Sensor Fusion and Fuzzy Logic for Stabilization System of Gimbal Camera on Hexacopter

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Abstract— **Hexacopter has the ability to fly in the air can be used as an air monitoring system. To get the video or images that have good quality then it is used gimbal camera as a movement stabilizer and vibration damping. Stabilization System consists of two axes, x axis (roll) and y axis (pitch) and has a 2-axis camera gimbal controller which is have microcontroller ATMEGA 328 that serves to regulate the stability of the gimbal camera. The Input of this system is derived from accelerometer and gyroscope sensors that are within the sensor module MPU 6050, to determine the tilt position of hexacopter. The output of this sensor will be filtered first using complementary filters that serve to reduce noise of both sensors and complement advantages and disadvantages of each sensor. The output of this system is the movement of two brushless motors, brushless roll and pitch, that are controlled with Sugeno fuzzy logic method because it has a simple calculation so the response is faster and more suitable for real-time applications. From the case study with the data of the roll at by 35 º and pitch at by 17 º resulting PWM duty cycle value by -69.47% roll and pitch resulting PWM duty cycle value by -25.5 %, where (-) represents the direction of movement.**

Keywords*— *Hexacopter, Gimbal Camera, Accelerometer, Gyroscope,Ccomplementary Filter, Fuzzy Logic

I. INTRODUCTION

Hexacopter an unmanned multicopter has 6 propellers as actuator. The advantages of the hexacopter are able to fly in all directions and heavy lift so that can be used to air monitoring system and aerial photography. When hexacopter airs, the position of the camera will be oriented and hindered by the movement and vibration of hexacopter itself so that the resulting video or image to crash.. To maintain the stability needed a tool and a method as a stabilizer. The stabilizer is a gimbal camera that has a control system based on the axis of motion, namely roll, pitch and yaw. Each axis movement governed by brushless motors. Gimbal camera input derived from the two sensors, accelerometer sensor and gyroscope sensors. To get the good angle and there is a lot of noise, input from both sensors will be filtered to complementary advantages and disadvantages of each. Filter method used is complementary filters. This filter combines the data from the two sensors to form an angle value. In this study will be tested using Sugeno fuzzy logic system is developed to control the gimbal camera stabilizer. This system is focused to maintain a stabilizier position when the camera follows the movement of the hexacopter. In addition, use of this method to obtain performance automatic control gimbal camera stabilization better because controlled with Sugeno fuzzy logic method because it has a simple calculation so the response is faster and more suitable for real-time applications.

II. BASIC THEORY

A. *Hexacopter*

Hexacopter is one type of multicopter that has 6 propellers or motor which located vertically from a hexagon and same distance from the the center of gravity [1]. There are 2 configuration synchronization brushless motors are commonly used in the hexacopter, the configuration of the frame plus (+) and frame plus (x) which can be seen in Figure 1.

Fig.1 Configuration Frame *Hexacopter*

Hexacopter has advantages and disadvantages, while the advantages are when the one of motors broke in the air, the vehicle can still be saved indirectly pierced the ground and heavy lift offered hexacopter greater in comparison quadcopter or tricopter. While the disadvantages are when hexacopter has bigger size so when maneuvering feels more bit responsive because the motors is larger.

B. *Accelerometer Sensor And Gyroscope Sensor*

Accelerometers are sensitive to both linear acceleration and the local gravitational field. The working principle of this sensor is based on the laws of physics that when a conductor is moved through a magnetic field will give rise to an induction voltage on the conductor. Accelerometer placed on the surface of the Earth can detect the acceleration of 1g (the size of Earth's gravity) at the point of the vertical, the acceleration due to horizontal movement of the accelerometer to measuring acceleration directly when moving horizontally. Accelerometer sensor output in the form of an analog voltage that represents the data in units of gravitational acceleration (g) is directly proportional to the slope[2].

Gyroscope has an output that is sensitive to the angular velocity of the x-axis direction which will be the angle phi (roll), on the y-axis will be the angle theta (pitch), and the z-axis will be the psi angle (yaw). Now gyroscope applied together with the accelerometer. When the accelerometer measurements combined with measurements gyroskope, developers can create applications that can sense motion on six-axis, ie the top and bottom, left and right, forward and backward, as well as rotational roll, pitch and yaw. The following describes the orientation of the gyroscope roll, pitch and yaw axis [2].

