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A Fuzzy Logic Control System for Quadcopter by Human Voluntary-Physical Movements

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Abstract

In recent years, many scientists in universities and research centers focused on quadcopters. One of the problems with quadcopters is the complexity of its manual control system. In a typical system, the user is the observer of robot in addition to controlling the radio controller. In this paper, using a fuzzy logic algorithm, a robot control system for main and subsidiary movements by human head or wrist voluntary-physical movements is considered. In this case, without looking at control board the user can control the robot only with changing the head control voluntary or physical movements. Simulation results show that using fuzzy algorithm for determining the bending scale in different angles can decrease the human errors and processor computations. Also using fuzzy logic algorithm in the designed system the robot can track the user voluntary-physical movements optimally. In addition, the system output noises adjust due to involuntary user movements.

Keywords: *Fuzzy logic algorithm, quadcopter, head control, voluntary-physical movements.*

1. Introduction

In everyday problems, human deals with a novel phenomenon. No creatures are like a human being who is always in training and improving his/her life so that this case every day gets more and more. Human likes to train his learned knowledge to others, so this knowledge outspreads generation to generation. Nowadays, most of the researchers in quadcopters field, work on controller systems, flight control, telemetry systems and controlling the robot motors speed parameters. In this intelligent system, determining the PID coefficients for tuning the flight control parameters is very considerable [1]. Also, making use of types of IMU modules for determining the flight stability level, and power electronic systems use for fast and reliable electrification to robot motors. Now, one of the considerable researches is using the Kalman filter for noise elimination due to deviation between gyroscope and accelerometer for robot location [2]. In the field of real-time systems, obtaining the autopilot robot location results in informing the robot location to ground station at any time. The main reason is preventing the damaging of devices of robot and user. In these conditions, global positioning system (GPS) is an important necessity. But sometimes data loss may occur due to poor signal coverage and week GPS signal and so a backup unit is needed to control the condition and save the map. Using the accelerometer and gyroscope sensors are important solutions in autopilot robots system [3]. Also, the fuzzy algorithm is considered by the system designer for PID factor determination to have stability [4, 5]. In [6], an

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intelligent system has designed and implemented in order to control a quadrotor unmanned air vehicle (UAV) based on fuzzy logic. Obtaining quadcopter dynamic equations to apply changes on robot physical system during flying have been used by engineers [7]. In these conditions, using these equations, designers have the ability to use system state equations and can perform the signal testing and system steady and transient states analysis without using robot and store the simulated data and design the stable system [8-10]. In other work, image and video processing are done by robot for locating on earth and tracking and pursuit the object. In this case, robot is the master and the aim is object [10].

In this paper, a system will be designed upon which the robot from the point of stability and control is ideal. Here, because of using a proper flight controller, PID factors without user interfering, apply to the system at any moment and there is not any necessity for calculations. In this design, with the ability of joystick elimination, the robot is controlled using head or wrist voluntary-physical movements [11]. In the proposal, commands running to left, right, forward and backward, use body angles variations by a fuzzy algorithm without need to control sticks. So a combined system from human and machine will be studied and used for future programming in motor and cognitive sciences.

The rest of this paper is organized as follows. In Section 2, the proposed hardware will be presented. In Section 3, fuzzy algorithm utilization in finding the rotating scale of robot control head will be investigated. In Section 4, the proposed quadcopter will be presented and then, simulation results will be discussed. Finally, Section 5 concludes this paper.

2. Proposed Hardware

In this section, we will investigate the different parts of the hardware to declare the proposed design. Hence we used a serial protocol to transmit accelerometer and gyroscope data. It should be noted that all accelerometer data enters MATLAB and transmits to USB after processing and filtering. Then data received by the microcontroller and digital data is converted to analog and finally, analog data is sent to radio transmitter.

2.1. Accelerometer

Accelerator measures the exact value of acceleration. One of the problems of using common commercial modules is the lack of exact calibration. Also, in addition to this problem, noise of the device is another limitation. The main problem is the long programming for connection to module internal registers. One of these modules is ADXL330. It should be noted that the problems of conversion of analog to digital are eliminated, but the problem of accelerometer or gyroscope error remains.

2.2. Using Mobile Sensor

For making using of the mobile internal sensor, we used S5-Samsung mobile to utilize both accelerometer and gyroscope sensors. This sensor, MPU6500, contains both mentioned sensors monolithically. This sensor has all necessities of a navigation system [12] and because of having the internal filter doesn't need complicated software filter to delete the system errors. In Fig. 1 two samples of non-calibrated and calibrated accelerometer output with filter are illustrated. In the calibrated system, media distortions don't affect the charts versus time and system acts in a stable state. This ability provides time delay reduction for important applications.

