IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Stabilizing system for quadrotor copter like flying robot by using proportional-integral-derivative (PID) controller

To cite this article: Rudy Susanto *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **195** 012067

Stabilizing system for quadrotor copter like flying robot by using proportional-integral-derivative (PID) controller

Rudy Susanto, Rico Wijaya, Anton Talok, John Reigton Hartono, Rinda Hedwig, Jonathan Lukas, and Satrio Dewanto

Computer Engineering Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480

Coresponding author: rudy.susanto@binus.ac.id

Abstract. In this research, a quardrotor copter like a flying robot is developed with its capability to stabilize itself during the steady flying in a determined position. In order to gain its stability, intentionally a simple filter with a low error rate of 1.67% during its full operation was placed. The time consumed during its steady flying in the air took approximately one second with the height of flying around 1 to 5 meters above the earth.

Keywords: quardrotor, copter like, flying robot, proportional integral derivative controller, filter.

1. Introduction

Flying robot which has been introduced in several experiments[1-6,24,25] has also been applied for surveying earthquake site [7] as a rescue flying robot. This topic is an interesting topic to be analyzed and applied in Indonesia since this country is a part of Pacific Ocean's 'Ring of Fire' which has more active volcanoes than other countries in the world. Therefore Indonesia experiences frequent earthquakes.

A flying robot will be suitable as a surveying tool to find the victims after an earthquake happens. The stability during its flying is necessary in which this robot can be controlled to stay from one position to another during capturing pictures of the victims. In this research, no camera was attached for surveying process since it solely tests its flying stability.

In this research a quadrotor robot[4-5,8-12] was designed and developed with the capability of steady flying in one spot during its operation. The body of the robot is self-designed with motors. Some algorithm [13,14,26,27] were once proposed in order to get the stability and then tested in this flying robot. It was found out that the stability could be achieved but the time needed in order to gain the stability was more than 10 seconds. Another method was also applied such as Linear Quadratic Regulator and Kalman Filter [15], nevertheless it was not easy to get the stability even though sensors were applied in the flying robot. The main purposes of this research are to gain stability of quadrotor copter like flying robot during steady flying, and to use refillable-battery as energy resources for aero modeling plane as part of green campaign. A quadcopter designed in this research is a plane with a leverage force from its four rotors as shown in **Figure 1**. The rotors are positioned across each other and perpendicular whereas one pair has clockwise rotation while the other pair has counter-clockwise rotation. This configuration will negate the kickback force during the rotation.

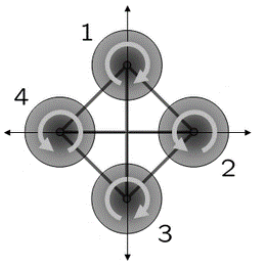

Fig. 1. Configuration of rotors from top view.

The designed robot can perform three basic maneuvers: horizontal movement, vertical movement, and rotation in vertical axes. The vertical movement can be done by applying similar rotation (either clock wise or counter-clockwise) in all of the rotors while the horizontal movement by inclining the quadrotor to the desired position. For example: If the quadcopter needs to be moved to the first rotor position, the rotor #1 should rotate slowly, the rotor #3 should rotate faster while rotor #2 and #4 should rotate steadily.

In the future, a small camera will be attached in the robot so its surveillance function can be achieved for aerial photograph, and it will be applied directly to the hazardous environment such as a collapsed building.

2. Experimental setup and Flowchart

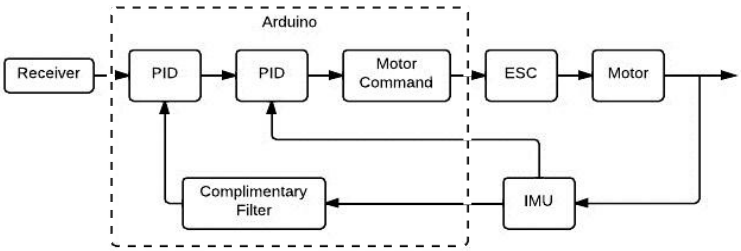

Fig 2. Block diagram of the system

Figure 2 shows the block diagram of the system which consist of input, process and output. A sensor and a remote control are used as inputs of the system. Two propotional integral-derivative (PIDs) are used in order to control the system in stabilizing the robot[16]. A complementary filter will produce angle value of the system by the use of accelerometer and gyroscope sensor. The control value that is resulted by the PIDs will be stored as motor command variable and will be translated as pulse widht modulation (PWM) signal. This signal will be transferred directly to electronic stability control (ESC) which will rotate the motor according to the speed sent from the microcontroller. Microcontroller used in this research is ATMega2560[17-19]. **Figure 3** shows how the program runs in this microcontroller.