C. Control Board

Brushless gimbal control board which utilizes a 6-axis gyro/accel with Motion Processing Unit to stabilize your camera gimbal while in flight. It offers highly precise and smooth brushless gimbal stabilization. Microcontroller this board is ATMega328. Onboard FT232RL for debug and On board logic level converter

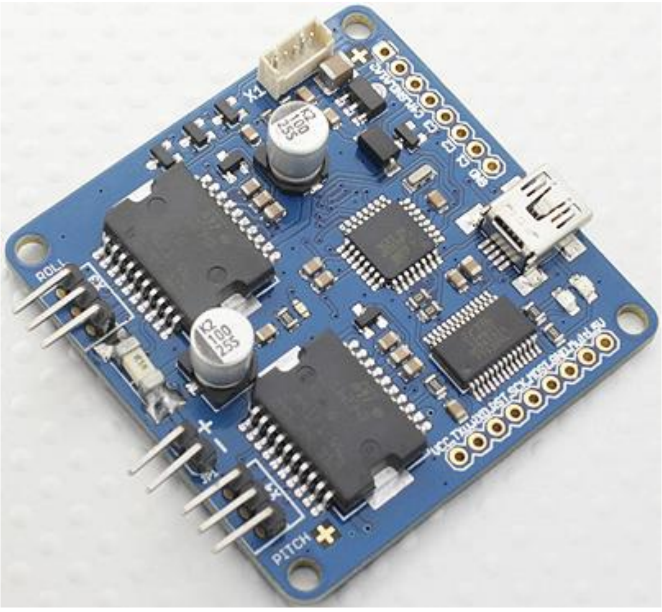

Fig. 2 Control board Gimbal Camera 2-Axis

D. Gimbal Camera and Brushless Gimbal Direct Drive

Gimbal Camera system that serves as a stabilizer and as a vibration damper for produced by the movement of multicopter. Gimbal is a device used cinematography to keep the camera so that the camera can take pictures with either at a particular point of view [4]. Gimbal has enhancements to rotate which allows the rotation of an object mounted on a single axis gimbal to remain independent of the rotation support. In implementation, the brushless motor is placed on roll axis and pitch axis. Depending on the application, a number of key performance characteristics are of primary importance when selecting a positioning system:

1. Accuracy is defined as the difference between the actual position in space and the position as determined by an independent measurement device.
2. Repeatability is the range of positions attained when the system is repeatedly commanded to one location under identical conditions.

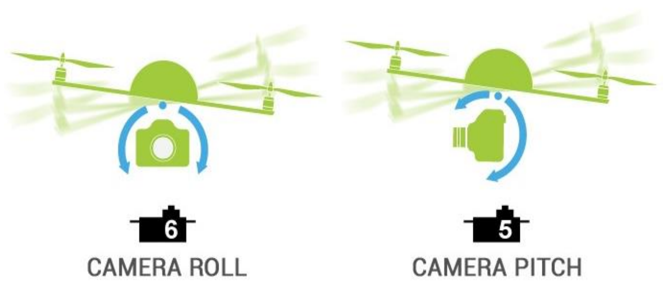

Fig.3 Example for Gimbal Stabilitation

Gimbal camera has a type. One type of gimbal camera is brushless gimbal direct drive. brushless gimbal direct drive is Direct drive mechanism to take the power that comes directly from the motor without reduction (such as the gearbox). So direct drive can achieve higher accuracy than using the gear. Brushless direct drive gimbal has three main components, the IMU controller, brushless motor and mechanical framework. Brushless dreadlocks require a very precise balancing of the center of gravity. This allows the motor to rotate the camera with ease and responsiveness.

E. Complementary Filter

Complementary filter algorithm is used to combine the readings from the sensor Accelerometer and Gyroscope sensor. The merger was intended to obtain results more accurate angle measurement. Accelerometer sensor can give an accurate value of the tilt angle when the system is at rest (static), but the accuracy is reduced when the system is in motion (dynamic) because the sensor accelerometer not able to follow the rapid movement because it has a slow response and also has a noise in the measurement. Meanwhile, Gyroscope sensor can provide value tilt angle in motion (dynamic) but become inaccurate in a state of long-term due to the effect of bias (drift) generated by the gyroscope. Below is a schematic of Complementary Filter algorithm. In general, the equation applicable to the algorithm Complementary Filter is:

*Angle = (a) * (Angle + Gyroscope's value * dt) + (1-a) * (Angle Calculation of the Accelerometer's Value)* (1)

When :

1. a = Filter coefficients
2. dt = sampling time, adjusted for the time value of sensor sampling
3. Angle = angle complementary filter output
4. Gyroscope's value = a gyroscope sensor output angular velocity
5. Calculation Angle of the Accelerometer's Value = output accelerometer sensor which has a angle

Value of a can used of 0.98 in the above equation is constant value for the High-Pass Filter contained in Gyroscope sensor, while the value of 0.02 (1-a) is the constant value of the Low-Pass Filter contained in accelerometer sensor.

