FUZZY-BASED OBSTACLE AVOIDANCE SYSTEM FOR QUADROTOR UNMANNED AERIAL VEHICLE

[1]ABDEL ILAHALSHBATAT, [2]ABDEL-HAMID SOLIMAN, [3]ANWAR AL-ASSAF

Tafila Technical University, Staffordshire University, King Abdullah II Design and Development Bureau
Email: a.alshabatat@ttu.edu.jo, a.soliman@staffs.ac.uk, aassaf@kaddb.mil.jo

Abstract- this paper presentsa fuzzy-based obstacle detection and avoidance system fora quadrotor unmanned aerial vehicle using an ultrasonic sensors. The system enables quadrotor to adaptively interactwith a dynamic circumstanceusing a reactive technique determined by sensory information. Ultrasonic sensory information is gleaned from a spherical sensor array and sent to the fuzzy logic controller. The controller is then command the flight controllerto gradually correct quadrotor's orientation according to the changes in the patterns of the range values collected from the consecutive frames.The system was implemented and tested using Arduino Nano board. The board was programmed and interfaced with the original circuitry kit. Experimental results have shown that the proposed control strategy provides an efficient collision avoidance schemes for an unknown environment.

Index Terms- Unmanned aerial vehicle, Quadrotor, Ultrasonic distance sensors, Collision avoidance, Arduino Nano.

I. INTRODUCTION

In the last few decades, quadrotor unmanned aerial vehicle (UAV) has become more commonly used for many applications. Despite of those tremendous applications, the use of quadrotor is limited to restricted airspaces due to the lack of obstacle detection and avoidance system. Due to importance of this topic, there are several approaches being researched on obstacle detection and avoidance capability for a quadrotorUAV [1]. Most of these approachesconcentrate on acquiring range data about distances to obstacles. Other approaches are concentrating on the orientation of the quadrotor and its speed and whether the obstacle is fixed or moving.
Quadrotor in particularis a flying robot that is lifted and propelled by four rotors.As shown in figure 2, the basic motion of this robot is generated by varying the speeds of the four motors. Quadrotor has the potential to do tasks that are too dangerous or impossible for humans. One of the predominant challenges when flying this type of vehicles is to employ them in an environment with unknown obstacles. In order to tackle this challenge, obstacles should be represented following an intelligent technique that retrieving data on fly.
The main contribution of this article is the presentation of a practical obstacle avoidance module that can be used in modifying any existing flight controller so as to be capable of sensing, and avoiding any type of obstacles. Flight controller will receive commands from the add-on on-board obstacle avoidance system, and depending on the sensory information, the controller will command the quadrotor to gradually correct its orientation.
In this work, we build an on-board obstacle avoidance system using ultrasonic sensors.The board has the ability to detect, and command quadrotor to avoid obstacles in anydynamic environment. Moreover, it can be integrated easily with any commercial flight controller. The remainder of this paper is structured as follows: Section 2 reveals some recent research on obstacle avoidance systemsdeveloped for quadrotor vehicles. Section 3, covers the architecture of obstacle avoidance system. Our approach in designing a fuzzy navigation system is describedin Section 4.In Section 5, we present the experimental results. Finally, we summarize the main results and future work in Section 6.

II. RELATED WORKS

The problem of obstacle detection and collision avoidance is very important and requires great attention. Methods based onappearance-based, and range-based obstacle detection were proposed in the literature [2]. Appearance-based obstacle detection was conducted by Courbon [3]. The UAV in this research travels between two points and consider a previously taken image as reference one. As the UAV traverses a distance, it compares the captured images with the reference image. Another instance of this approach is based on extracting useful information about environment and obstacles [4]. Qualities of the returned images are vital issueand require heavy computation in this approach. Besides that, other factors such as weather and lighting have an impact on the image-related processing.
Range-based obstacle detection such as infrared range finders and ultrasonic sensors were also proposed in the literature. The author in [5] uses four infrared sensors for collision avoidance. This system steers the quadrotor towards the opposite direction in the case that there is an obstacles. In [6] the author uses low-cost ultrasonic sensorsand simple data fusion to navigate the quadrotor without colliding with obstacles.The ultrasonic sensors used in his project are limited in its range (250cm) in which farer distances surfaces are not detected at all. His

experiments have shown that ultrasonic sensors are useful in smoky environments.