In the input parts, there are four sensors used; accelerometer, gyroscope, magnetometer, and barometer. Both accelerometer and gyroscope are used to gain the angle value of the system while magnetometer is used to gain orientation value of the system. Barometer is used to gain the height value of the flying robot. Complementary filter has the ability to combine data from both gyroscope and accelerometer. It needs smaller computational process comparing to Kalman filters[20]. The blue print of the robot's design can be seen in **Figure 4 and 5** for the quadrotor copter like flying robot. 4 motors with each current is 30A are applied. Therefore, the robot can lift up weight up to 5.6Kg. Qt Programming[21,22] as software development kit is also used and can be run in Arduino.

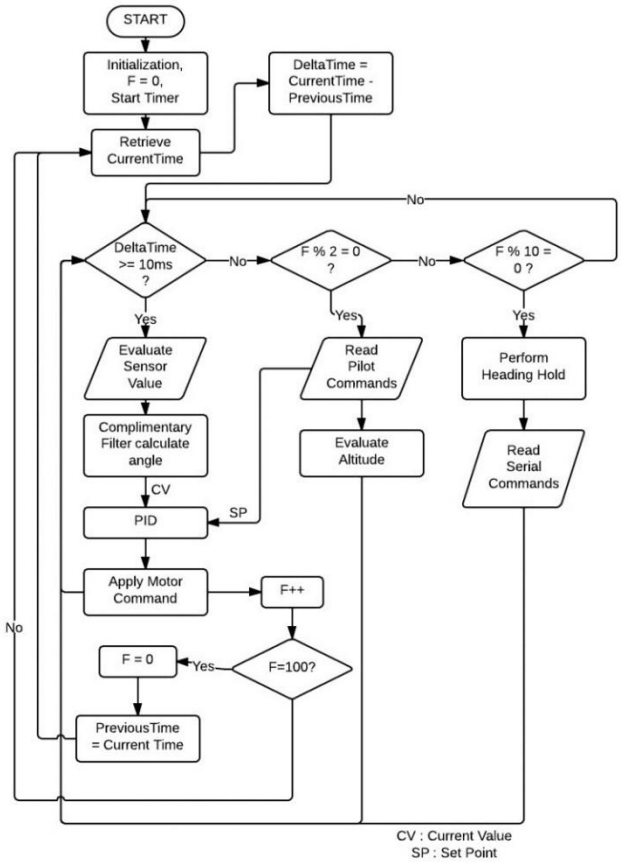

Fig. 3. Flowchart of the running program in microcontroller.