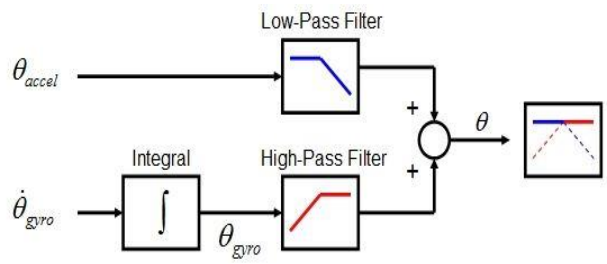

Fig. 4. Complementary schemes Filter algorithm [5]

F. Fuzzy Logic Method

Fuzzy logic is a logic that has a blur value between right and wrong. A fuzzy rule-based system consists of three main components: Fuzzification, Inference and defuzzyfication as shown in Figure 5. Shows block diagram system of the fuzzy rule-based.

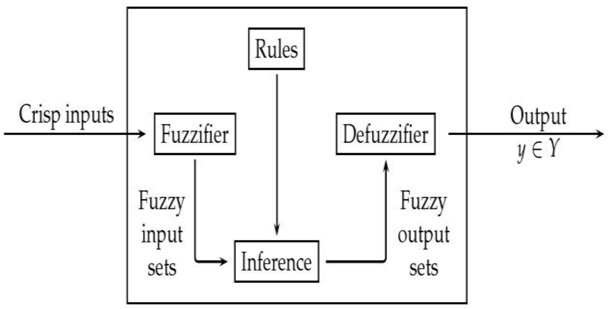

Fig.5 Block Diagram System Of The Fuzzy Rule-Based[7].

Fuzzy logic has several methods of which Takagi-Sugeno method, Mamdani method and fuzzy logic, and etc. Tagaki Sugeno method proposed by Takagi and Sugeno [2] is described by fuzzy IF-THEN rules which represents local input-output relations of a nonlinear system. The main feature of a Takagi-Sugeno fuzzy model is to express the local dynamics of each fuzzy implication (rule) by a linear system model. Sugeno models using singleton membership functions. Singleton is a fuzzy set with a membership function which has a degree of membership of 1 in a single crisp value and 0 at all other crisp values [7].

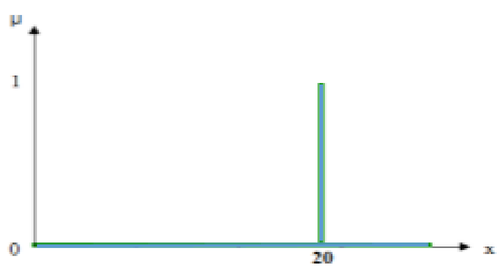

Fig. 6 Membership Function Singleton

Fuzzy model with the sugeno method of having rules in the form:

IF (x1 is A1) AND ... AND (xn is An) THEN y = f (x1, ...xn) (2)

where f can be any function of the input variables whose values are in the interval of the output variable. In the Sugeno method, defuzzification is done by calculating Weighted Average (WA) which takes the average value using a weighted membership degrees. So y * is defined as follows [7]:

$$y^* = \sum \frac{\mu(y)y}{\mu(y)} \quad (3)$$

where y is the crisp values and μ (y) is the degree of membership of crisp values of y.

III. DESIGN AND IMPLEMENTATION SYSTEM

A. General Design of Stabilization System 2-Axis Gimbal Camera

The system is designed for 2-axis gimbal camera stabilization can be seen in Figure 7.

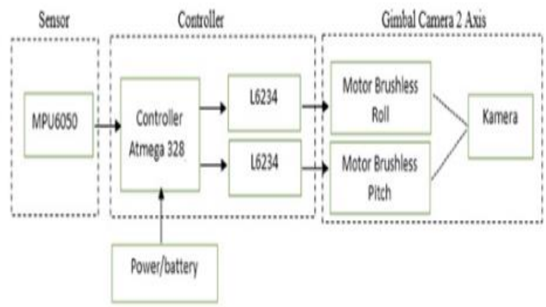

Fig. 7 Block Diagram System

From Figure 7 is an illustration of the design of the 2- axis gimbal camera stabilization system as a whole based on the block diagram. Needs of the system in this study is a hexacopter that already has a good configuration as the plant to be controlled. The system input is derived from accelerometer sensor and gyroscope sensors are integrated in the module datu MPU6050 hexacopter a tilt angle which will in advance filters using complementary filters. The input will be processed in the module control board 2-axis gimbal that is integrated with the controller ATMega 328. Method used to control the camera gimbal stabilizer using fuzzy logic as an automatic controller. The system used is a method of fuzzy Sugeno. The output of the microcontroller in the form of the movement of two brushless motors roll and pitch that functions as a stabilizer gimbal camera.

