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HIL-Based Fuzzy PID Controller for Quadcopter

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ABSTRACT

This paper presents the design of fuzzy logic controller (FLC) for a quadcopter. The controller and the quadcopter are made to interact in a hardware in loop (HIL) based matlab simulink environment. The real time accelerometer and gyroscope data to calculate the roll and pitch angles are obtained from MPU6050 (Motion processing unit) located on the quadcopter. The output of this unit via mbed board is applied to the fuzzy PID controller designed in simulink. Four BLDC motors are used to rotate the rotors. The speed of these motors are controlled by the FLC controller using PWM technique to obtain the desired output. The performance of the quadcopter is analyzed in the HIL environment and the fuzzy rules are tuned to have a better control. The implementation results are presented and discussed.

Keywords: quadcopter, pitch, roll, yaw, HIL, Fuzzy PID, Simulink

1. INTRODUCTION

Quadcopter is a vertical take-off landing (VTOL) unmanned aerial vehicle (UAV). Recently, the use of quadcopters have attracted significantly by scientists due to the wide range of applications include military[1], area surveillance[2], image capturing, research-data collection[3], indoor-outdoor commercial applications[4] and so on. Besides, the research in their modelling and control have also been increased rapidly. A controller is playing an important role in the quadcopter design and it is designed using a mathematical model [5] of the quadcopter system. But, the controller design is complex because of its nonlinear behavior. Alternatively, a rule based control strategy like Fuzzy logic [6-8] is used to design a controller. Fuzzy controllers have been widely used in flight control systems[12-17] because of their simplicity and ease of implementation. One of the main parts in designing the controller is framing a set of rules. These rules are written after gaining sufficient knowledge about the system dynamics and they are to be tuned to enhance the performance of the control system. In this context, HIL creates an user friendly environment to interact the quadcopter with the fuzzy logic controller in the matlab simulink environment. In addition, the embedded components such as MPU 6050 (Motion processing unit)[9], rapid prototyping boards (mbed board, Arduino uno boards)[10-11] helps in communicating between the hardware and the software. Nowadays, these components have become commercially available at reduced cost due to the recent developments in VLSI technology. With this platform, one can gain the knowledge on quadcopter performance in real time to design a rule based fuzzy logic controller.

The remaining part of the paper is organized as follows. In section II the survey on the related work and in section III the theoretical background of the proposed work are presented. The hardware implementation and the results are discussed in sections IV and V respectively. Finally, the conclusions are drawn in section VI.

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2. RELATED WORKS

Fuzzy PD(proportional derivative) type controllers [12] were implemented using MultiWiiCopter board (v0.6.3). Twentyfive rules were framed for each controller to obtain the desired response. However this design is vendor dependent i.e., the controller design is applicable only to MultiWiiCopter. Further, the performance of the controller was improved [13] in the presence of external disturbances through online tuning of proportional and derivative gains. Attitude stabilization of the quadcopter was achieved using back stepping algorithm [14]. The coefficient of the algorithm are tuned using fuzzy logic for better performance. Since, the selection of membership function plays an important role in fuzzy controller, a C-Mean clustering technique [15] is used for the appropriate selection of the membership function. Adaptive neuro fuzzy inference system (ANFIS) [16] was developed for a quadcopter and it is trained using the data from a PD controller. Further, the data from a PID controller is also used for training the ANFIS [17] controller. From the above reported works, it is observed that the design of fuzzy PID controller in an HIL based environment is not addressed significantly. Fuzzy logic is highly suitable for non-linear control problems [18-19]. In this paper, the controller and the quadcopter are made to interact in an HIL-based matlab simulink environment and the rules are tuned to enhance the performance of the control system.

