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AUTONOMOUS NAVIGATION FUZZY SYSTEM FOR UNMANNED AERIAL VEHICLES

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Abstract. This Academic research aims to develop an autonomous navigation system for unmanned aerial vehicles (UAV) of quadrotor type, based on fuzzy logic and the vehicle sensing, in order to automate the pilot function, to allow the maximum degree of autonomy. To develop the project, the radio hardware control of the drone Syma X8HC and the common ultrasound sensors used on the market were changed to allow the vehicle to identify the presence and distance of several obstacles during the course. The fuzzy controller of structures was tested by computer simulations and laboratory tests. The experiments results conducted on a test platform and computer simulations have demonstrated the effectiveness and performance of the both used methods and the main system in this work.

keywords: Fuzzy system, UAV, Intelligent control, Radio control, Autonomous navigation.

1. Introduction

Unmanned Aerial Vehicle (UAV), commonly known as drone, has a great potential for civil and military applications that even exceed the aviation field. The drones have greater flexibility than conventional aircraft and can perform complex maneuvers and getting into hard to reach places. Drones are used in a wide range of applications such as filming areas, forest mapping, goods delivery, inspections and monitoring in different environments (electrical transmission lines and oil industry). In these activities, the UAV in order to cover a certain area, it must have a high degree of mobility and especially being able to perform hovered flights while performing maneuvers to avoid obstacles. Therefore, a navigation system is required allowing to make the best decision on the problem and to provide synchronization between the data collected by sensors in real time through high performance flight control, enabling the vehicle to have satisfactory results in any environment or tasks. This paper proposes the development of an autonomous navigation system based on Artificial Intelligence (AI) for the unmanned aerial vehicle quadrotor type that, after the best route determined, it is able to avoid the obstacles along the path, using ultrasonic sensors. This result is obtained from relationship between sensing data of the vehicle and the intelligent control strategy based on fuzzy logic.

2. VEHICLE MODIFICATION

After the UAV dynamics study and intelligent control theory, it was conducted an analysis of the flight system Drone Syma X8HC. Because of the construction of aircraft hardware, it was not feasible to carry out modifications on the vehicle flight controller board. Frustrated the first hypothesis, we chose to study the operation of the radio control. After the tests, it was observed that each joystick consists of a pair of potentiometer perpendicular to each other (forming a voltage divider); when they are moved, they produce signals that are responsible for movement control of the vehicle, as seen in Melo [1]: The left joystick is responsible for vertical flight control when moved backward or forward. This same joystick, when moved to right or left, makes the drone to rotate clockwise or counter-clockwise - yaw. When the right joystick is pushed forward or backward, the aircraft must lean forward or backward (pitch) respectively. And when it is pushed to the left or to the right, the aircraft should lean (roll) to the corresponding side - roll. Analyzing the parameters of voltage signals produced by the sticks with a digital oscilloscope, as seen in Fig. 1, it was possible to know the commands necessary to control the aircraft's altitude movements, allowing to relate the applied voltage in each transmission channel with the movements of the vehicle as described in Table 1.

Table 1. Relationship between the movements of joysticks, voltage signals and movements of the vehicle.

Joysticks of movement	Attitude movement	Voltage signal (V)	Aircraft flight direction
Left	Yaw	1.65 - 3.5	Clockwise
Left	Yaw	1.65 - 0	Counter-Clockwise
Left	Vertical	1.65 - 3.5	Ride up
Left	Vertical	1.65 - 0	Go down
Right	Roll.	1.65 3.5	Left
Right	Roll	1.65 - 0	Right
Right	Pitch	1.65 - 3.5	Advance
Right	Pitch	1.65 - 0	Back off
Rest	Stopped	1.65	Stopped

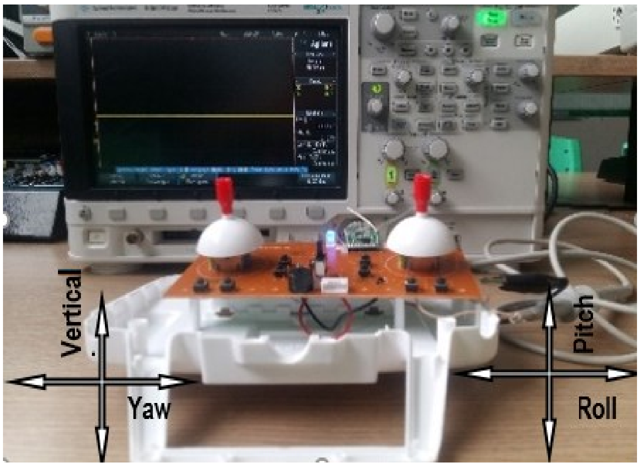

Figure 1. Analysis of the signs of stick movements Radio Control.

2.1 Control proposals

Immediately after the few changes in the radio control board performed, it was possible to replace the joysticks and they were controlled by a microcontroller board Arduino UNO using Pulse Width Modulation (PWM) technique. Since it does not have resources to operate directly as a digital-to-analog converter (DAC), a low-pass filter for attenuating high frequency components and maintain the DC component of the PWM signal is required, generating a reference voltage signal prior to the analog one produced by the movements of the joysticks.