B. Hardware Design

Hardware used in this study consists of MPU 6050 module, 2-Axis Gimbal Control Board and motor brushless 2-axis gimbal camera gimbal. This section, the design of a prototype 2-axis gimbal camera stabilization system can be seen in Figure 9. Where there is a 2-axis gimbal control board that has been integrated. MPU6050 module that serves as an input accelerometer sensor and gyroscope sensor connected to the control board via the I2C lines. I2C lines is one type of communication between electronic components with a microcontroller. This communication requires 2 cables which SDA cable and SCL cable. SCL cable is used to give the corresponding clock. SDA cable is used to obtain the data from the electronic components. Two 2-axis gimbal brushless DC motor driver connected to L6234PD integrated on the control board. And the battery used as a power supply of the system 2 axis camera gimbal stabilization is battery 3 cell Li-Po 1000 mAh capacity and 11.1 V. Programming on 2-axis gimbal control board using the Arduino programming the microcontroller ATMEGA 328. Where the latter has been found firmware from the vendor that is open source. Hardware design 2-axis gimbal camera stabilization can be seen in the figure below:

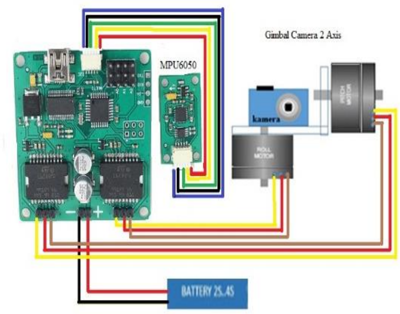

Fig. 8 Design Hardware Stabilization System

C. *Software Design*

The software design in this study consisted of two, that is complementary filters and Sugeno Fuzzy logic. In this final design software used to create the program that is microcontroller using the C programming language. Design Software (software) is done by creating a flow diagram (flowchart) first. After that, the program is made by following the flow diagram (flowchart) as shown in Figure 9.

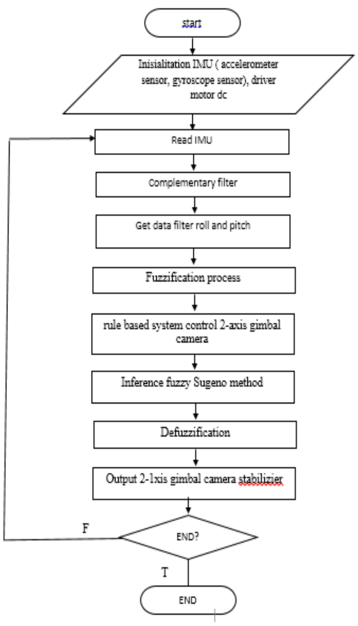

Fig. 9 Flowchart of Software

1) *Complementary Filter*

Basically complementary filter is the sum of the angles between the accelerometer readings are passed LPF (Low Pass filter) and the angle of the gyroscope readings after passed HPF (High Pass Filter). Here is a flowchart from complementary filters on the IMU sensor as shown in Figure 10.