3. THEORETICAL BACKGROUND

A quadcopter is a multirotor helicopter that is lifted and propelled by four rotors. These four rotors are divided into two counter rotating pairs as shown in Fig. 1. The forward and backward movement is along X axis, sideways movement is along Y axis and the rotation is about Z axis. Rotation of quadcopter about X, Y and Z axis are known as roll, pitch and yaw respectively. These are the three basic control variables of quadcopter. The desired pitch is achieved by controlling the lift generated by the rotor pairs M1-M2 and M3-M4. Likewise, the roll is controlled by the rotor pairs M1-M4 and M2-M3. Yaw can be controlled by controlling the torque produced by the clockwise (CW) and counter-clockwise (CCW) rotating rotors M1-M3 and M2-M4 respectively. CW rotating rotor pair (M1-M3) produces anti-clockwise torque about the Z axis and vice versa by the other CCW rotating rotor pair (M2-M4). When all the four rotors are rotating at the same speed, the net torque about the Z axis of the quadcopter is zero. In order to, perform these maneuvers without loss of stability, the job of the fuzzy controller is to suitably adjust the speed of the motors (M1, M2, M3, and M4).

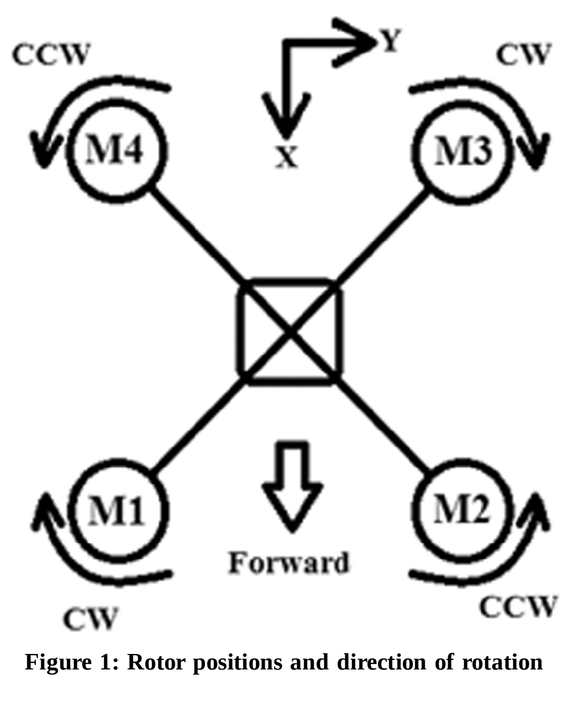
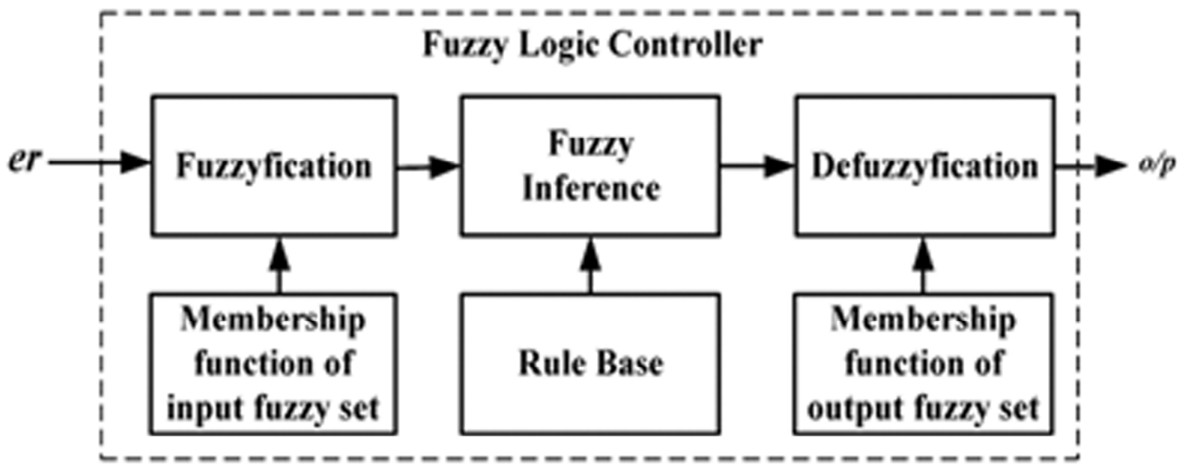


Figure 1: Rotor positions and direction of rotation

The three important components in a fuzzy logic controller (FLC) are fuzzification, rule base and defuzzification as shown in Fig. 2. The FLC is designed using a set of rules and subsequently, the rules are tuned after gaining good knowledge about the system for better control action.

