Autonomous Pole Balancing Design In Quadcopter Using Behaviour-Based Intelligent Fuzzy Control

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***Abstract*— Quadcopter is a helicopter UAV that uses four rotors of propeller to maneuver [1]. Some Quadcopter development uses the concept of artificial intelligence behavior-based intelligent fuzzy control (BBIFC). Some quadcopter maneuver movements that are currently being developed include cooperative movement between quadcopter, rotating and reversing movements, ball throwing movements, obstacle avoidance movements, ball capture movements, and automation of balancing motion on quadcopter. The balancing motion includes balancing when flying at a certain position, balancing for landing, and balancing when carrying loads [2]. Autonomous Pole Balancing on Quadcopter has been designed and implemented using Behavior-Based Intelligent Fuzzy Control, the design of automation of quadcopter motion in balancing with carrying loads namely a pole placed on a quadcopter. Quadcopter is used to balance the pole, so that in one calculation cycle must be completed before the pole falls. With an angle of 800 tolerance, the pole will arrive at the slope angle within 1 second, so that, in one calculation cycle must be completed in less than 1 second.**

***Keywords*— Quadcopter, Autonomous Pole Balancing, Behavior-Based Intelligent Fuzzy Control**

I. INTRODUCTION

In the last decade the world of aviation experienced rapid development with the presence of unmanned aerial vehicles or the so-called Unmanned Aerial Vehicle (UAV). One type of UAV that is widely researched today is quadcopter, because the quadcopter has dynamic maneuverability and a simple mechanical system. Quadcopter is a helicopter UAV that uses four rotors of propeller to maneuver [1]. Some Quadcopter development uses the concept of artificial intelligence behavior-based intelligent fuzzy control (BBIFC).

Behavior-based intelligent fuzzy control is an algorithm for automating pole balancing motion control on quadcopter. Behavior-based algorithms are one of the algorithms that are widely used in robot development. Behavior-based control algorithms are derived from the natural properties of living things in accordance with their environmental conditions. The BBIF concept is used to maximize the motion potential of a quadcopter [3]. Some quadcopter maneuver movements that are currently being developed include cooperative movement between quadcopter, rotating and reversing movements, ball throwing movements, obstacle avoidance movements, ball capture movements, and automation of balancing motion on quadcopter. The balancing motion includes balancing when flying at a certain position, balancing for landing, and balancing when carrying loads [2].

This study discusses the design of automation of quadcopter motion in balancing when carrying loads, namely a pole placed on a quadqopter. Initially the quadcopter requires control in the form of a radio transmitter that is manually controlled by humans so that there is often an imperfect balancing motion. The balancing movement is very difficult to control manually by a quadcopter pilot [1].

Quadcopter automatic control system includes hardware architecture in the form of processing units and software architectures. The hardware architecture of the balance control system includes sensors, motors, propellers, and controllers. While the software architecture is in the form of an artificial intelligence algorithm to automate by regulating the rotating speed of the propeller to carry out balancing movements based on input data from the sensor. While fuzzy logic acts as a determinant of the existence of elements [4]. Furthermore, fuzzy logic acts as an algorithm that will determine the direction of quadcopter motion.

With the error in the manual control using the radio transmitter to perform balancing motion on the quadcopter, researchers want to design autonomous pole balancing on the quadcopter using behavior-based intelligent fuzzy control. So that errors in the manual control using radio transmitters can be minimized by changing the manual control to automatic control. The aim of this research is to produce a quadcopter that can be controlled automatically by the controller by using behavior-based intelligent fuzzy control to balancing on a pole.

II. METHODOLOGY

A. Definition of Quadcopter

Quadcopter is one type of rotorcraft which has 4 rotors as propeller drive which produces lift force. Quadcopter can take off and landing vertically. Vertical Take Off Landing (VTOL) [5]. Aircraft is a type of aircraft that can take off and landing perpendicular to the earth so that it can be done in a narrow place. Helicopters, tricopter, quadcopter and multirotor of the same type are included in this category. By changing the speed of the fourth rotation of the motor, the quadcopter can move up, down, forward, backward, left, right, and rotate.

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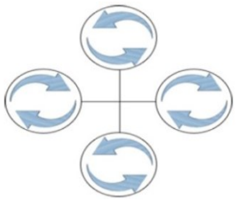

Fig.1. Direction of rotary motion of a quadcopter propeller [6]

Quadcopter has two pairs of propellers that are placed crossed as shown in 2.1. The direction of the propeller motion also has opposing motion. This aims to reduce the rotating moment in the center of the quadcopter frame [6].

