Design of Flight Control System for Flying Wing UAV Based on Pitch and Roll Rotation

Tri Kuntoro Priyambodo, Andi Dharmawan, Oktaf Agni Dhewa, Nur Achmad Sulistyo Putro

Abstract— **Unmanned Aerial Vehicle (UAV) has capabilities to observe the earth surface from the air. But, to conduct the mission require a certain level of expertise to fly and control the UAV. It is not a simple thing to fly UAV for people who are new to the aero modelling. Flying wing as a fixed wing aircraft has an advantage of gliding flight. It can reduce the dependence on the thrust of the brushless motor. This is due to the support by a pair of wide wings so it can be maneuvered with sufficient speed. This paper shows how to develop a good flight control system design to make UAV can fly in the semi-auto mode. It also resulted design can overcome the rotation angle of roll and pitch that can occur when a plane disturbed in the sky.**

Index Terms— **Elevon, flying wing, sensor fusion**

I. Introduction

Unmanned Aerial Vehicles are unmanned aircraft that usually operated remotely by a pilot at a ground station. But, it can also fly autonomously conreolled by an algorithm that implanted [1]. At the beginning, UAV was developed to fulfil military purposes only, but as time goes by now the UAV has been used for other fields. Some missions like surveillance, reconnaissance, monitoring, air patrol, aerial photography usually used the UAV [2].

Flying wing is one of fixed-wing type UAV. Unlike other fixed-wing aircraft, the motion control of the aircraft is controlled not by the elevators, the ailerons nor the rudder, but through the elevons. It still uses a brushless motor as a power booster. Elevons is a combination of the elevators and the ailerons [3]. As a result of the absence of the rudder on this aircraft type, the aircraft is unable to perform yawing motions. As for the pitch and roll movements, this aircraft will use the elevons. Due to this elevons, the flying wing aircraft types do not require the presence of the tail (tailness). The design of flying wing aircraft is presented on the Fig.1.

By using a wide wing shape design, this plane has a good gliding ability. So, when it fly, it can reduce the dependence on the thrust of the brushless motor. In the other words, these aircraft have higher level of the efficiency on the power usage compared with other types of aircraft.

Manuscript received Sep 15, 2016

Tri Kuntoro Priyambodo, Department of Computer Science and Electronics, Universitas Gadjah Mada, Yogyakarta, Indonesia
Andi Dharmawan, Department of Computer Science and Electronics, Universitas Gadjah Mada, Yogyakarta, Indonesia
Oktaf Agni Dhewa, Department of Computer Science and Electronics, Universitas Gadjah Mada, Yogyakarta, Indonesia
Nur Achmad Sulistyo Putro, Department of Computer Science and Electronics, Universitas Gadjah Mada, Yogyakarta, Indonesia

With the differences in the motion flight dynamics on this flying wing type, the flight controller was also different from the other types of aircraft. This paper will discuss the design of flight control systems for flying wing UAV.

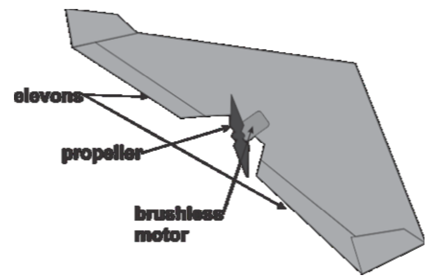


Fig.1 Design of flying wing UAV

II. SENSOR FUSION

Sensor fusion method is a method used to increase accuracy and eliminate noise in the sensory system. Only by using a single type of sensor, the output might only be accurate but is not resistant to noise. Every time there is noise, the sensor output will be inaccurate or change quickly. Currently, manufacturers embed sensor low pass filter for the sensor. So, it will reduce the noise due to the environment such as vibration, electrical sparks, or other things. However, only the use of low pass filter will not get the accuracy of the sensors for the better. So that the sensor fusion is one alternative that can be done. Moreover, the addition of a sensor filter can also obtain better results.