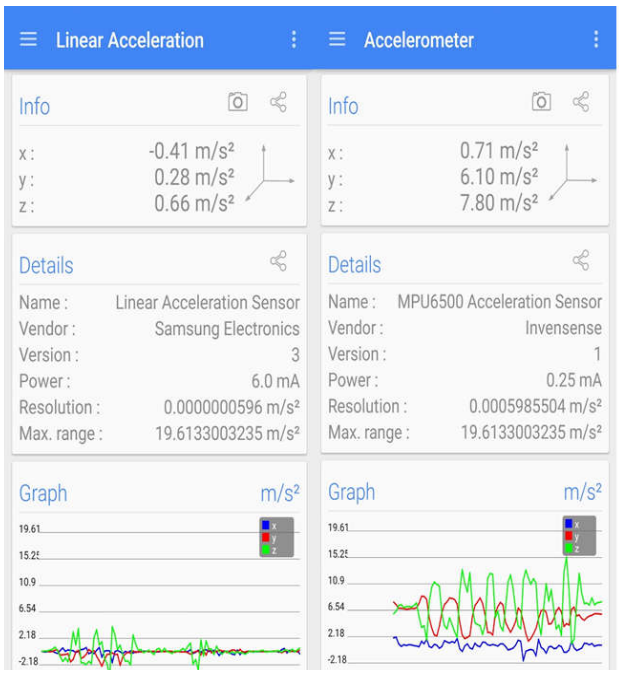

Fig. 1. Accelerometer output using two outputs.

2.3. Connection System Description

For the connection between mobile and computer, we used Bluetooth module HC05. In this case, the baud rate for mobile and computer is 4200. Also, baud rate reduction results in system error reduction. For mobile system connection Bluetooth electronics software made by Keuwlsoft under android was used. This software provides the ability of direct connection with cell phone.

2.4. Analogue to Digital Converter

Accelerometer data exit from USB output in digital format which needs a digital to analog converter (DAC) after entering the computer and fuzzy algorithm analysis. In Table 1, a sample of output data from MATLAB which transmits from USB port of DAC is mentioned. As we see, this data contains control head bending scale of user head or hand which after being transmitted to the fuzzy algorithm is sent to DAC in four numbers format. In this case, the system sends the proper angle value to RF transmitter and finally, the robot pursues the proper direction toward the control head angle. Fig. 2 shows the digital to analog converter circuit using converting IC DAC0800.

Table 1. Fuzzy system output for transmit to robot

Transmission output	4 main movements			
	Forward	Backward	Right	Left
Amount	21.9456	156.9778	91.0743	91.0743

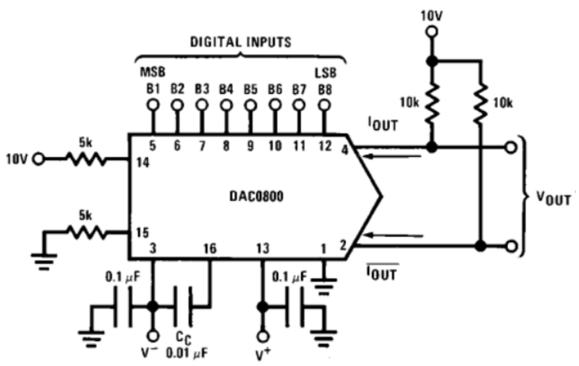

Fig. 2. Driver circuit DAC0800 with amplified output.

3. Head Control Rotation Calculation using Fuzzy Algorithm

In this section, head control rotation value using a fuzzy algorithm will be investigated. When we talk about uncertainty, mathematic relations lose their reliability. It is clear that the control structure needs absolute certainty in its output. The best algorithm in this field is the use of expert system results for obtaining local information. In the presented system, head control can be an accelerometer system or cell phone set on the user head or hand. Bending scale of head or hand is measured by accelerometer sensor and using fuzzy algorithm. Generally, there are four main directions, forward, backward, right and left. Plus four subsidiary directions, willing to forward right, willing to forward left, willing to backward right, and willing to backward left, totally create eight states. It is worth noting that in willing states, percent of two main states may occur during bending [13].

Fig. 3 shows the willing to forward area. As we see, if this object is considered for other directions, with classic programming, some limited numbers of dots can be determined on the subsidiary dots. By doing this, one can see a considerable reduction in resolution in measurement and losing some sensitive dots. However, using the fuzzy algorithm this problem is solved completely.