B. Quadcopter movement

Quadcopter moves based on the speed of each propeller. There are 4 basic movements of the quadcopter, namely: [1]

1) Throttle or height.

This motion can be done by increasing or decreasing the speed of all propellers in the same amount

2) Roll

This motion can be done by increasing or decreasing the speed of one of the left or right propellers

3) Pitch

This motion can be done by increasing or decreasing the speed of one of the front or rear propellers.

4) Yaw

This motion can be done by increasing or reducing the speed of the rear and right rear propellers toget.

C. Quadcopter Forming Components

1) Frame

Quadcopter frame is an important component that functions as a maker of quadcopter and as a place to assemble other components. The design of the quadcopter frame varies. In general, the quadcopter frame has four arms, as shown in Figure 2.

Fig. 2. Quadcopter frame

2) Propeller / propeller

In the quadcopter consists of two propellers will be made to rotate clockwise, and two more rotate counter-clockwise. The propellers will produce a wind boost so that the quadcopter can maneuver. The selection of propellers focuses on the size, material and precise shape. This is because it will affect the flight balance, shown in figure 3.

Fig. 3. Propeller

a. Motor

The motor is the part that drives the propeller. The motor is placed at the ends of the quadcopter frame arm. These motors are usually available in motor dimension sizes and their strength in units of kv (kilo volts) or rpm / v (rotation per minute / volt), shown in figure 4.

Fig. 4. Motor Movers

b. Electronic Speed Control (ESC)

Electronic Speed Control (ESC) acts to regulate the speed of each motor. This ESC will usually automatically adjust the speed or current to each motor. When the plane's position is tilted, the ESC will automatically send or make one or several motors spin faster to make the plane balance. The number of ESCs on a quadcopter corresponds to the number of motors, shown in Figure 5.

Fig. 5. Electronic Speed Control (ESC)

c. Ardu Pilot Mega

Flight controller is a component that acts as the main control on a quadcopter. Flight control receives data from the sensor then processes the data and sends it to the actuator. In general, flight control has the main components, including: main processor, sensor and actuator connecting ports, programming ports, and power ports, such as figure 6.

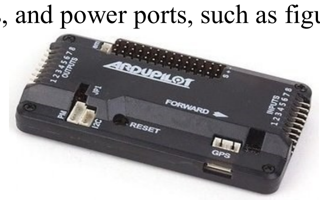

Fig. 6. Ardu Pilot Mega

D. Behavior-Based Intelligent Fuzzy Control.

BBIFC (Behavior-Based Intelligent Fuzzy Control) is a modification of the behavior-based control by adding intelligent fuzzy control into a behavior-based intelligent fuzzy controller architecture which is a fuzzy controller designed and implemented to control quadcopter, both for rotational motion and translational motion. Rotational motion includes roll, pitch and yaw motion. Whereas translational motion consists of motion x, y, and z. [1].

E. Fuzzy Logic

Fuzzy logic control system is also called Fuzzy Inference System (FIS) or fuzzy inference engine is a system that can do reasoning with principles like humans do reasoning with their instincts. There are several types of FIS known, namely Mamdani, Sugeno and Tsukamoto. Fuzzy logic control system consists of several stages as in the following diagram. [7].

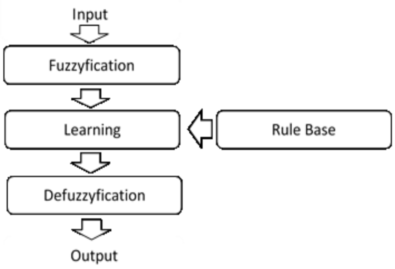

Fig. 7. Fuzzy Logic Control Process [4]

F. Stages of Design using the Waterfall model.

Model design using the waterfall method is often also called a linear sequential model. The sequential or sequential waterfall model starts from analysis, design, coding, testing and supporting phase. The following illustration of the waterfall model can be seen in Figure 8

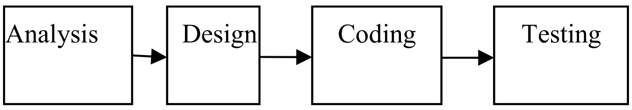

Fig. 8. Waterfall Model

The design stage is the stage where the needs are translated into a representation of software that can be assessed for quality before the encoding process begins [8].

III. RESULTS AND DISCUSSIONS

A. User Characteristics

This BBIFC controller user is a quadcopter. Explanation can be seen in table 1.