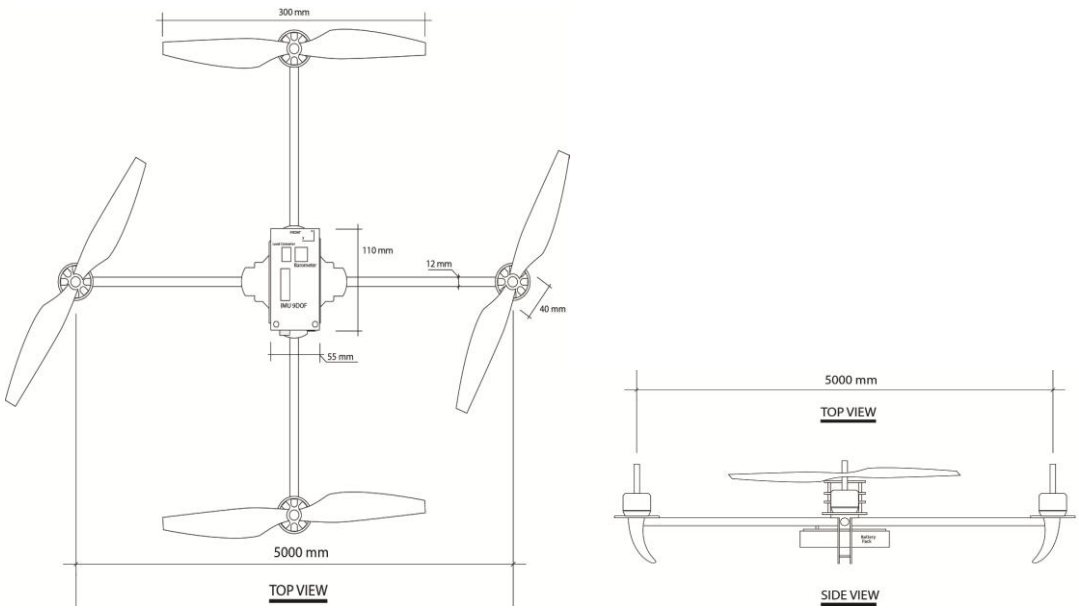

Fig. 4. Blue print of the quadrotor copter like flying robot.

Fig. 5. Picture of quadrotor copter like flying robot.

3. Results and discussion

In this research, the noise in the sensor is measured while an attempt to increase the rise time for balancing the copter like flying robot is carried out.

Figure 6 shows that the robot cannot be fully on the flat position during the flight. The inclining position is 0.5^{o} from the desired flat position. It is seen that there is so much noise in angle value of accelerometer even though it is put in a low-pass filter. The angle value in gyroscope is better than accelerometer but the inclining also happens after few hours. On the contrary, complementary filter shows its stability. By this measurement it can be understood that a complementary filter performs better. In order to prove this statement, measurement in inclining position is provided as it can be seen in **Figure 7**.

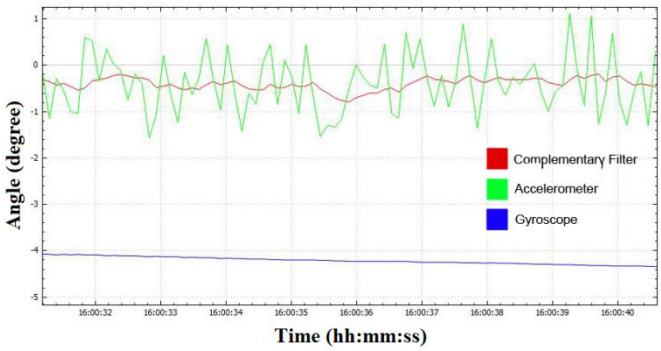

Fig. 6. The filters comparison at steady angle.

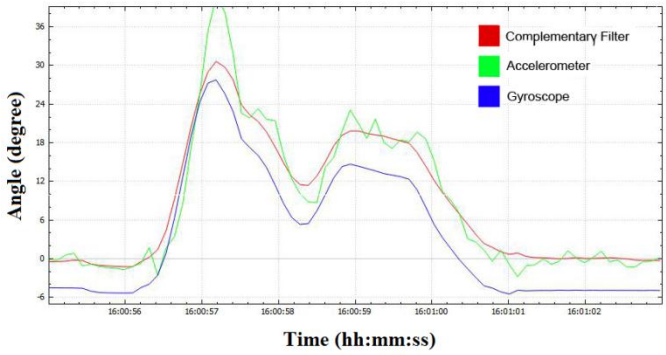

Fig. 7. The filters comparison at moving position.

In the experiment, as seen in **Figure 7**, the filter was not compared with Kalman Filter since from previous experiment it was understood that complementary filter was quite adequate to represent Kalman Filter in accelerometer and gyroscope. The value of accelerometer as seen in the **Figure 7** was

passed through the low pass filter since the value of accelerometer was too random, while low pass filter was not applied in gyroscope.

Figure 8 shows the accuracy of complementary filter while it was inclined 60°. It showed the inclining position was moved from 60° to 61° which meant the average error was 1.67%. This result was better comparing to accelerometer or gyroscope where the deviation was 2° and 0.2° per second, respectively. It is hoped that there is no much inclining happens during one minute flying. That is why complementary filter is suitable for this application.

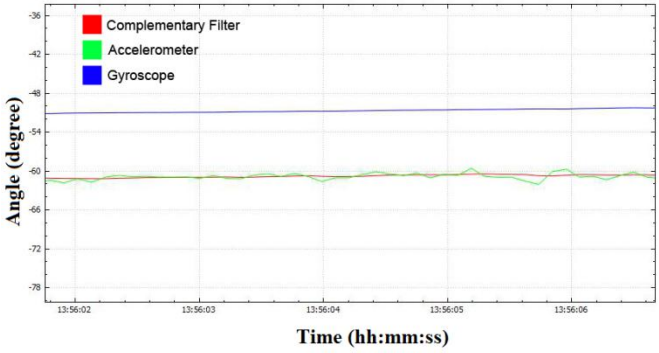

Fig. 8. The comparison of error rate.