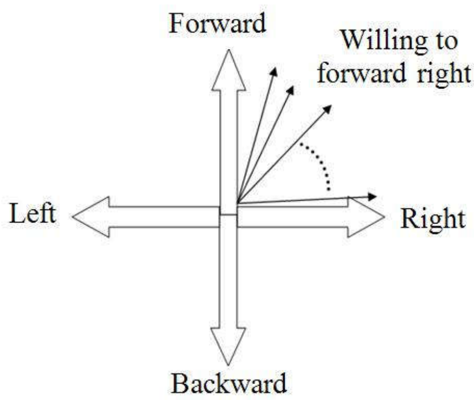

Fig. 3. Showing of extreme number of dots willing to forward right.

3.1. Fuzzy Rules

Determining head control angles and transforming of these angles need some rule based on if-then in the fuzzy algorithm. In the considered system “AND” is selected as min, “OR” as max, implication as min, and defuzzification as a centroid. According to Eq. (1), under summation-multiplication, the fuzzy inference system output is equal with centroid defuzzification and centroids weighted average of each one of the membership functions. Each weight is equal to multiplication of degrees of perfection at membership function area of results.

$$\mu_{C'} = w_1\mu_{C1}(z) + w_2\mu_{C2}(z) \tag{1}$$

It should be mentioned that membership function can get a value more than one. Hence using defuzzification algorithm, final output centroid is as:

$$\begin{aligned} Z_{OCA} &= \frac{\int_z \mu_{c'}(z)zdz}{\int_z \mu_{c'}(z)dz} \\ &= \frac{w_1\int z\mu_{c1}(z)dz + w_2\int z\mu_{c2}(z)dz}{w_1\int \mu_{c1}(z)dz + w_2\int \mu_{c2}(z)dz} \\ &= \frac{w_1a_1z_1 + w_2a_2z_2}{w_1a_1 + w_2a_2} \end{aligned} \tag{2}$$

In the above relation, and are area and membership function centroid of respectively:

$$a_i = \int_z \mu_{c_i}(z)dz \tag{3}$$

$$z_i = \frac{\int_z z\mu_{c_i}(z)dz}{\int_z \mu_{c_i}(z)dz} \tag{4}$$

3.2. Robot System Membership Function

For four main movements, right, left, forward and backward two membership functions are defined. One membership function is considered for right and left and one for forward and backward in MATLAB. Fig. 4 shows input and output structure of fuzzy program. As we observe, system has two left&right and up&down inputs. Also, this system has four outputs which show the bending degree with the specific fit. In the range part, [-90, +90] is related to the minimum and maximum angle in head control bending. As we see, the membership function uses in a trapezoid shape. The system has four outputs which should provide a movement criteria and factor for four main directions. Speed scale to forward, backward, right and left should be sent to transmitter to serial port output as a factor of fuzzy function. Fig. 5 shows the created level by fuzzy inference system (FIS) in MATLAB. Also, Fig. 6 shows all membership functions of fuzzy system for inputs contain Up & Down, and outputs contain Forward & Backward and Right & Left.

4. Proposed Design Presentation and Simulation Results

In this section, we present the proposed design and simulation results. In this regards, after linking the radio connection with the receiver and final flight control tuning, the robot is ready for flight. After locating the robot in proper height, head control containing cell phone set sends accelerometer data to digital to analog converter board. In this condition processed data is sent to radio control. Radio data is sent to quadcopter transmitter and robot tracks the head control movement. Fig. 7 shows the algorithm used for the robot.

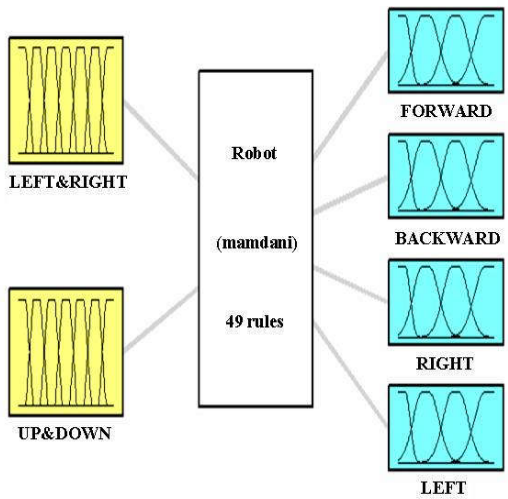

Fig. 4. Fuzzy system input and output structure.