Detecting and avoiding obstacles through the implementation of Fuzzy logic techniqueis researched for its adaptability,and robustness. The integration of sensor fusion using fuzzy logic approach to collision avoidance in smart UAVs is seen in [7]. The author successfully uses fuzzy logic to produce a flight plan and then determine an appropriate avoidance maneuver after a possible collision isdetected. Similar to the previous work, the author in [8] accomplished sensor fusion using fuzzy logic based on multiple sensors and stationary obstacles. On the other hand, the author in [9] develops an effective algorithm that could handle high-density flight situations. He explored the fuzzy logic collision avoidance techniques between UAVs and static obstacles.Fuzzy logic has also been implemented for the altitude and hovering control of quadrotor [10].

The obstacle detection algorithm discussed in this paper falls under the range-based category. Flight controller will receive commands from the obstacle detection system, and, depending on the sensory information regulated by the fuzzy controller, the flight controller will command the quadrotor to gradually correct its orientation and avoid obstacles.

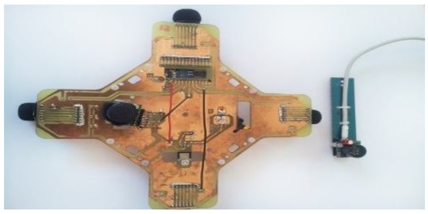
III. ARCHITECTURE OF OBSTACLE AVOIDANCE SYSTEM

The software architecture of obstacle avoidance system consists of two layers: Sensor layer and sensor processing layer. The second layerhas access to the raw data coming from the sensors layer. It uses a standard interface to communicate with the sensors and the quadrotorflight controller.The sensor processing layer is also divided into two sublayers: pre-processing sublayer and post-processing sublayer. Pre-processing sublayer provides management of the sensor'sreadings so that the sequence in reading sensors is not uniform and it depends on the presence of obstacles. Post-processing sublayer providesflexible and smooth commands for quadrotor to navigation inside a sphere. Thisarena is createdwhile the UAV is in flight and the post-processing sublayer is capable of reusing any areato counter unexpected obstacles and to fast find safe path. The vehicle must react immediately according to some given input from post-processing sublayer.The inputs to the flight controller are based on a set of carefully defined linguistic rules. These rules can be bypassed based on the existence of obstaclesto ensure that the quadrotor is fully compliant with the current mode.

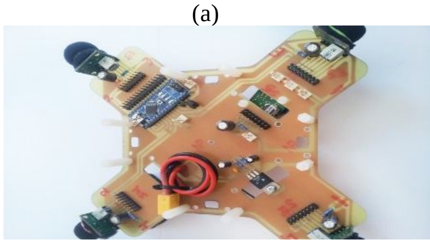
The hardware architecture of obstacle avoidance system presented in this article divides the area around the quadrotor into six zones.As shown in figure 1, we built a small and light-weight module which can be attached to quadrotor with minimum connections. The ultrasonic sensors are mainly used for positioning and identifyingof obstacles.The sensor used in this article is XL-MaxSonar-EZ4. Sixof them are usedin this article, where one sensor is used for each direction. Sensors gather data and send it to Arduino development board, where data is processed and accordingly quadrotor is moved in the commanded direction. Commands are obtained through a fuzzy controller and then transmitted toflight-control board. The flight controller will decode and execute the commands.The development board used for this system is Arduino Nano which is basedon ATmega328 microcontroller.It communicates with the flight-control board via digital pins. Since the microcontroller and the sensors need only 5 V power supply, a 12 V to 5 V voltage converter is implemented. We have chosen a rechargeable 12 V Lithium Polymer battery as an external power supply for our obstacle avoidance system.