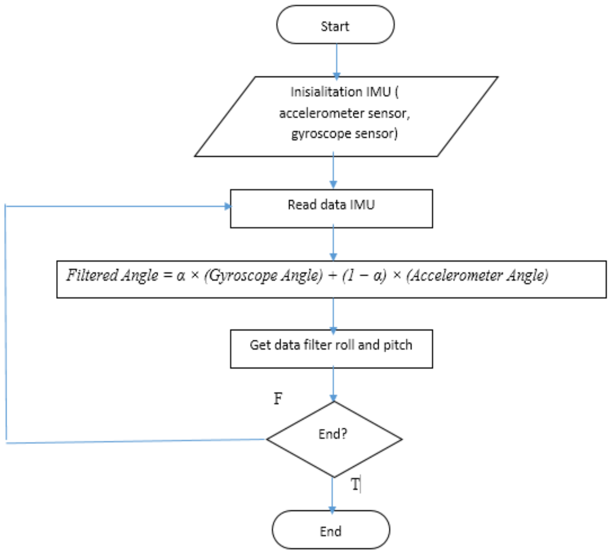

Fig. 10. Flowchart of Complementary Filter

2) *Fuzzy Logic*

Fuzzification

Design of Fuzzy Controller intended that the controller output as wished in order to obtain the expected output. Determination of fuzzy control diagram using the reference gimbal desired way of working, which can stabilize the position of the camera. Fuzzification process in roll variable has theree linguistic variable that are Miring Kiri, Stabil, and Miring Kanan. Based on specified linguistic variables, then the membership function of the roll variable can be seen in the figure 11 below

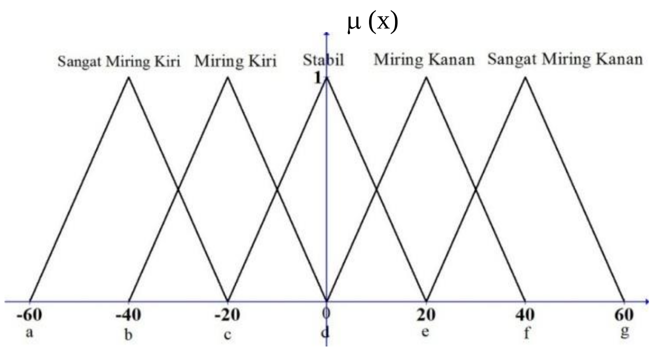

Fig.11 Membership functions Roll Variables

Fuzzification process in pitch variable has three linguistic variable that are Angguk Bawah, Stabil, and Angguk Atas. Based on specified linguistic variables, then the membership function of the roll variable can be seen in the figure 12 below

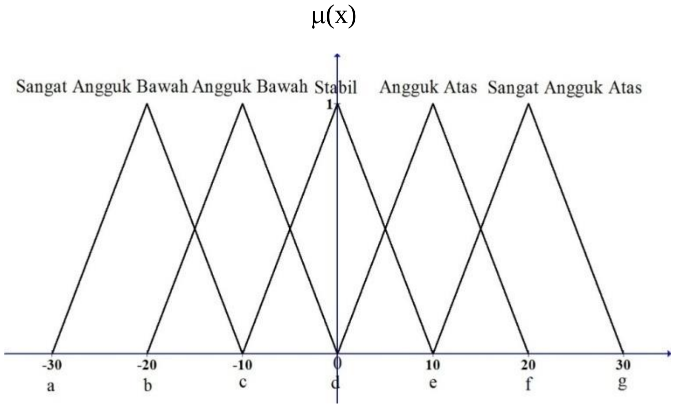

Fig. 12 Membership fuctions Roll Variables

Fuzzy Inference

Inference process used is a clipping method, that is Max-Min function of the linguistic values of the fuzzy rule base and generate output with singleton function. In figure 13 and 14 shows the linguistic variables to the output of a brushless roll and brushless pitch.

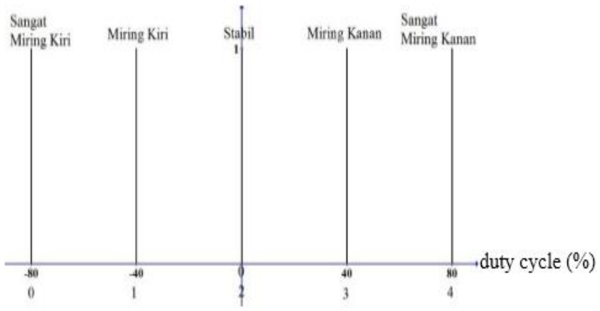

Fig. 13 Membership Functions Value Variables PMW (Roll)

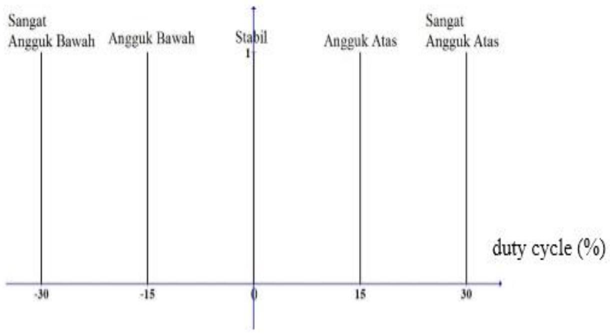

Fig. 14 Membership Functions Value Variables PMW (Pitch)

Defuzzification

In defuzification using the Weighted Average method as suitable for Sugeno method which has one dimension. This method takes the average value using a weighted membership degree. The formula of the Weighted Average used can be seen in equation 3.