The second experiment was the stability test for the system as it is shown in **Figure 9**. It is seen that a little unstable in the system will enhance the copter like flying robot to be back in its steady position. Intentionally, the flying robot, inclined as far as 30°, was made and as a respond; the front motor directly decreased its speed while the front motor increased its speed. This happened to give leverage force to the system back to its stable position. This value would be maintained during flying time as long as there was a difference between the actual angle and the input angle.

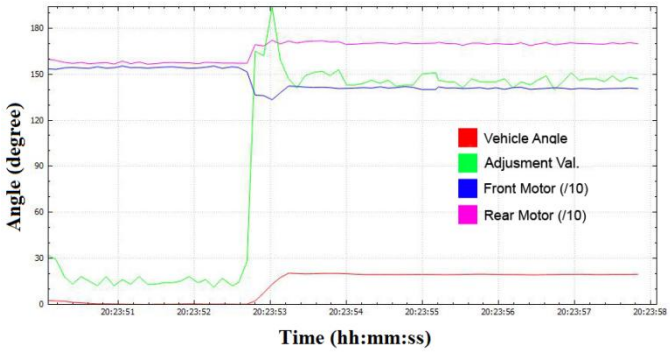

Fig. 9. Stability of the system

The respond of the system happened both in rapid or slow changing of the system as shown in **Figure 10**. During the slow stability changes, the responses were also slow and no overshoot happened. However, when the value was 0, the difference due to no-zero value of the remote control was found. The remote control itself did not actually give the exact value. This could be managed by trimming remote control or move the zero value to exactly zero in the remote control.

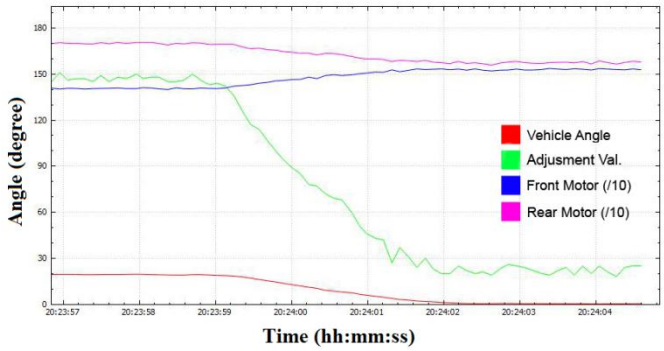

Fig. 10. Stability of the system during slow changing.

The third experiment was about stabilizing time at pitching position with PID value as seen in **Figure 11**. It is seen that the deviation gained for one second were 26.8°, 36.16°, and 46.67° on the left side, middle, and right side figure respectively. This figure showed the consistency of the system during stabilizing its flying position, nevertheless oscillation still happened during the stabilizing process. The rise time for each figure was 0.5s, 0.5s, and 0.75s on the left side, middle, and right side figure respectively. In order to lower the oscillation, D value was added and the stabilizing process could be done lower than 10 seconds as seen in **Figure 12**. It is seen that the settling time increased significantly after reducing the oscillation; however the slower rate also happened due to D value added. In this experiment, P value was also added in PID in order to increase the response time, as seen in **Figure 13**.

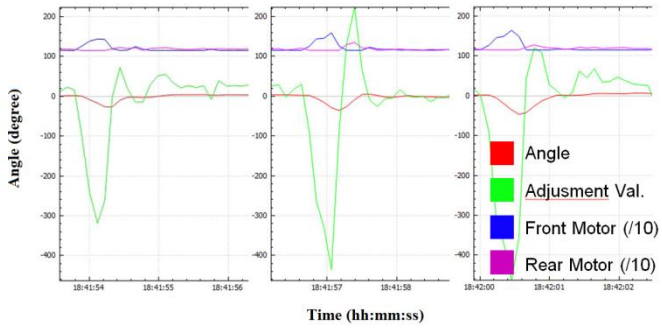

Fig. 11. Experiments of pitch measurement with PID value.