IV. DESIGN OF FUZZY LOGIC SYSTEM

As shown in figure 1 and figure 2 (part a), quadrotor used in this paper is equipped with six ultrasonic sensors (S3_1, S1_4, S4_2, S2_3, Su, Sb), where the names represent front, right, back, left, upper, and bottom sensors respectively. Each sensor has a range of 0 to 6000 cm and distributed to maintain a spherical shape. Depending on which ultrasonic sensor detects an object, the fuzzy logic control will choose the inputs and the outputs and thus controlling the movement of the quadrotor. As shown in figure 3, ten inputs and six outputs are chosen to the fuzzy logic system. The inputs to the



(a)



(b)

Figure 1: Hardware architecture of obstacle avoidance system: (a) bottom side of the board, (b) upper side of the board.

fuzzy logic systemare the ranging data from the sensor and denoted as S1,S2, S3,S4, S5, S6, S7, S8, S9, S10, where the denoted names represent the readings from sensors S3_1, S1_4, S4_2, S2_3, S3_1 and S1_4, S1_4 and S4_2, S4_2 and S2_3, S2_3 and S3_1, Su, and Sb respectively.Tendirectionsare generated due to the outputs from the fuzzy logic system; negative pitch, positive roll, positivepitch, negative roll, negative pitch then positive roll, positive roll then positive pitch, positive pitch then negative roll, negative roll then negative pitch, up, and down, where negative pitch is due to the reading from sensor S3_1, positive pitch due to the reading from sensor S4_2, positive roll due to the reading from sensor S1_4, negative roll due to the reading from sensorS2_3, negative pitch then positive roll due to the reading from sensors S3_1 and S1_4, positive roll then positive pitch due to the reading from sensors S1_4 and S4_2, positive pitch then negative roll due to the reading from sensors S4_2 and S2_3, negative roll then negative pitchdue to the reading from sensors S2_3 and S3_1, and finally up and down are due to the readings from sensors Su, and Sb respectively.

The outputs form the fuzzy system are defined as a forward movement (FM) which obtained by commanding the quadrotor to increase the speeds of motor M2 and M4, and decreases the speeds of motor M1 and M3, back movement (BM) which obtained by commanding the quadrotor to increase the speeds of motor M1 and M3, and decreases the speeds of motor M2 and M4, right movement (RM) which obtained by commanding the quadrotor to increase the speeds of motor M3 and M2, and decreases the speeds of motor M1 and M4, left movement (LM) which obtained by commanding the quadrotor to increase the speeds of motor M1 and M4, and decreases the speeds of motor M3 and M2, up movement (UM) which obtained by commanding the quadrotor to increase the speeds of all motors, and finally down movement (DM) which obtained by commanding the quadrotor to decrease the speeds of all motors. Figure 2 part (b) shows the directions of the quadrotor due to the first four outputs.

The membership functions that represent input values are shown in figure 4 part (a).The output from the system determines the direction that the quadrotor will take. The input variables are simply expressed using three linguistic labels: Near (N), Medium (M), and Far (F). The membership functions that represent the output variables are shown in figure 4 part (b) and the linguistic variables like Small (S), Medium (M), and Big (B) are chosen to describe the outputs. To find a relationship between the inputs and outputs, rules were created and are shown in table 1, and table 2. The rules can be read as follows: If S1 is N AND S2, S3, S4, S5, S6, S7, S8, S9, S10 are F, then BM is B AND LM, FM, RM, DM, UM are S. Hence, the outputs from the system are fuzzy; a center average defuzzifier is used to obtain the crisp outputs and feed them to the comparator that is shown in figure 3.

As shown in figure 3, an intermediate block is created to compare the outputs from the fuzzy controller to the outputs from the receiver. Simply, if there is no output (small) from the fuzzy controller, the quadrotor will be controlled by the user. Meanwhile, if there is an output from the fuzzy controller, the input from the receiver will be disabled and fuzzy outputs are applied.

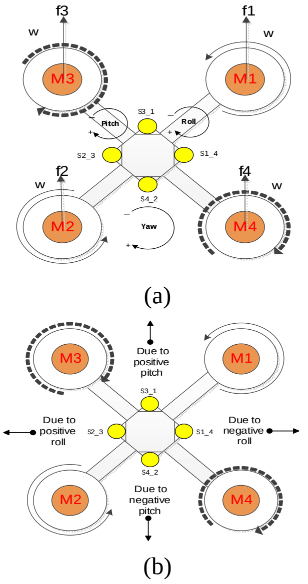


Figure 2: Basic motions of a quadrotor: (a) roll, pitch and yaw (b) directionsof quadrotor based on sensors readings.