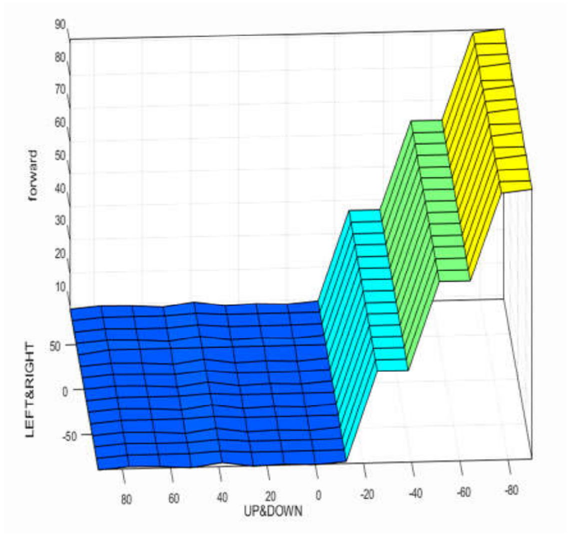

Fig. 5. Created level in FIS.

Fig. 8 shows the head control for two movements to the right and left. As figure shows, in the first part of the chart, system is stable. Stability is a state in which the user's hand has no movement to any side after head control accelerometer calibration. It should be noted that some tolerances have been considered to hold head control with no angle because hand vibrations due to user breathing or involuntary body muscles are inevitable. For this case, trapezoid membership function has been used. In this case accelerometer has no angle that is, Left&Right=0 and Up&Down=0. Corresponding outputs parameters for robot movements to the right, left, forward and backward are 90.8, 90.8, 21.9 and 21.9 respectively. These values nullify the force of quadcopter four motors, and consequently robot will be fixed in its location. These criteria result in head control stability in fuzzy system output. Fig. 9-1 shows all outputs with constant value. By entrance to active region, head control tends to right and forward, Right=27.3 (right angle is in range [0, 90] and left angle in range [-90, 0]) and Up=-27.3 (up angle in range [-90,0] and down angle in range [0,90]). In this case, fuzzy system output increases for two movement states to right and forward, Forward=377 and Right=21.9 (there is no increment in left and right movement). This variation is shown in Fig. 9-2. In this state, robot tends to right and forward. Finally, head control tends maximum to right (right=90), which we consider maximum speed for fuzzy output at the right movement. In this situation, robot trend is to forward Up=44.5, so system fuzzy output for forwarding movement is 550, for backward 110 and right 225 and for left is 28.4. The output is shown in Fig. 9-3. Here, robot tends to right with maximum speed and slightly to forward. In all states, system work continuously and output generates without time delay. The robot with receiving signals from four outputs (equal to four main states) considers the proper angle for passing the route. Results show that using fuzzy system in design proposal, the noise of user involuntary movements in robot control process regulates considerably.

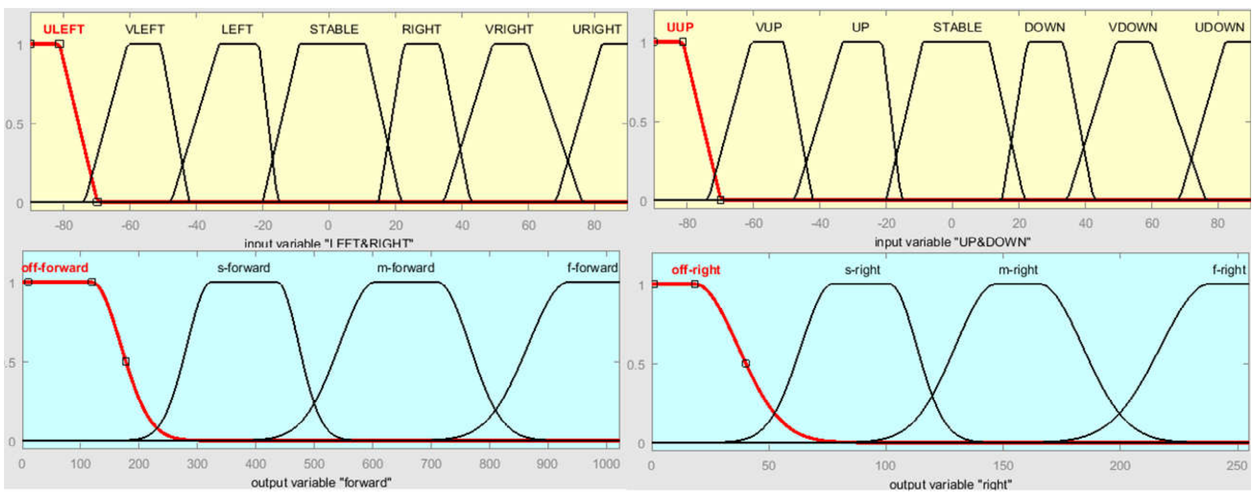

Fig. 6. All trapezoid membership functions defined in fuzzy system.