IV. TEST RESULTS AND ANALYSIS

A. Design Results

The result of the design of a mechanical system of 2-axis gimbal camera on hexacopter that a proper connection at each of its components. Overall, stabilization 2-axis gimbal camera system on hexacopter seen in Figure 15.

Fig.15 Stabilitation System Gimbal Camera on Hexacopter

B. Sensor Test Results

Output accelerometer sensor and gyroscope sensor in the design of this system will produce output of angle on the x-axis (roll) and the y-axis (pitch). In graph below will be seen the comparison angle on each axis before and after filtration by using complementary filters. This is graph x-axis results

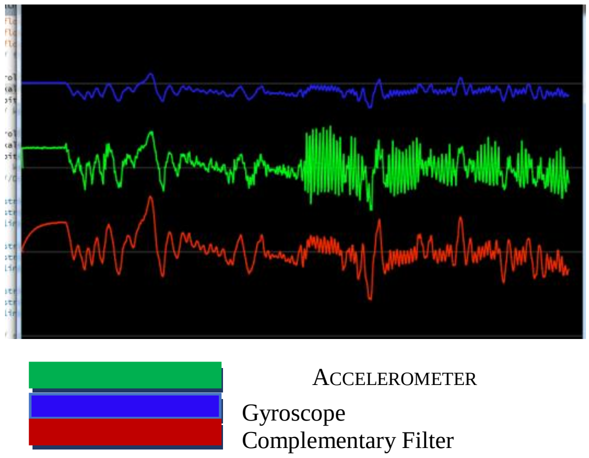

Fig. 16 Output Sensor x-axis

This is graph y-axis results :

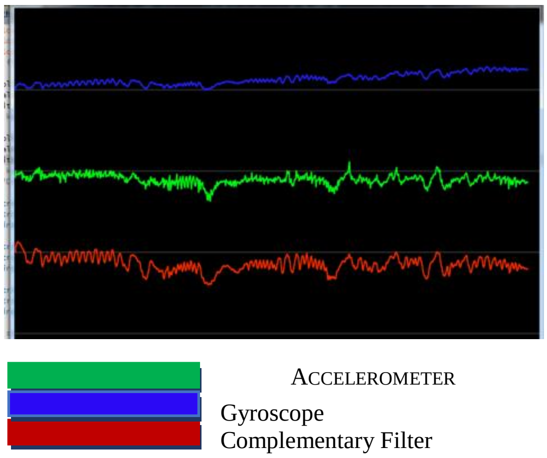

Fig. 17. Output Sensor y-axis

V. Analysis and Simulation Result

Testing in this paper using MATLAB Fuzzy Inference System Editor (FIS Editor) with Takagi Sugeno method. Fuzzy Toolbox is used to facilitate the use of fuzzy logic in MATLAB that can be seen in Figure 18.

Fig. 18 . Fuzzy Inference System Editor (FIS Editor)

The first validation process is performed while fuzification process where we determine that the input angle x-axis (roll) and the input angle y-axis (pitch) and the output of a brushless gimbal duty cycle consisting of roll and pitch output. The range of values for the input linguistic angle of the x-axis (roll) is (-60°) -60°. While the angle of the y-axis (pitch) is (-30°) - 30°. The range of values of the linguistic output brushless roll is (-80%) - 80%. As for the output brushless pitch is (-40%) - (40%).

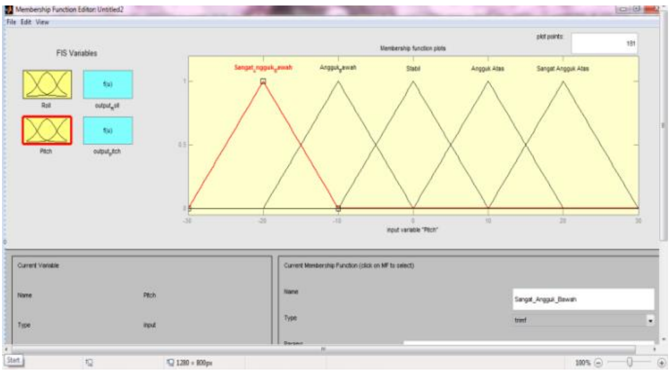

Fig. 19 Degree of Membership Functions Input x-axis (roll)