TABLE I. USER CHARACTERISTICS TABLE

No	Actor	Description
1	Quadcopter	Quadcopter can read input and output to pole balancing

Quadcopter with BBIFC control system can balance the pole above it and maintain flying height. The sensor will provide input data that will be forwarded to the flight controller to make the BBIFC decision process and produce output to be forwarded to the actuator.

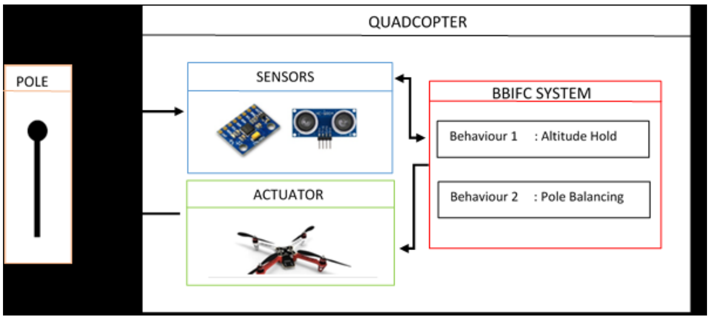

Figure 9. Software Architecture Designing autonomous pole balancing on a quadcopter uses behavior-based intelligenet fuzzy control.

B. Hardware Components and Architecture

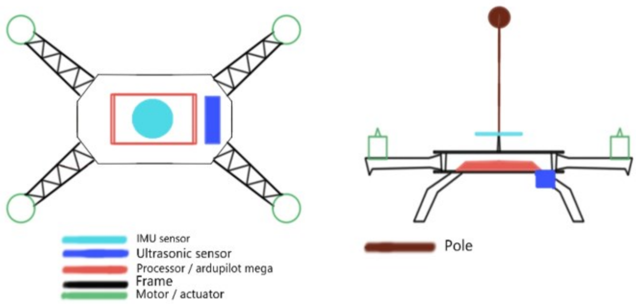

Fig. 10. Hardware Architecture Designing autonomous pole balancing on a quadcopter uses behavior-based intelligenet fuzzy control.

The hardware needed to run this application is:

1) Sensor

The sensor consists of 1 IMU sensor (Inertial Measure Unit) with MPU6050 type and 1 ultrasonic proximity sensor with type HC SR-04.

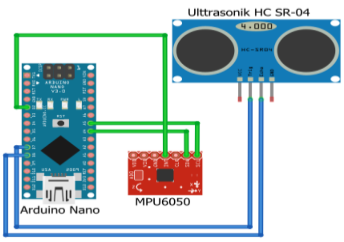

Fig. 11. Sensor devices consisting of IMU MPU6050 sensor and HC-SR04 ultrasonic proximity sensor

2) Control Unit

The Control Unit used in this study is Arduino Nano V3.0 and Ardupilot Mega. Arduino Nano receives sensor input and then perform calculation calculations with fuzzy logic controllers and the results are forwarded to Ardupilot Mega as PWM signal to control the actuator used to drive the motor in accordance with the velocity value generated by a BBIFC system.

3) Actuator

The actuator on the quadcopter consists of 4 pieces of ESC with Simonk type 30A 3s-4s, Li-Po 4s 1300 mah 14.8 volts, 4 920Kv brushless motors. This actuator receives electric waves according to the velocity values generated from fuzzy logic calculations. The design of the actuator circuit to the control unit is as follows:

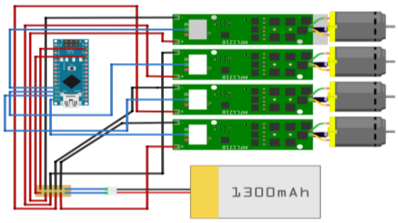

Fig. 12. Actuator devices consisting of 4 brushless motors

C. *Quadcopter performance*

Quadcopter with BBIFC control system can balance the pole above it and maintain flying height. The sensor will provide input data that will be forwarded to the flight controller to make the BBIFC decision process and produce output to be forwarded to the actuator. Quadcopter is used to balance the pole, so that in one calculation cycle must be completed before the pole falls. With an angle of 800 tolerance, the pole will arrive at the slope angle within 1 second, so that, in one calculation cycle must be completed in less than 1 second.

D. *Input variables for Quadcopter movements (fuzzy model)*

The input of this Fuzzy controller is variable speed for roll, pitch and throttle motion. Position variables for mamdani and sugeno methods use the same set, as shown bellow.