On this research, sensor fusion is used to fuse some sensor like gyroscope, accelerometer and magnetometer, to give a better accuracy on the orientation angle calculation result. For the fusion sensor method we can use any method such as Digital Motion Processing (DMP), Direction Cosine Matrix (DCM) [4], Kalman Filter [5], and Complementary Filter methods, but in this research we use DMP fusion sensor. On this research, we used fusion sensor to detect the orientation angle (pitch, roll and yaw) on the UAV. The orientation angle is the relative orientation of a body (UAV) relative to a global coordinate system (earth), that have the same origin. The body frame are x, y, and z axes (O_{xyz}) and the global frame is X, Y and Z axes (O_{XYZ}). Fig.2. shows the relativity between body frame and global frame.

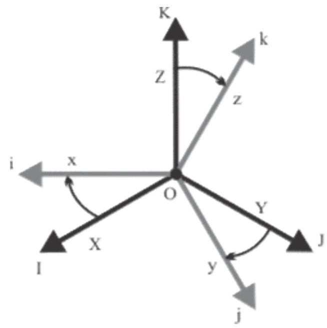


Fig.2 The relativity between body frame and global frame.

Digital Motion Processing (DMP) is a unit of digital signal processing that is embedded on the device MPU (gyroscope and accelerometer), which DMP receives the signal from the gyroscope and accelerometer via the I2C interface in the screening process sensor data and processing motion, where the motion information will be processed and forwarded to the processor. One advantage of using DMP is the availability of output data measured for the sample data gyroscope at high frequencies.

On the other hand fusion sensor and motion processing can be accessed via an algorithm embedded in the processor by adding libraries that are known Motion Processing Library, where the library contains algorithms such as compass sensor fusion, calibration, GPS integration, and much more [6]. MPU architecture of the processor communication with DMP shown in Fig.3.

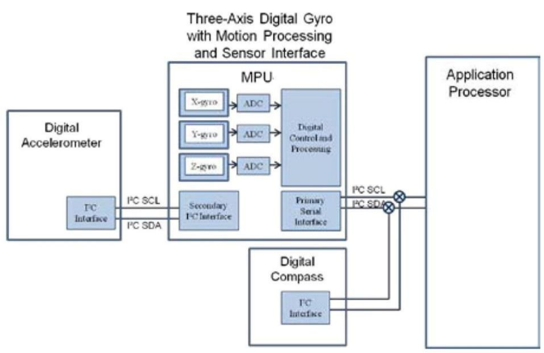


Fig. 3 MPU architecture of the processor communication with DMP[6]

III. FLYING WING FLIGHT DYNAMICS

As said before, the flying wing aircraft has a different flight dynamics to the flight dynamics of other fixed wing aircraft in general [7]. Flying wing aircraft cannot perform yaw movement because the movement is only governed by elevons only. It has no rudder. To give a thrust to the aircraft, it has a brushless motor which is placed at the rear of the plane. To move forward, the plane will get a thrust from the brushless motor, while the elevons' state is in neutral position [8]. Fig.4 shows how the flying wing flight forward.

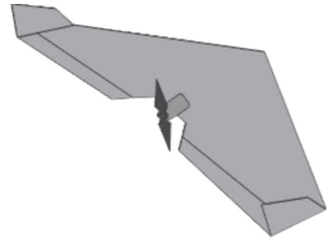
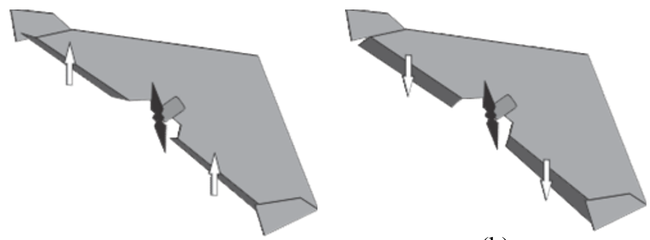


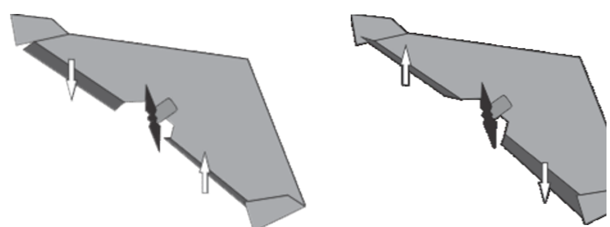
Fig. 4 Elevons in neutral position

The pitch movement on the flying wing obtained by arranging the elevons state (right elevon and left elevon) in the same position, which both up, or both down. In order to move the flying wing up, both of the elevon is being in up position. This situation is illustrated in the Fig. 5(a). Similarly, when the aircraft will be driven down, then both of the elevon will be arranged in the down position. This situation is illustrated in Fig. 5(b).