After the breadboard experiment assembly concluded and the microprocessor signal analyzed, it was made modifications to the hardware for carrying out various tests and measuring signals, correcting the possible errors. Four PWM outputs of the Arduino are used and each one have its own low-pass filter, connected to the inputs of each channel, but with a common reference to all. Then, four potentiometers were used to each responsible for controlling the vehicle movements. Thus, it was possible to compare the expected output and actual output through an oscilloscope and the radio control display.

2.2 Methods for identifying Aircraft obstacles

By means of the alteration in radio control board circuit and its original broadcast keeped, it was determined the method for vehicle dodge the obstacles encountered on its path. This way, it is proposed the use of four ultrasound sensors HC-SR04 positioned as follow: on the front, left side, right side and bottom of the UAV. Thus, when the front distance sensor identifies the obstacle ahead of the aircraft, the sensors positioned on the sides will determine which direction the vehicle must follow: Left side, if the distance indicated by the right side of the sensor is smaller; right side, if the distance from the left side of the sensor is smaller. Similarly, the sensor positioned on the bottom controls the vertical movement up and down, and assists the takeoff and landing of the aircraft.

From this proposed, the prototype of vehicle navigation system of the vehicle was implemented. This system allows the the data from sensors connected to the vehicle are processed by the Arduino Mega and transmitted to the Arduino UNO located in the radio control board through NRF24L01 module. So, when data are received, the Arduino UNO sends the voltage signals via radio control transmitter to the flight board; this enables the drone attitude movements be controlled.

3. OBSTACLE AVOIDANCE SYSTEM BASED ON FUZZY CONTROLLER FOR UAV.

The goal of fuzzy controller is to avoid obstacles encountered along the way. this requires the fuzzy controller receives information from four ultrasonic sensors HC-SR04 on presence and direction of obstacles. based on the information received, the fuzzy controller assesses the need to change the trajectory or not, by PWM signs application to the Vertical channels, Pitch and Holl. However, for the fuzzy control that is not using the Yaw channel, it is controlled by this movement (clockwise and counter-clockwise) that can be performed by combining the channels applied to pitch and Holl commands. The main input and output variables involved in fuzzy controller has been developed based on Ronald and Filev [2] work.

3.1 Construction of membership functions

The membership function that describes the four inputs behavior of the system, the distance in meters (M), were defined as shown in Fig. 2. Each input is characterized by three functions with the same linguistic terms - Near, Medium and Far. The universe of discourse limited to the range [0, 3], in which near and far linguistics terms are trapezoidal shape, and medium linguistic term is triangular shape. The output memberships functions were associated with commands Roll, Pitch and Vertical, in which they are related to the PWM signal applied to transmission channels. The universe discourse was limited in a range [0, 255] that correspond the resolution of 8 bits of digital outputs of the Arduino, and the minimum limit 0 represent 0 volts and the maximum limit 255 represent the voltage of 3.5 volts. Each output is characterized by three linguistic terms (Land, Main in and Taking off); each fuzzy set represent the joysticks movements and consequently the aircraft movements as in Fig. 3. The triangular function defines the set which represents the joystick in stand-by mode while the trapezoidal ones define the joint movement of longitudinal joysticks.

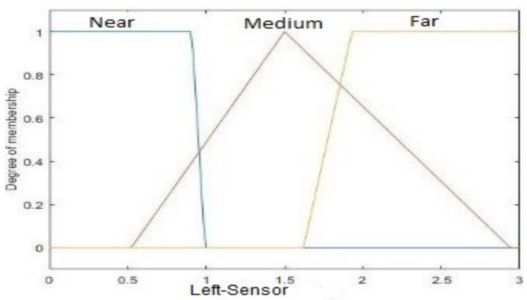

Figure 2. Input concern the Left Sensor fuzzy system: Membership function related to distance.

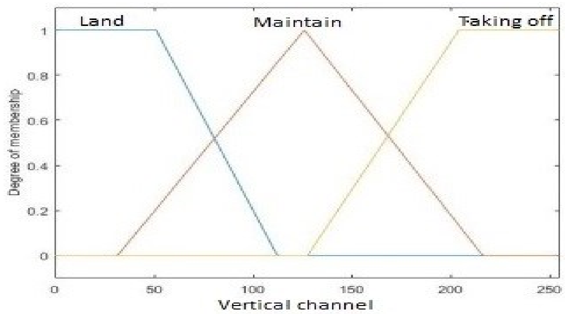

Figure 3.Output Channel - Vertical Fuzzy System: Membership function related to voltage signal