TABLE II. VARIABLE SPEED DISTRIBUTION

No	Fuzzy Set	Description
1.	NEGATIVEBIG (NB)	Negative big position
2.	NEGATIVESMALL (NS)	Negative small position
3.	ZERO (Z)	Centre position
4.	POSITIVESMALL(SN)	Positive small position
5.	POSITIVEBIG(PB)	Positive big position

1) The membership input function for pole balancing behaviour.

a) The membership input error function for *roll* and *pitch* motion is shown in figure 13.

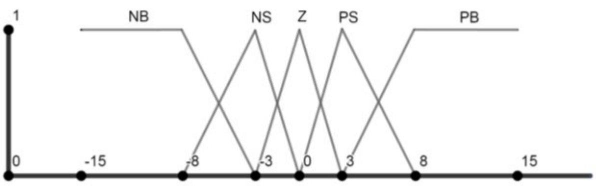

Fig. 13. Membership function input error for roll and pitch motion

b) The de_error input membership function for roll and pitch motion has the following equation

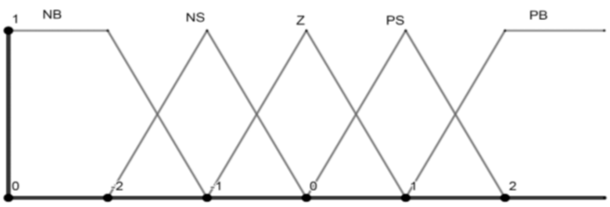

Fig. 14. De_error input membership function for roll and pitch motion

2) The membership input function for pole balancing behaviour.

a) The *input error membership function for throttle motion has the following equation:*

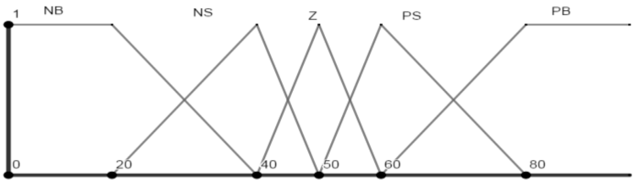

Fig. 15. Membership function input error for throttle motion

b) The membership function of the input de_error for throttle motion has the following equation:

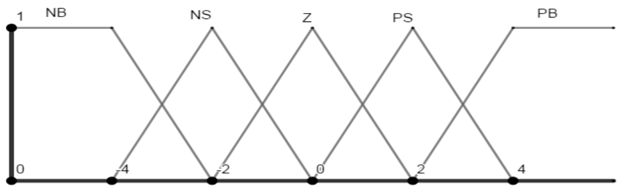

Fig. 16. The membership function input is de_error for throttle motion

E. *Quadcopter Output Variable*

The output of this Fuzzy controller is variable speed for roll, pitch and throttle motion. Speed variables for mamdani and sugeno methods use the same set, as shown bellow.

TABLE III. VARIABLE SPEED DISTRIBUTION

No	Fuzzy Set	Description
1.	FASTPOSITIVE (FP)	Fast positive motion
2.	SLOWPOSITIVE (SP)	Slow positive motion
3.	STOP (S)	No motion
4.	SLOWNEGATIVE (SN)	Slow Negative motion
5.	FASTNEGATIVE (FN)	Fast negative motion

For fuzzy logic, mamdani uses fuzzy set speed variables which are represented as follows:

1) Output membership function for roll and pitch motion.

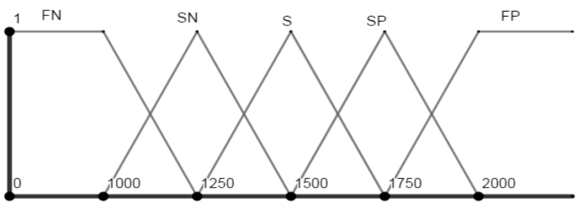

Fig. 17. Output membership function for roll and pitch motion

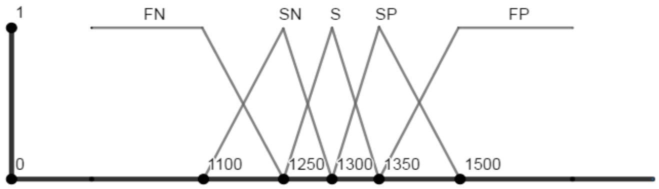

Fig. 18. Output membership function for throttle motion

2) Output membership function for throttle motion.

F. Fuzzy rule base

Fuzzy rule base contains basic rules that define fuzzy sets for the input and output regions in the control rule device. FIS consists of several rules, inference obtained from collection and correlations between rules. Both Mamdani method or Sugeno method use MIN implication. Rule base implication shown bellow.

TABLE 4. FUZZY RULE BASE TABLE.