(a) (b)

Fig.5 Pitch movements on the flying wing (a) up and (b) down



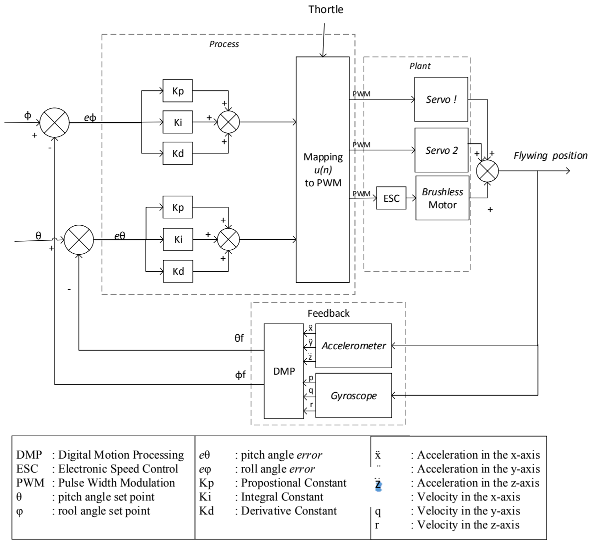
(a) (b)

Fig.6 Roll movements on the flying wing, (a) right and (b) left.

Roll movements on the flying wing aircraft is used to move the plane to the right or left. Roll movement is obtained by arranging the two pieces of the elevons at different positions, one in the up position while the other is in the down position. To move to the right, the elevon on the right wing is set in the up position, while the elevon on the left wing is set in the down position. Conversely, to enable a left movement, then the elevon on the left wing is set in the up position, while the elevon on the right wing is set in the down position. Fig. 6(a) shows the illustration of the elevon conditions to enable a move towards the right, while Fig. 6(b) shows the illustration of the elevon conditions to enable a move towards the left.

IV. CONTROL SYSTEM

The control system is needed so that the aircraft can fly more stably optimal. The control system that used is a PID control system. In the picture it appears that the position information of the flying wing is detected by the sensor IMU (accelerometer and gyroscope) where values are converted into an angular shape roll (φ) and pitch (θ) using the DMP by the microcontroller on a flying wing, while the value for yaw angle will be obtained from the magnetometer sensor.



The sensors reading will be compared with the value of a predetermined set point. The comparison results are called error value ($e(t)$). By using the PID control calculations the value of $e(t)$ which will be used to work the actuator (servo 1, servo 2 and brushless motors), in the form of a PWM signal that has previously been converted by the microcontroller first. The control system diagram for the flying wing is shown on the Fig.7.

With the control system, we expected when the UAV on the flight position it can be close to perfect attitude, i.e. where each orientation angle (roll, pitch and yaw) measured in accordance with the desired input by the system. For example, when the desired position is stationary, so the parameters angle (roll, pitch, and yaw) formed by the plane body axis with the earth's axis is 0°.

V. ELECTRONIC SYSTEM

Electronic system consists of a power supply, a microcontroller, sensors (accelerometer, gyroscope and magnetometer), actuators (two servos and a brushless motor), and data communications hardware. The electronic diagram of the flying wing system is presented in Fig.8.

The main power supply is battery with the voltage is around 12V. This battery will supply the microcontroller and the brushless motor. While the other components used 5V that get from the microcontroller or from Universal Battery Elimination Circuit (UBEC).