3.2 Construction of Rule Base

The stage of membership functions generation was finalized and then a method map (or table) of fuzzy rules by Shaw and Simões [3] and the graphical interface Rules Editor Fuzzy Logic Toolbox - MATLAB, for the construction of base rule. These tools enable users create rules bases automatically, based on the input and output variables descriptions. Each rule of the fuzzy controller follows the instructions of Eq. (1), by Babuska [4]. Where x_n corresponds to the linguistic variables of the input antecedent of the fuzzy rule. A_n corresponds to the fuzzy partitions of linguistic variables; u_m is the system output, represented by the fuzzy partition B_m. All rules were generated and tested using expert knowledge and analysis of the behavior of the driver inputs and outputs, through computer simulations. inference rules were calculated by Mandani model, seen in Timothy [5] and Zadeh [6], Max-Min operator for composition, minimum operating for involvement and Center of Area method for defuzzification.

$$R^i = if\ x_1 \text{ is } A_1\ and\ ..\ x_n \text{ is } A_n\ then\ u_1 \text{ is } B_1\ and\ ..\ u_m \text{ is } B_m \quad (1)$$

4. RESULTS

The low-pass filter showed to be effective, since as shown in Silva and Libard [7], it was configured the wave frequency generated by Arduino to operate $F_{PWM} = 7{,}81kHzF_{bW}$ and it was designed a low-pass filter with 10k resistor and a 100 nF capacitor, so that the frequency bandwidth F_{bW}, operates at a frequency of $100\ kHz$. This allows the time constant remove all the AC of the PWM signal, producing an analog signal to the former signal produced by the motions of the radio control joysticks.

The control surfaces obtained by applying the proposed method, as shown in Fig. (4, 5, 6) demonstrates the duty cycle of each output depending on the distances measured by the ultrasonic sensors. Also, according to Shaw and Simões [3], it was observed that the number of membership functions influence the smoothness of response and accuracy of the fuzzy control system. However, a large number of membership functions cause an increase in the number of rules for the controller, which becoming the tuning system complicated.

The computer simulation using Fuzzy Logic Controller with Rule - MATLAB, are represented in table 2, in which allowed to visualize the behavior of the fuzzy controller outputs and the rules from the variation of the input variables. Thus, the voltage signal of the system output represented by the movements - Roll [R], Pitch [P] and vertical [V], in relation to the distances detected by the sensors: Front [s_c], Right [s_D], left [s_E] and Vertical [s_v] correspond to the flight controls necessary for the vehicle to bypass the obstacle according to the detected direction and distances.

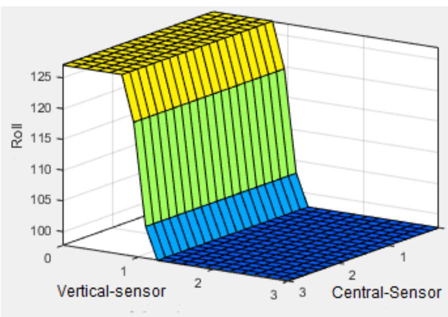

Figure 4. Roll command behavior.

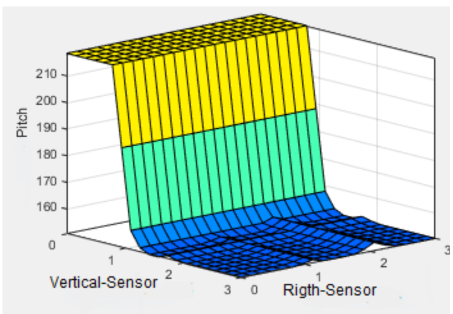

Figure 5. Pitch command behavior.

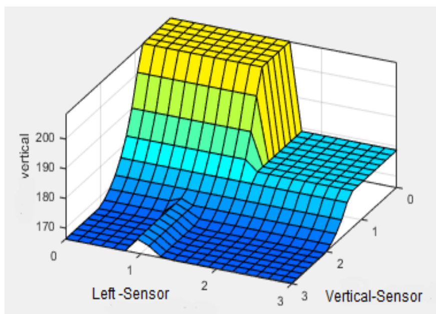

Figure 6. Vertical command behavior

Table 2. Results of Simulink simulation: relationship between inputs and outputs of the main movements of the vehicle.

Main Movements	Inputs				Outputs		
	s_C	s_D	s_E	s_v	R	P	V
Left	1	1	3	1.5	1	1.5	2.5
Right	1	3	1	1.5	2.5	1.3	1
Back off	0.5	0.5	0.5	1.5	1.6	1.	1.68
Advance	3	3	3	3	1.65	3	1.68
Stopped	1	1	1	3	1.67	1.7	1.68

5. CONCLUSIONS

This paper presents the development of an autonomous navigation system for unmanned aerial vehicles, in which the proposed method is to modify the radio control Drone Syma X8HC, keeping the original transmission and replacing the radio control sticks by a microcontroller board Arduino UNO.

Four ultrasound sensors were arranged on vehicles sides to identify possible obstacles on a particular path. The use of PWM control signals techniques combined with low-pass liters, proved efficient and can still be used in applications like this work.

The logic fuzzy were used to decision-making in relation to obstacle. Computer simulations and experimental tests were performed to designer parameters and validating the efficacy of the fuzzy controller. The next stage of the project is the study and development of a system for vehicle location in space and determination of flight routes.

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