Error/ de_err	**NB**	**NS**	**Z**	**PS**	**PB**
NB	FP	FP	SP	S	SN
NS	FP	SP	S	S	SN
Z	FP	SP	S	SN	FN
PS	SP	S	S	SN	FN
PB	SP	S	SN	FN	FN

Explanation:

1. If error = NB and de_error = NB then output = FP
2. If error = NB and de_error = NS then output = FP
3. ….
25. If error = PB and de_error = PB then output = FN

IV. *IMPLEMENTATION*

The system implementation of the design has been done based on the results of the design of Autonomous Pole Balancing on Quadcopter using Behavior-Based Intelligent Fuzzy Control.

a. Hardware Implementation. The results of robot hardware implementation can be seen in Figure 21.

Fig. 19. Hardware implementation top view.

Fig. 20. Hardware implementation side view.

V. *TESTING*

Testing plan autonomous pole balancing design in quadcopter using behaviour-based intelligent fuzzy control is divided in two experiments.

1) Experiment 1 (computation speed)

Experiment 1 was tested the system by calculate how long the system computing several datas started from input to output in a loop of the program and compares among mamdani and sugeno method.

TABLE V . EXPERIMENTS 1'S RESULT TABLE.

No	Input			Output			Calculation Time (milisecond)
	roll	pitch	throttle	roll	pitch	throttle	
1	-5	-7	10	1317	1210	1493	17
2	2	-1	38	1522	1398	1342	17
3	10	4	62	1874	1606	1261	18

2) Experiment 2 (actual test)

Experiment 2 was tested the system by running the system in actual environment and shows data in two graphs (mamdani graph and sugeno graph) which has 2 result variable. First variable is optimum result, second variable is actual result.

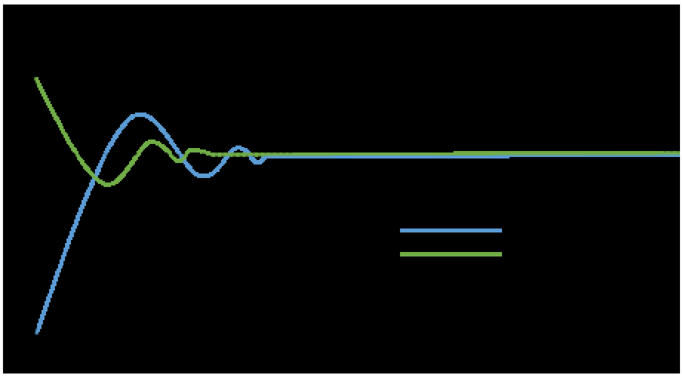

Fig. 21. Actual result chart for pitch and roll motion.

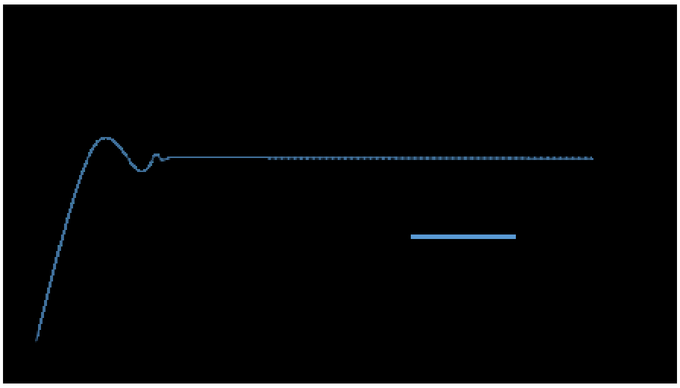

Fig. 22. Actual result chart for throttle motion.

VI. CONCLUSIONS AND RECOMENDATIONS

Autonomous Pole Balancing on Quadcopter has been designed and implemented using Behavior-Based Intelligent Fuzzy Control. The design of automation of quadcopter motion in balancing with carrying loads namely a pole placed on a quadcopter. Quadcopter is used to balance the pole, so that in one calculation cycle must be completed before the pole falls. With an angle of 800 tolerance, the pole will arrive at the slope angle within 1 second, so that, in one calculation cycle must be completed in less than 1 second.

Based on the experiments. Researcher has several recommendations for the future development about autonomous balancing. First, to improve Computation speed by replacing the processor which has higher clock speed such as arduino uno or arduino mega. In addition, to improve the precisions of the hardware component and the precissions of the hardware architecture. Lastly, for further research can study the conversion from Mamdani to Sugeno using heuristic algorithm methods such as genetic algorithms and adaptive neuro-fuzzy inference methods in order to produce more accurate set of output or use the sugeno fuzzy logic with ordo above zero.

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