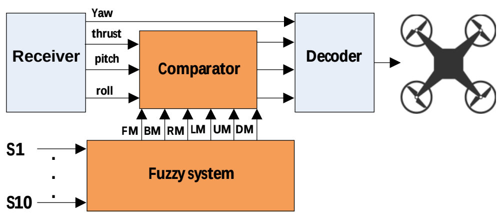


Figure 3:Typical structure of fuzzy-based obstacle avoidance system

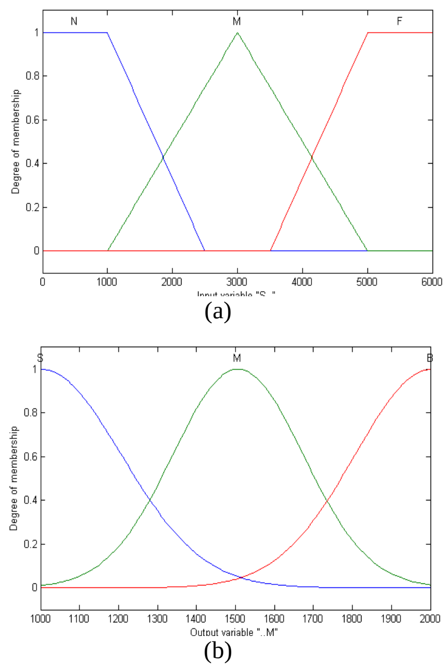


Figure 4: Membership functions for fuzzy logic system(a) Input membership functions, (b) Output membership functions.

Table 1: Fuzzy logic rules (conditions according to obstacles detection).

Rule	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1	N	F	F	F	F	F	F	F	F	F
2	F	N	F	F	F	F	F	F	F	F
3	F	F	N	F	F	F	F	F	F	F
4	F	F	F	N	F	F	F	F	F	F
5	F	F	F	F	N	F	F	F	F	F
6	F	F	F	F	F	N	F	F	F	F
7	F	F	F	F	F	F	N	F	F	F
8	F	F	F	F	F	F	F	N	F	F
9	F	F	F	F	F	F	F	F	N	F
10	F	F	F	F	F	F	F	F	F	N
11	M	F	F	F	F	F	F	F	F	F
12	F	M	F	F	F	F	F	F	F	F
13	F	F	M	F	F	F	F	F	F	F
14	F	F	F	M	F	F	F	F	F	F
15	F	F	F	F	M	F	F	F	F	F
16	F	F	F	F	F	M	F	F	F	F
17	F	F	F	F	F	F	M	F	F	F
18	F	F	F	F	F	F	F	M	F	F
19	F	F	F	F	F	F	F	F	M	F
20	F	F	F	F	F	F	F	F	F	M
21	F	F	F	F	F	F	F	F	F	F

Table 2: Fuzzy logic rules (output variables).

Rule	B M	L M	F M	R M	D M	U M
1	B	S	S	S	S	S
2	S	B	S	S	S	S
3	S	S	B	S	S	S
4	S	S	S	B	S	S
5	B	B	S	S	S	S
6	S	B	B	S	S	S
7	S	S	B	B	S	S
8	B	S	S	B	S	S
9	S	S	S	S	B	S
10	S	S	S	S	S	B
11	M	S	S	S	S	S
12	S	M	S	S	S	S
13	S	S	M	S	S	S
14	S	S	S	M	S	S
15	M	M	S	S	S	S
16	S	M	M	S	S	S
17	S	S	M	M	S	S
18	M	S	S	M	S	S
19	S	S	S	S	M	S
20	S	S	S	S	S	M
21	S	S	S	S	S	S

V. EXPERIMENTAL RESULTS AND DISCUSSION

Several experiments have been performed to demonstrate the feasibility and benefits of the proposed fuzzy-based obstacle avoidance system. Figure 5 shows a snapshot of the quadrotor after implementing and mounting all the sensors. The hardware architecture of the system is very flexible; it can be attached to any type of quadrotor without doing big modification to it. The quadrotor was tested for a set of different obstacles such as human and walls. We built small arena 100mX100m and initially quadrotoris placed randomly in it. We first experimented with each sensor individually to find the sensitivity of the flight controller and its effects on motor's speed. We found that the rotor's speed is proportional to any closet obstacles. Then, a real flight test is conducted. TheInitial results of this experiment show that if obstacles are far, the quadrotor turns smoothly, and if the obstacles are close, the quadrotor turns sharper which resulting in crash.After several experiments, we found that the time required for the quadrotorto avoid close obstacles is small when compared with its speed. This problem was solved by reducing quadrotor's speed as soon as an obstacle is detected.