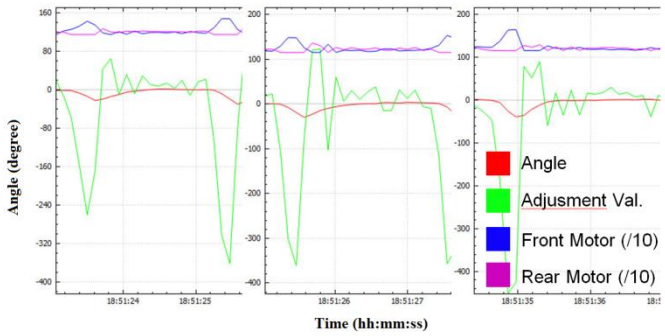

Fig. 12. Additional D value is added in PID.

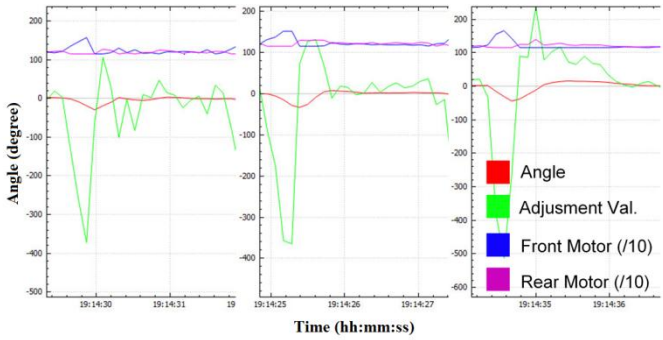

Fig. 13. Additional P value added in PID.

In order to ensure the pitch stability function, another experiment for stability was proposed where the flying robot was intentionally inclined as far as 44.07° and the result showed that it could stabilize itself within 0.9 seconds as seen in **Figure 14**. This result was better than H. Meric [13] with 2 seconds or J.M. Domingues [23] with 5 seconds with LQG.

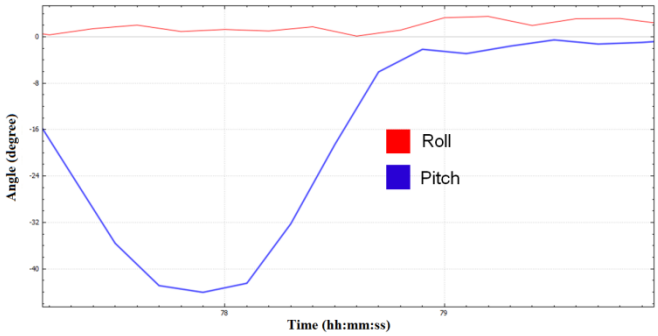

Fig. 14. Retrying for stability measurement.

The fifth experiment focused on PID adjustment for rolling position such as on pitching position experiment as shown in **Figure 15**. It was observed that the first value looked stable but oscillation happened after the stable value. The deviation gained were 15.86° for 0.5-0.75 s, 17.09° for 0.75 s, and 24.76° for 0.75 s on the left side, middle, and right side figure respectively. The small angels were applied in this experiment since there is no certainty on the stability of the system during rolling position. In order to suppress the oscillation, D value in PID was also added as shown in **Figure 16** and it was successful. The deviation gained were 25.84° for 0.5 s, 28.77° for 0.5s-0.75 s, and 35.46° for 0.5 s on the left side, middle, and right side figure respectively. Nested PID for the whole experiment used for common PID could not stabilize the system within one second.

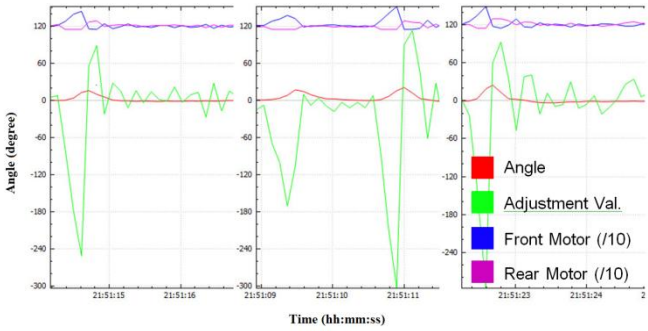

Fig. 15. Experiments of roll measurement with PID value.

