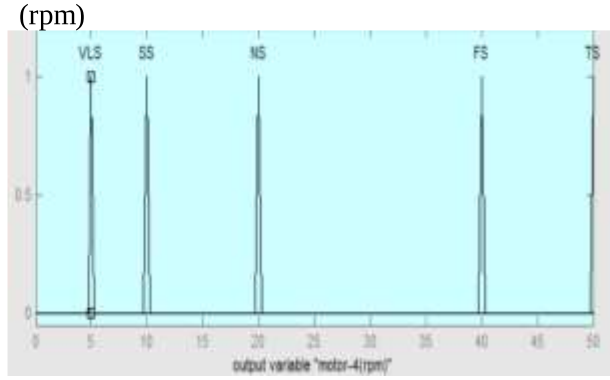

Figure 9: Membership function for motor 4 (rpm)

4.2 Fuzzy Associative Memory Matrix(FAMM)

Table 1 shows the Fuzzy Associative Memory Matrix (FAMM) of the system. FAMM was used for storing and representing fuzzy rules. The number of inputs or antecedents to the fuzzy rules determines the dimensions of the matrix.

Table 1 Fuzzy Associative Memory Matrix (FAMM)
For Rotational Speed of Each Motor

	danger	warning	safe
(L)large	VLS-M1,SS-M2,NS-M3,SS-M4	SS-M1,NS-M2,TS-M3,NS-M4	SS-M1,NS-M2,TS-M3,NS-M4
(L)medium	NS-M1,FS-M2,NS-M3,SS-M4	VLS-M1,SS-M2,NS-M3,SS-M4	SS-M1,NS-M2,TS-M3,NS-M4
(L)small	SS-M1,NS-M2,SS-M3,VLS-M4	VLS-M1,SS-M2,NS-M3,SS-M4	SS-M1,NS-M2,TS-M3,NS-M4
zero	NS-M1,NS-M2,NS-M3,NS-M4	VLS-M1,SS-M2,NS-M3,SS-M4	SS-M1,NS-M2,TS-M3,NS-M4
(R)small	SS-M1,NS-M2,SS-M3,VLS-M4	VLS-M1,SS-M2,NS-M3,SS-M4	SS-M1,NS-M2,TS-M3,NS-M4
(R)mediun	NS-M1,FS-M2,NS-M3,SS-M4	VLS-M1,SS-M2,NS-M3,SS-M4	SS-M1,NS-M2,TS-M3,NS-M4
(R)large	VLS-M1,SS-M2,NS-M3,SS-M4	SS-M1,NS-M2,TS-M3,NS-M4	SS-M1,NS-M2,TS-M3,NS-M4

4.3 Rules

The total fuzzy rules created was 21 rules. The sample if then rule was described below.

1. *If distance is **danger** and obstacle angle is **(L)small** then motor-1(rpm) is **SS** and motor-2(rpm) is **NS** amd motor-3(rpm) is **SS** and motor-4(rpm) is **VLS.***
2. *If distance is **danger** and obstacle angle is **zero** then motor-1(rpm) is **NS** and motor-2(rpm) is **NS** amd motor-3(rpm) is **NS** and motor-4(rpm) is **NS.***
3. *If distance is **warning** and obstacle angle is **(L)medium** then motor-1(rpm) is **VLS** and motor-2(rpm) is **SS** amd motor-3(rpm) is **NS** and motor-4(rpm) is **SS.***
4. *If distance is **warning** and obstacle angle is **(R)small** then motor-1(rpm) is **VLS** and motor-2(rpm) is **SS** amd motor-3(rpm) is **NS** and motor-4(rpm) is **SS.***
5. *If distance is **safe** and obstacle angle is **(L)large** then motor-1(rpm) is **SS** and motor-2(rpm) is **NS** amd motor-3(rpm) is **TS** and motor-4(rpm) is **NS.***
6. *If distance is **safe** and obstacle angle is **(L)medium** then motor-1(rpm) is **SS** and motor-2(rpm) is **NS** amd motor-3(rpm) is **TS** and motor-4(rpm) is **NS.***

4.4 Defuzzification

The defuzzification of the controller ouputs was accomplished using center of gravity method. This can be calculated using equation 1.

$$\text{C.G.} = \frac{\sum_{i=1}^{n} O_i \cdot \mu_i}{\sum_{i=1}^{n} \mu_i} \tag{1}$$

Where n represents the number of elements of the sampled membership function. The maximum value of n is equal to the number of fuzzy rules in the fuzzy logic system. μ_i is the firing weights of the *ith* rule, O_i is the ouput variable of the *ith* fuzzy set.

5 EXPERIMENT RESULTS

To show the effectiveness of fuzzy logic in path planning, Matlab was used for the design and simulation. The maximum rotational speed was approximated based on the specification of the Crazyflie 2.0 1 x 7mm coreless DC motor (Web-1). It has 14,000 rpm/V with rated voltage of 4.2V. The assumed maximum rotational speed of the motor in no load condition was 50,000 rpm. Figure 10 shows the surface view of the FLC for motor 1. The surface viewer shows the three-dimensional curve that represents the mapping of distance and obstacle angle to rotational speed of each motors.

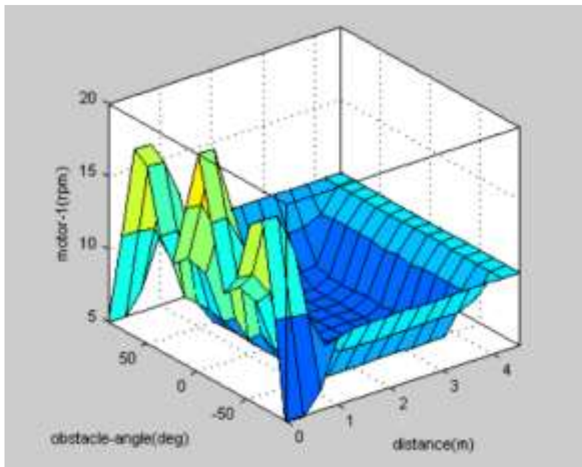

Figure 10: Surface view for motor 1

6 CONCLUSIONS

In this work, a fuzzy logic based path planning was designed to avoid obstacles while the quadrotor is in motion. Assumptions have been made to verify the effectiveness of the proposed controller.

The type of fuzzy inference used was mamdani type that was based on Lotfi Zadeh's paper on fuzzy algorithms for complex systems. The fuzzy logic controller developed has 2 inputs and 4 outputs. The results of experiments greatly shows the robustness and efficiency of fuzzy logic in controlling complex systems like quadrotor dynamics without knowing its mathematical description.

For future research, the fuzzy logic controller will be applied in a real quadrotor to test its response with the real environment.

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