4. HIL-BASED FLC IMPLEMENTATION

The desired response of the quadcopter is obtained by varying the control variables pitch, roll and yaw. This in turn, depends on the speed of the four BLDC motors (M1, M2, M3, and M4). Hence, FLC will adjust the speed of the motors using PWM technique so as to get the desired response of the quadcopter.



er-error

Figure 2: Basic fuzzy controller block

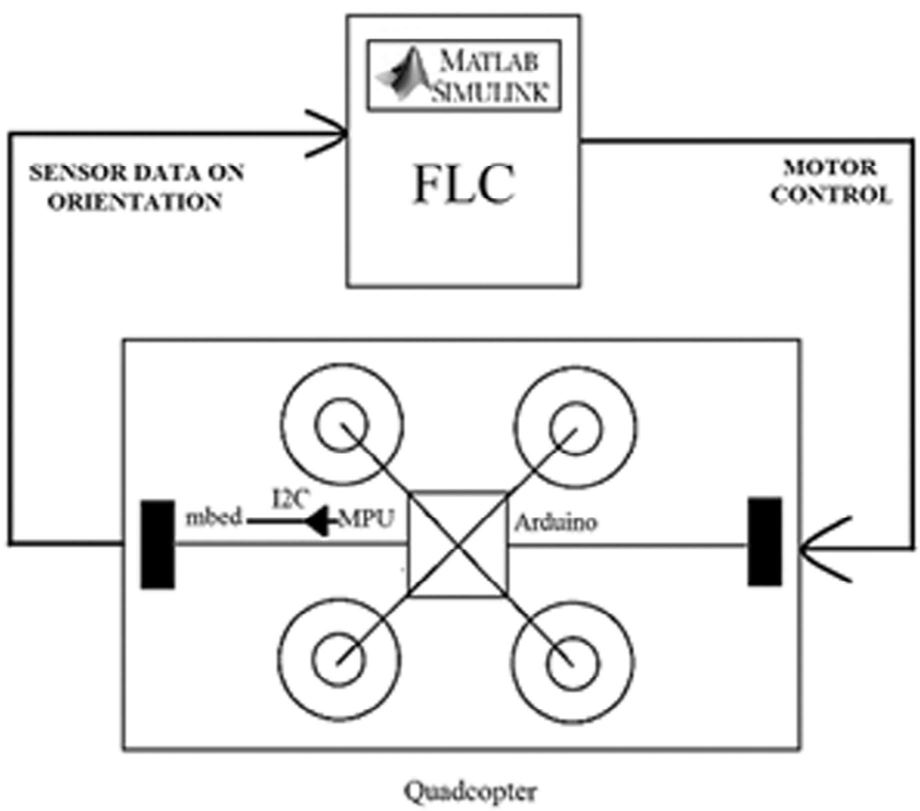


Figure 3: HIL test setup

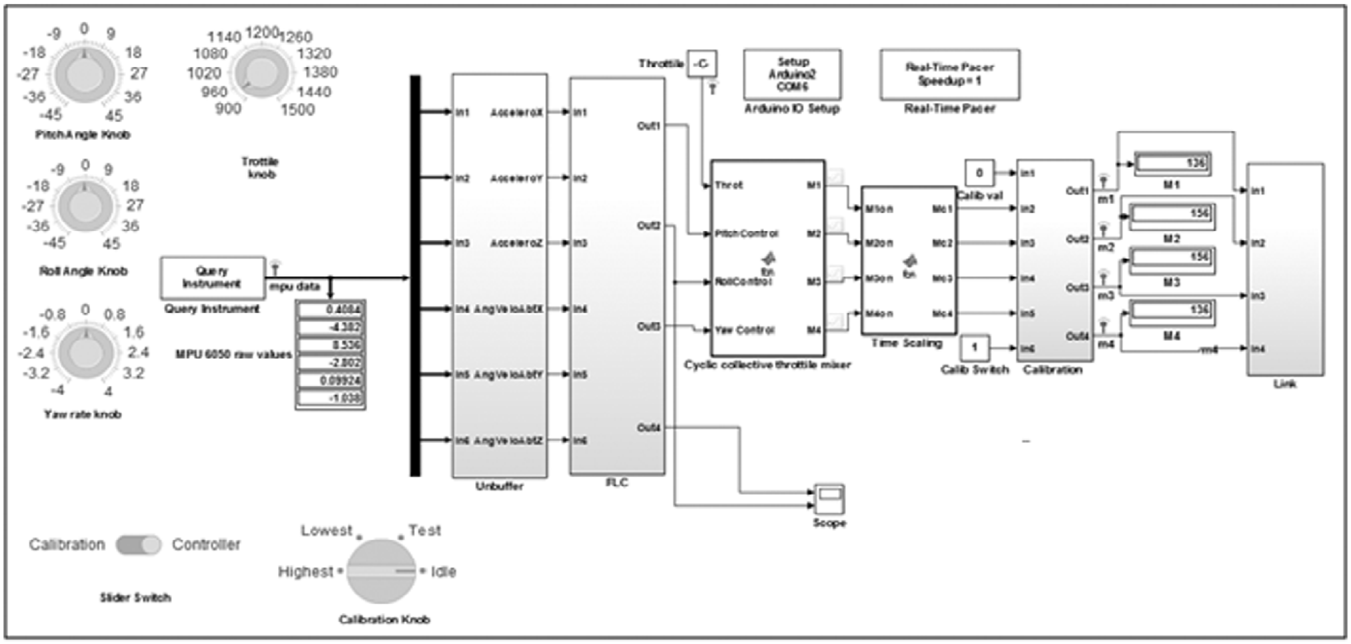