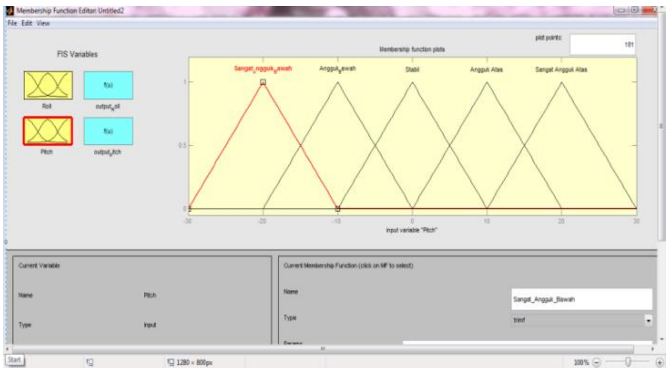

Fig. 20 Degree of Membership Functions Input oy-axis(pitch)

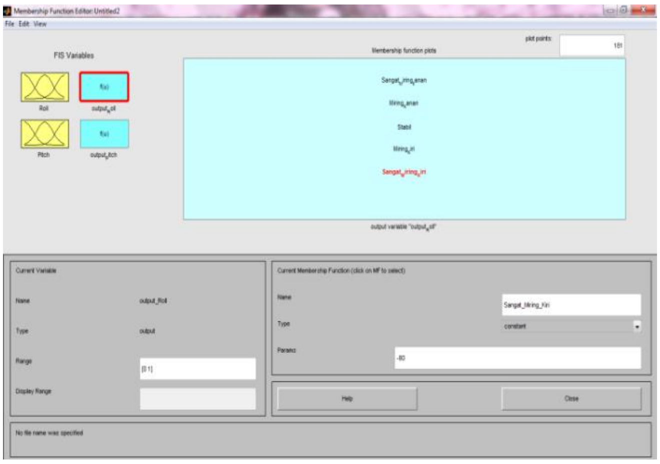

Fig. 21 Degree of Membership Function Duty Cycle Output (Roll)

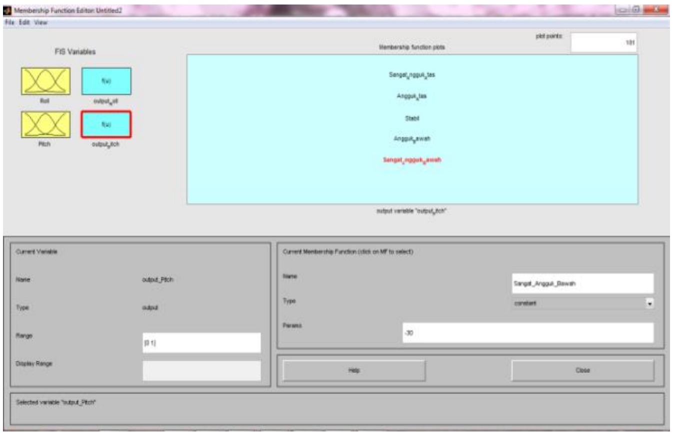

Fig. 22 Degree of Membership Function Duty Cycle Output (Pitch)

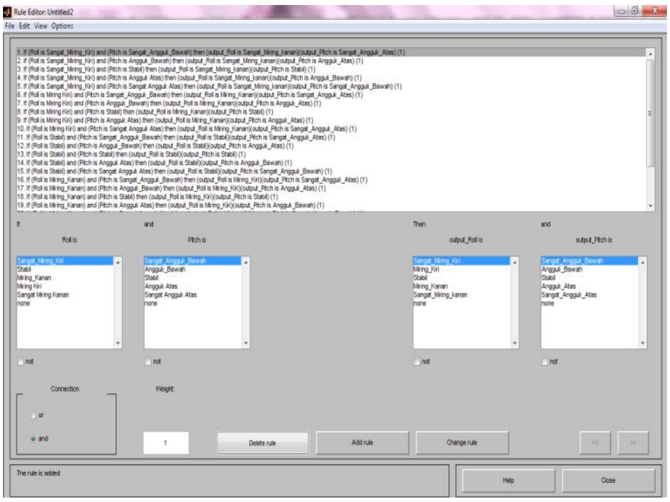

Fig. 23 Rule Base_1

The second process validation on Fuzzy Inference System Editor determine the rule base. In this system there are 25 rule base, each of which has a corresponding input and output. To see the rule base of the fuzzy inference system editor can be seen in Figure below :