To communicate with the IMU sensor, we use the I^2C communication. For the Global Positioning System (GPS) and the communication hardware (telemetry), we use serial communication. For the Electronic Speed Controller (ESC) and the motor servos, we use PWM pins. Then for the Remote Control receiver, we use ADC pins.

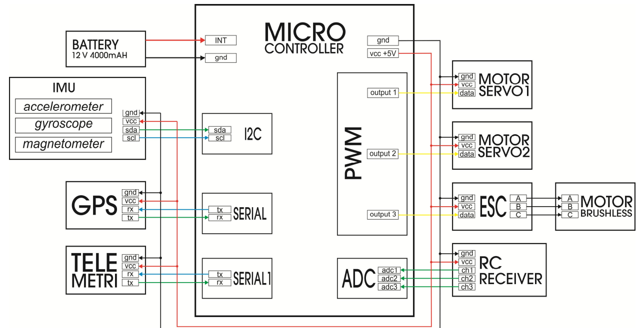


Fig. 8 Electronic diagram of flying wing UAV

VI. DISCUSSION

From the concept above, we have invented the mechanical design of the flying wing aircraft. Mechanical design aircraft shown in Fig. 9. From these designs shows that the aircraft only has three actuators consisting of two elevons controlled by two motor servos and a brushless motor.

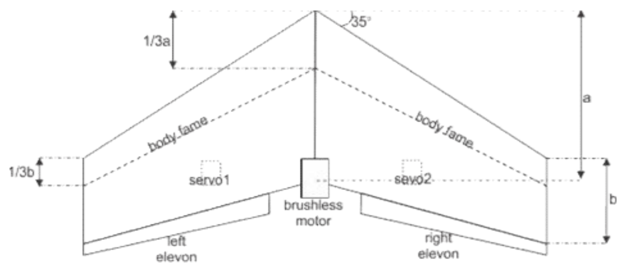


Fig. 9 Flying wing mechanical design

Elevon itself is a concept whereby movement of the actuator comprising two ailerons and elevators. This makes the auto-merge concept aircraft flying wing become not require tail (tailless). It is also supported by the absence of the rudder on the aircraft which caused the aircraft cannot move around the yaw axis directly. The aircraft can still be reasonably used around the yaw axis actuator by using the elevon principle.

The results of the design are implemented using basic materials polyfoam. The reason for choosing this material is because polyfoam easy to set up but has a texture that is quite rigid and strong so that it fits into the basic material of this flying wing aircraft. Fig. 3 shows the results of the implementation of the mechanical design.

To the microcontroller, we design control systems to address the needs of the auto pilot of the plane. The control system design process begins with the design of the model using Simulink software. The purpose of the design of this model is to be able to simulate the control system to be made.

The design is based on the following algorithm stability as follows:

Altitude

$$pwm = Deadzone_{plus} + \frac{e_z}{z_{max}} x\ Deadzone_{plus} \quad (1)$$

Roll

$$S_1 = \frac{error\ \phi}{roll\ max} \times 45^o \quad (2)$$

$$S_2 = -\frac{error\ \psi}{roll\ max} \times 45^o \quad (3)$$

Pitch

$$S_1 = S_2 = \frac{error\ \theta}{pitch\ max} \times 45^o \quad (4)$$

Deadzone is a value range of PWM (Pulse Width Modulation) where it cannot rotate the brushless motor (the motor is dead). So deadzone plus is the minimum value of the PWM that is possible to rotate the brushless motors

VII. CONCLUSION

This paper has presented the design of a flying wing UAV. The control system was shown to be able to handle its feedback. The PID constants from the control system are able to tune its components based on its error and its delta error. PID constants is tuned using Ziegler-Nichols method automatically using Routh Stability.

Although the controller does not possess the robustness properties of a robust controller, it is fairly robust to most feedback variations. The future directions of the research include the design and implementation of the self-tuning PID constants on more than Euler angle set point inputs, but also altitude, range finder, auto pilot, etc.

ACKNOWLEDGMENT

Ministry of Research, Technology and Higher Education is acknowledged for research grants with contract number 156/LPPM/2016. We also would like to thank to all students in eDrone community who have collaborated in this research.