Figure 4: Fuzzy PID controller in Simulink

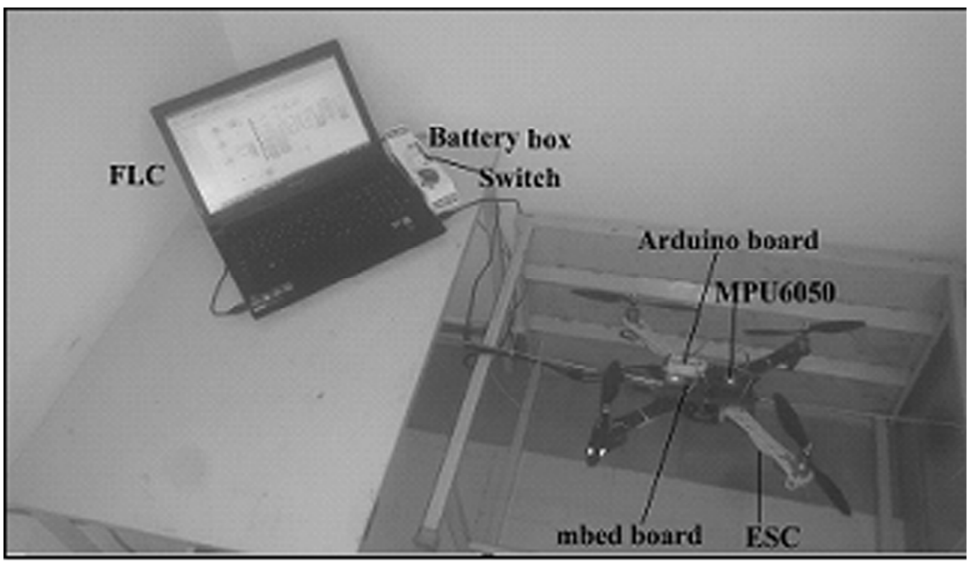


Figure 5: HIL-based setup

4.1. Importing data into simulink environment

The HIL based setup to fetch the real time data is shown in Fig.3. The motion processing unit(MPU 6050) fetch the acceleration (Acc) and angular velocity (ω *degrees/second*) data and communicates it to the mbed board via I2C protocol. This data is sent to the FLC by the mbed board via USB serial communication. The above data is used to calculate the pitch and roll angles.