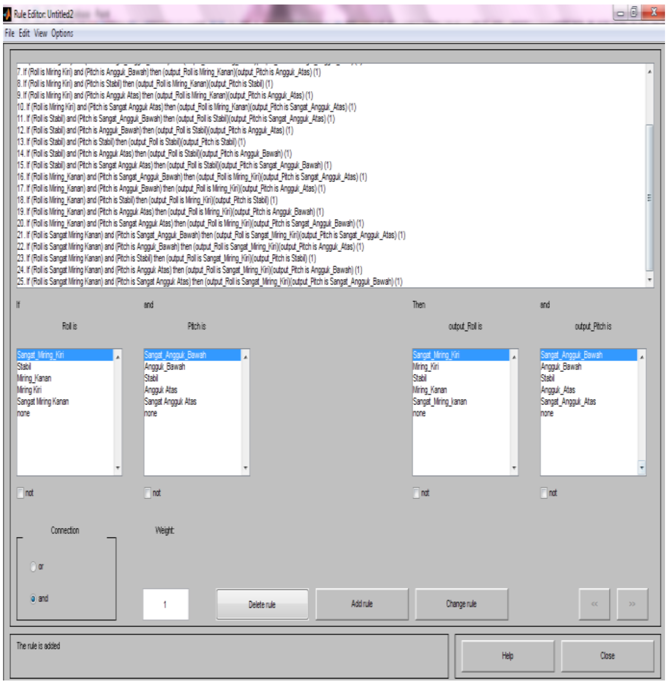

Fig. 24 Rule Base_2

A simple case studies of the value of the two inputs on the roll and pitch is 35° and 17°. What is the value of output duty cycle is generated?

In the rule viewer FIS Editor, the value of both inputs 35° and 17°. will be entered into the *Fuzzy Inference System Editor (FIS Editor)* to see the results of fuzzy simulation. The output can be seen in figure 24 which shows the results of roll -70% and the results of pitch -25.5%.

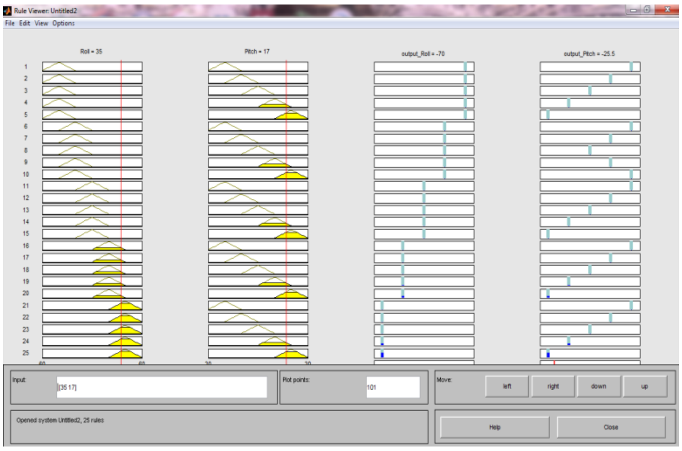

Fig. 25 Results of MATLAB FIS Editor

To test this MATLAB simulation results, we can use a manual calculation using the formula.

a. Output Roll

$$y *= \frac{[(0.25) * (-40)] + [(0.7) * (-80)]}{(0.25) + (0.7)}$$

$$\frac{(-10)+(-56)}{0.95}$$

$$\frac{(-66)}{0.95}$$

$$y *= -69{,}47\ \%$$

b. Output Pitch

$$y *= \frac{[(0.3) * (-15)] + [(0.7) * (-30)]}{(0.3) + (0.7)}$$

$$\frac{(-4.5)+(-21)}{1}$$

$$\frac{(-25.5)}{1}$$

$$y *= -25{,}5\ \%$$

VI. CONCLUSIONS

After testing and analysis on the implementation of the stabilitation gimbal camera system, it can be concluded:

1. The results showed that the sensor output data has noise that greatly affect the stability of the 2-axis gimbal camera, so the author uses a complementary filter to reduce the noise of the sensor output in order to get more accurate data and mengabunggkan cover the advantages and disadvantages of each sensor.
2. Studies case to output brushless 2-axis gimbal camera using fuzzy logic method manually later in validation while using MATLAB (Fuzzy Inference sytem Editor) showed similar results with 2 inputs and 2 outputs. Where the duty cycle output for brushless roll (x-axis) is -69.47% is rounded to -70% on MATLAB and the output duty cycle for brushless pitch (y-axis) is -25.5%.

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