5. Conclusion

In this paper, a meta-heuristic guiding controlled system by human voluntary-physical movements using a fuzzy algorithm was proposed. In the proposed system, fuzzy algorithm plays a role to determine coordinate and directions of user's head or hand for guiding a quadcopter which deletes the joystick, in addition, to control the quadcopter using user head or wrist voluntary-physical movements. Results show that proposed system tracks user head or hand angle exactly, in addition, to transfer the head control output to robot without any delay. Also one of the important specifics of this system is reduction of noise due to user involuntary movement in robot control process. It is worth noting that with an improvement of some conditions and combining this algorithm with artificial neural network one can reach to novel methods in complicated robotic systems controlling which result in learning robotic systems and artificial intelligence.

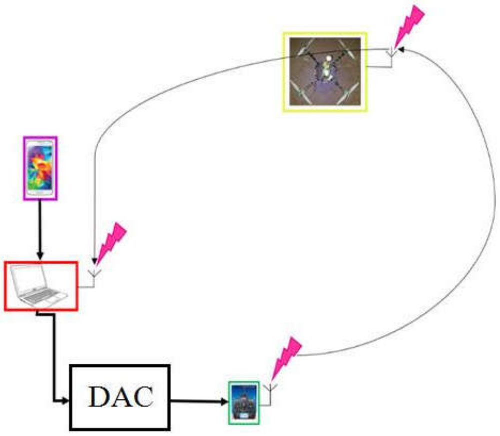

Fig. 7. Proposed system.

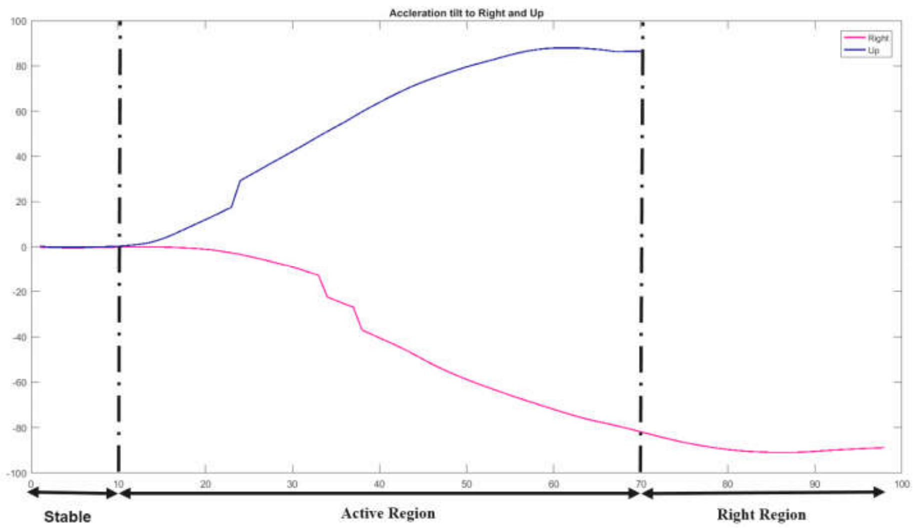

Fig. 8. Head control movement to right and forward (tends to right and forward).

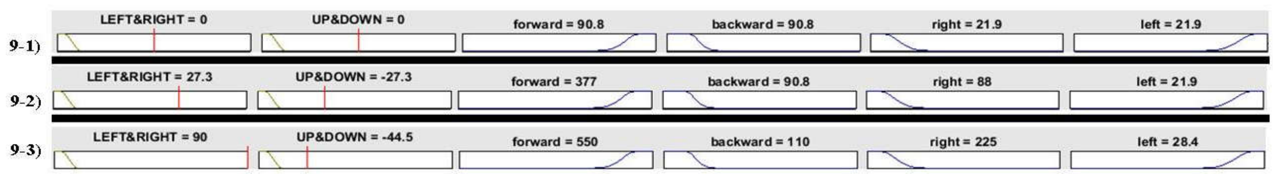

Fig. 9. 1- Head control signal is stable (head control has no angle) 2- Fuzzy output when signal enters the active region 3- Fuzzy output when signal tends to forward and tendency to right is maximum.

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