4.2. Rule base for FLC

Totally 165 rules are used by the controller to take the control action. 75 rules for pitch controller, 75 rules for roll controller and 15 rules for the yaw controller. Table 1 shows the 25 out of 75 rules of pitch controller and the membership function for pitch error is shown in Fig. 6. The pitch, roll and yaw are assigned a reference value and using the real time data from the mbed board, the actual value of pitch roll and yaw are calculated using equations (1) and (2).

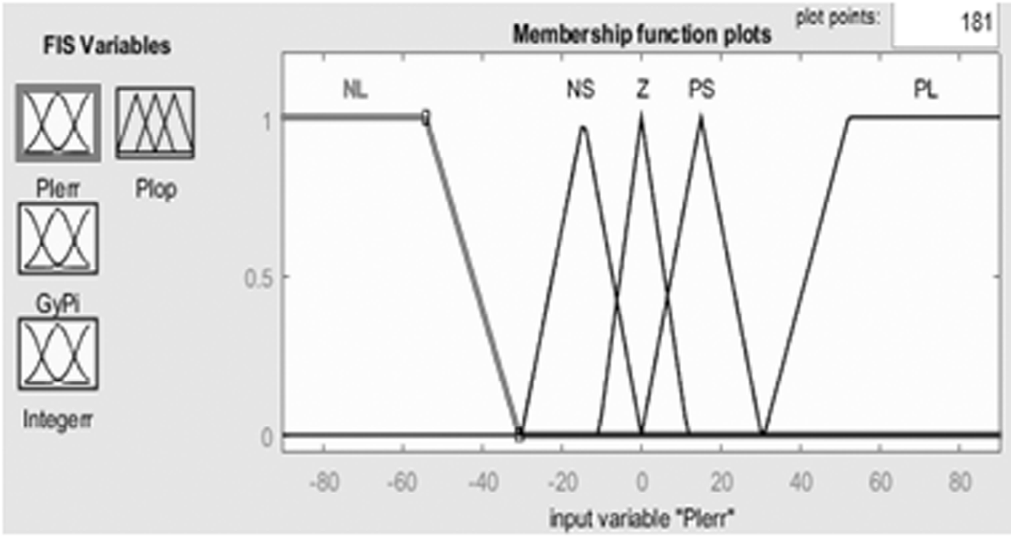


Figure 6: Membership function plot for $\theta_{pitch\ error}$

$$\theta_{pitch} = \tan^{-1}\frac{ACC_x}{2\sqrt{ACC_y^2 + ACC_z^2}} \tag{1}$$

$$\theta_{roll} = \tan^{-1}\frac{ACC_y}{2\sqrt{ACC_x^2 + ACC_z^2}} \tag{2}$$

where, Acc_x, Acc_y, and Acc_z are the acceleration along x, y and z axis respectively.

The controller will use the rule base to take necessary action depending upon the error between the actual and the reference values of the control variables.

Table 1
Rule table for pitch controller

$\theta_{pitcherror}/G_y$	NL	NS	Z	PS	PL
NL	PL	PL	PL	PS	Z
NS	PL	PS	PS	Z	NS
Z	PL	PS	Z	NS	NL
PS	PS	Z	NS	NL	NL
PL	Z	Z	NL	NL	NL

4.3. FLC implementation for quadcopter

The HIL-based implementation of fuzzy controller in matlab simulink environment is shown in Fig.4. It consists of blocks namely query instrument, unbuffer, controller, collective throttle mixer, time scaling, electronic speed controller (ESC) calibration and link. The real time data (Acc_x, Acc_y, Acc_z, ω_x, ω_y and ω_z) from the MPU 6050 is received and communicated serially to the query instrument block (QIB) by the mbed board. The QIB will output a frame which consist of the above six data. Then, the unbuffering block is to simultaneously input the six data into the controller block. The exploded view of the controller block is shown in Fig.7. It will generate appropriate roll, pitch and yaw control signals to vary the on-time of the four motors (M1, M2, M3 and M4) via the cyclic collective throttle mixer (CCTM). Using the following relations (3)-(6), the CCTM calculates the on time for the four motors.

$$M1 = Throt\text{-}Pitch\ Control\text{-}Roll\ Control+Yaw\ Control \quad (3)$$

$$M2 = Throt\text{-}Pitch\ Control+Roll\ Control\text{-}Yaw\ Control \quad (4)$$

$$M3 = Throt+Pitch\ Control+Roll\ Control+Yaw\ Control \quad (5)$$

$$M4 = Throt+Pitch\ Control\text{-}Roll\ Control\text{-}Yaw\ Control \quad (6)$$

where, 900 μs on-time <*Throt* <1500 μs on-time.