CONCLUSIONS AND FUTURE WORK

In this paper, we have presented a strategy for obstacle avoidance using fuzzy logic technique and how to interface the system with quadrotor flight-control board.

Figure 5: A prototype of quadrotor that shows the positions for ultrasound sensors.

Fuzzy Logic technique is successfully employed using Arduino development board. The hardware architecture of the quadrotor has been established previously at our university, and the obstacle avoidancesystem for this UAV combined with six XL-MaxSonar-EZ4 ultrasonic sensors has been developed. The angular velocity of the four rotors was independently controlled. The outputs from the fuzzy control system were the pitch, roll,yaw and thrust whilethe input variables were the range data about distances to obstacles. The practically experimental results illustrate the feasibility and effectiveness of the proposed technique in avoiding obstacles. In future work,fusing other types of sensors with ultrasonic, and prediction techniques will be taken into account to improve quadrotor behavior when obstacles are close.

REFERENCES

[1] F. Martel, R. Schultz, et al, "Unmanned Aircraft Systems Sense and Avoid Avionics utilizing ADS-B Transceiver,"AIAAInfotech@Aerospace conference, Seattle, Washington, April 6-9, 2009.

[2] I. Ulrich, and I. Nourbakhsh, “Appearance-Based Obstacle Detection with Monocular Color Vision,” Proceedings of the AAAI National Conference on Artificial Intelligence, Austin, TX, July/August 2000.

[3] J.Courbon, Y.Mezouar, N.Guenard and P.Martinet, “Visual Navigation of a Quadrotor Aerial vehicle,” IEEE/RSJ International conference on intelligent Robots and Systems, 2009.

[4]X. Yang, L. Mejias, and T. Bruggemann, “A 3D collision avoidance strategy for uavs in an noncooperative environment,” in Journal of Intelligent Robotic Systems, vol. 70, No. 1-4, pp. 315-327, April 2013.

[5] J. F. Roberts, T. S. Stirling, J.-C. Zufferey, and D. Floreano, ‘‘Quadrotor using minimal sensing for autonomous indoor flight,’’ in Proc. MAV, 2007, pp. 1–8.

[6] N. Gageik, T. Müller, and S. Montenegro, ‘‘Obstacle detection and collision avoidance using ultrasonic distance sensors for an autonomous quadrocopter,’’ in Proceedings of 1st microdrones International Research Workshop UAV Week 2012, Germany.

[7] M. Hromatka, J. West, J. Holt, and S. Biaz, “A fuzzy logic approach to collision avoidance in smart UAVs,” Computer Science and Software Engineering Department, Auburn University, Tech. Rep. CSSE12-05, Aug. 2012. [Online]. Available: http://eng.auburn.edu/comp/research/pubs.html.

[8] A. Martinez, E. Tunstel, and M. Jamshidi, “Fuzzy logic based collision avoidance for a mobile robot,” in Industrial Fuzzy Control and Intelligent Systems, 1993., IFIS’93., Third International Conference on. IEEE, 1993, pp. 66–69.

[9] T. Dong, X. Liao, R. Zhang, Z. Sun, and Y. Song, “Path tracking and obstacles avoidance of uavs-fuzzy logic approach,” in Fuzzy Systems, 2005. FUZZ’05. The 14th IEEE International Conference on. IEEE, 2005, pp. 43–48.

[10] N. I. Vitzilaios, and N. C. Tsourveloudis, “An experimental test bed for small unmanned helicopters,” Journal of Intelligent and Robotic Systems, vol. 54, pp. 769-794, May 2009.

★★★