REFERENCE

[1] S. Gupte and J. M. Conrad, "A Survey of Quadrotor Unmanned Aerial Vehicles," in *Proceedings of IEEE Southeastcon*, 2012, pp. 1–6.

[2] B. J. M. Domingues, "Quadrotor Prototype," Instituto Superior Tecnico, Universidade Tecnica de Lisboa, 2009.

[3] S. Markin, "Multiple Simultaneous Specification Attitude Control of a Mini Flying-Wing Unmanned Aerial Vehicle," University of Toronto, 2010.

[4] E. Edwan, J. Zhang, J. Zhou, and O. Loffeld, "Reduced DCM Based Attitude Estimation Using Low-Cost IMU and Magnetometer Triad," in *2011 8th Workshop on Positioning, Navigation and Communication*, 2011, pp. 1–6.

[5] M. Grewal, *Kalman Filtering : Theory and Practice Using MATLAB*, vol. 5. New York, USA: John Wiley & Sons, 2001.

[6] S. Nasiri, S. Lin, D. Sachs, and J. Jiang, "Motion Processing: The Next Breakthrough Function in Handsets," *Inven. Inc., July 2009*, 2010.

[7] B. Raghavan, "Flight Dynamics and Control of Highly Flexible Flying-Wings," Virginia Polytechnic Institute and State University, 2009.

[8] S. Bagheri, "Modeling, Simulation and Control System Design for Civil Unmanned Aerial Vehicle (UAV)," Umeå University, 2014.

Tri Kuntoro Priyambodo. He was born in Banyumas, Indonesia in 1959. He received Sarjana degree in Physics from Universitas Gadjah Mada, Indonesia, in 1986, M.Sc. Degree in Computer Sciences from Department of Computer Sciences, University of Manchester, UK, in 1990, and received Ph.D. degree in Physics from Universitas Gadjah Mada, Indonesia in 2014. Since 2008, he has been an Associate Professor with the Department of Computers and Electronics, Universitas Gadjah Mada, Indonesia. From 2010 to 2013 he was responsible for the development of Indonesia Inter-University Student Satellite Project as National Project Leader. He is the author of five books, more than 20 articles. His research interests include intelligent control systems, autonomous unmanned systems, satellite and aerospace electronics, computer networks security and eGovernment related issues.

Andi Dharmawan, was born in Surakarta, Indonesia, in 1984. He received the B.S. In Electronics and Instrumentations, in 2006 and M.S. degrees in Computer Sciences in 2009, from the Universitas Gadjah Mada, Indonesia. From 2007 to 2009, he was a Research Assistant with the Department of Computer Sciences and Electronics, Universitas Gadjah Mada Indonesia. Since 2009 until now he joints as a teaching staff at the Department of Computer Sciences and Electronics, Universitas Gadjah Mada, Yogyakarta, Indonesia. He is currently pursuing the Ph.D. degree in computer sciences and electronics at Universitas Gadjah Mada Indonesia. His research interests include the development of control systems for robotics, especially in the control system for Unmanned Aerial Vehicle (UAV),

Oktaf Agni Dhewa, was born in Yogyakarta, Indonesia, in 1991. He received the B.S. In Electronics and Instrumentations, in 2014. From 2014 to now, he has been a Research Assistant with the Department of Computer Sciences and Electronics, Universitas Gadjah Mada, Indonesia. He is currently pursuing M.S. degrees in Computer Sciences at Universitas Gadjah Mada, Indonesia. His research interests include the development of control systems for robotics, especially in the control system for Unmanned Aerial Vehicle (UAV),

Nur Achmad Sulistyo Putro, was born in Sleman, Indonesia in 1992. He received the B. S. in Electronics and Instrumentation in 2014 from Universitas Gadjah Mada Indonesia. From 2013 he is a research assistant with the Department of Computer Sciences and Electronics, Universitas Gadjah Mada Indonesia. He is currently pursuing the Master degree in computer sciences and electronics at Universitas Gadjah Mada Indonesia. His research interests include the development of control systems for robotics, especially in the control system for Unmanned Aerial Vehicle (UAV)