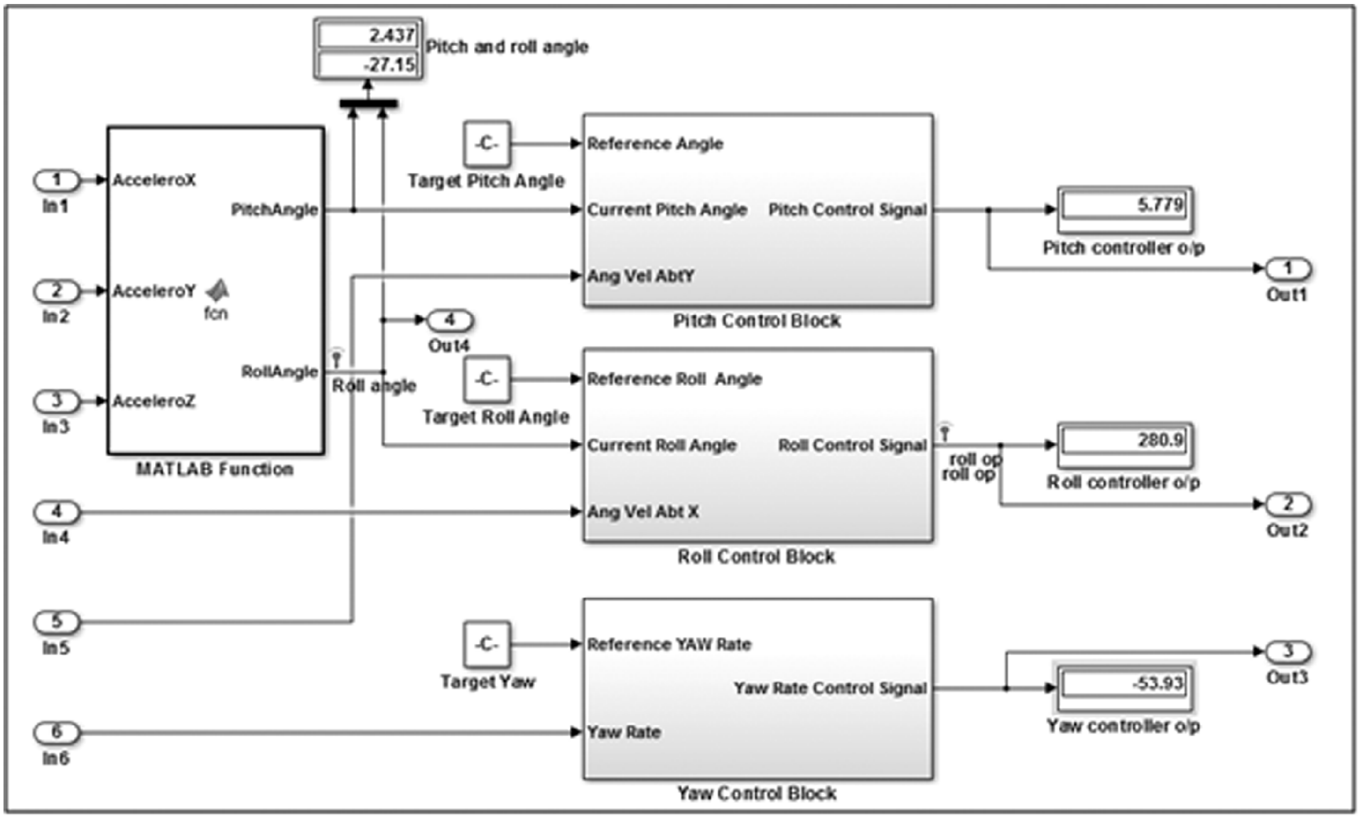


Figure 7: Controller block

In addition, the time scaling block scales the on time to 8-bit word length so that the value of the on-time is transferred to the arduino board. The maximum and minimum on time is fixed using the calibration block. Finally, the control signals from the simulink environment are applied to the motors via link block.

5. RESULTS AND DISCUSSION

The quadcopter is designed using four BLDC motors, each of 1000KV. By conducting a suitable test, the payload of each motor is found to be 534 grams and the total payload of the quadcopter is $4 \times 534 = 2.136$kg. The total current drawn by the motors is 44A. The minimum and maximum on-time of each motor are 1030 μs and 1999 μs respectively. The on-time in the above range is varied appropriately by the fuzzy logic controller so as to meet the desired roll, pitch and yaw angles. The FLC and quadcopter connected in HIL-based environment is shown in the Fig. 5. A good knowledge about the performance of the quadcopter is obtained in this environment and based on that, the fuzzy rules are tuned. It is observed that the output of the accelerometer contains much noise due to motor vibration as shown in Fig. 8. This cause difficulty in retrieving the roll pitch and yaw angles. To suppress this noise, the bandwidth of the internal low pass filter of the MPU6050 is changed to 5Hz. Fig. 9 shows the filtered output of the accelerometer. For a desired roll angle of 0°, the roll correction made by the controller is shown in Fig.10. The overall controller operation is detailed in Fig.11.

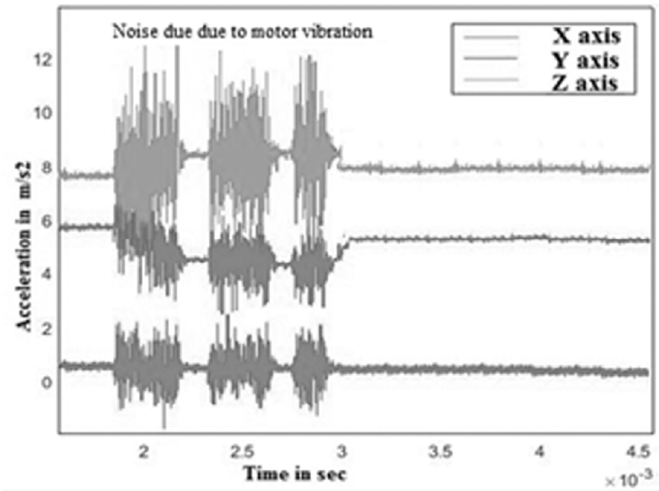


Figure 8: MPU 6050 with added noise

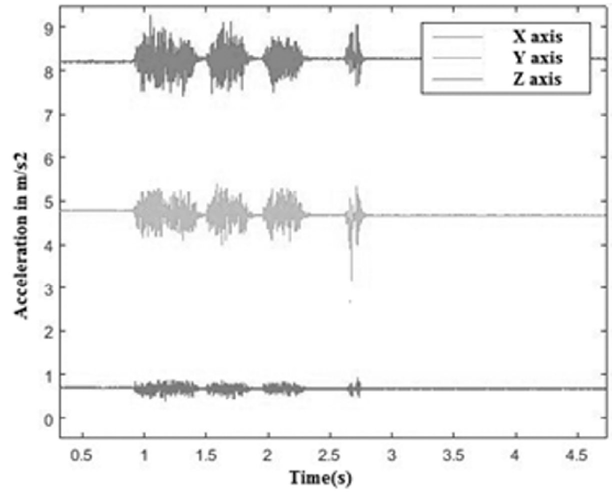


Figure 9: Filtered output of MPU 6050

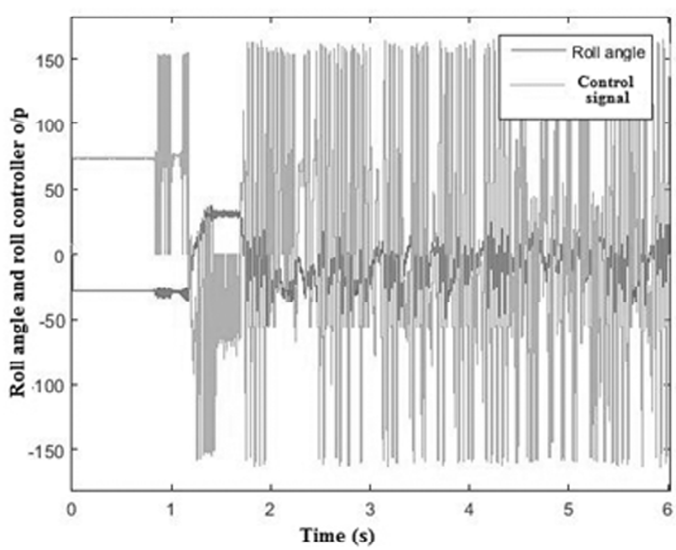


Figure 10: Control action taken by the controller for the desired roll angle.

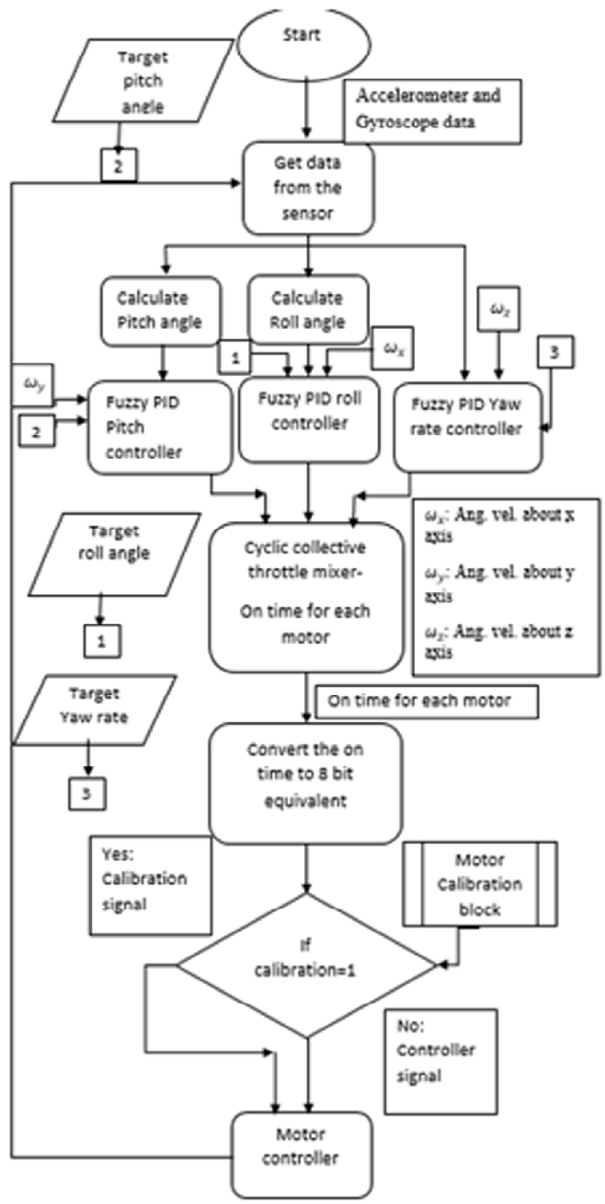


Figure 11: FLC flow chart

6. CONCLUSION

A fuzzy logic PID controller for a quadcopter in HIL based environment is proposed. The real time orientation data is fetched using MPU6050 sensor via mbed board. The control signals from FLC are applied to the motors via arduino board. The noise from the MPU6050 is filtered using a low pass filter. The payload for the quadcopter is 2.136 kg. The total current drawn by the motors is 44A and to vary their speed the on-time range is from 1030 μs to 1999 μs. The performance of the quadcopter is analyzed in real time and accordingly the fuzzy rules are tuned to design the FLC. In this context, the proposed HIL based FLC controller based design is useful in gaining the knowledge about the quadcopter performance in real time and to tune the fuzzy rules to have a better control.

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