An experiment on roll stability function was also performed and it was found out that there was 1.5° oscillation with rise time about one second which meant better than H. Meric [13] with 2 seconds. Nevertheless, the last experiment was performed in order to see the respond time between remote control triggering and actual positioning. It needed about one second for the system to respond from

remote control to actual position. Error could be seen when the system was asked to make negative angel. It was due to the failure of motor #3 during experiment and this problem could be solved after changing the motor with the new one.

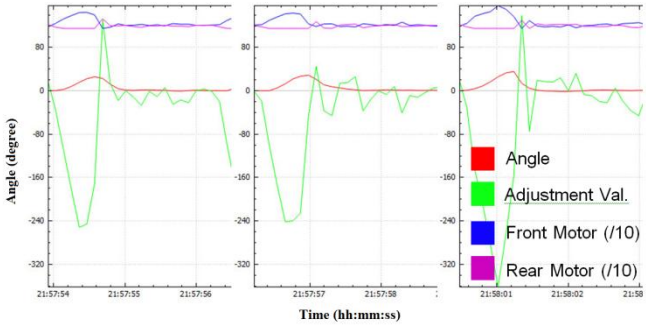

Fig. 16. Additional D value is added in PID during roll measurement.

4. Conclusion

The use of nested PID and complementary filter in this experiment is quite effective comparing with the result of previous experiments [13, 23] where the flying stability could be done within one second. Accelerometer and gyroscope can be used to gain stability of x and y axes with error rate of 1.6% and low pass filter is highly recommended in this research. For future study, quarterion based filter instead of Kalaman filter and complementary filter will be used since Kalman filter has high computational needs and complementary filter is less accurate.

5. References

[1] R.W. Longman, *The Kinetics and Workspace of a Satellite-Mounted Robot* in Space Robotics: Dynamics and Control, edited by Yangsheng Xu, Kluwer Academic Publishers, 1993, pp. 27-44.

[2] K. Yoshida, R. Kurazume, and Y. Umetani, *Dual Arm Coordination in Space Free-Flying Robot*, in Proc. of IEEE Int. Conf. on Robotics and Automation, Sacramento – CA, 1991, vol. 3, pp. 2516-2521.

[3] P. Corke, R. Peterson, and D. Rus, *Network Robots: Flying Robot Navigation Using a Sensor Net*, in Robotic Research – The 11th International Symposium, 2005, pp. 234-243.

[4] D. Gurdan, J. Stumpf, M. Achtelik, K.M. Doth, G. Hirzinger, D. Rus, *Energy Efficient Autonomous Four-Rotor Flying Robot Controlled at 1kHz*, in IEEE International Conference on Robotics and Automation, Rome – Italy, 2007, pp. 361-366.

[5] T. Madani and A. Benallegue, *Backstepping Sliding Mode Control Applied to a Miniature Quadrotor Flying Robot* in *The* 32nd Annual Conference on IEEE Industrial Electronics, Paris – France, 2006, pp. 700-705.

[6] J.C. Zufferey, A. Klaptocz, A. Beyeler, J.D. Nicoud, and D. Floreano, *A 10 Gram Vision Based Flying Robot*, Advanced Robotics, vol. 21, issue 14, 2007, pp. 1671-1684.

[7] Wei Wang, Gang Song, K. Nonami, M. Hirata, and O. Miyazawa, *Autonomous Control for Micro-Flying Robot and Small Wireless Helicopter X.R.B*, in IEEE/RSJ International Conference on Intelligent Robots and Systems, Beijing – China, 2006, pp. 2906-2911.

[8] S. Bouabdallah, P. Murrieri, and R. Siegwart, *Design and Control of an Indoor MicroQuadrotor*, in IEEE International Conference on Robotics and Automation, vol. 5, 2004, pp. 4393-4398.

[9] Kong Wai Weng and M.S.B. Abidin, *Design and Control of a Quad-Rotor Flying Robot for Aerial Surveillance*, in 4th Student Conference on Research and Development, Selangor – Malaysia, 2006, pp. 173-177.

[10] S. Bouabdallah and R. Siegwart, *Backstepping and Sliding Mode Techniques Applied to an Indoor Micro Quadrotor*, in Proc. of IEEE International Conference on Robotics and Automation, 2005, pp. 2247-2252.
[11] S. Bouabdallah and R. Siegwart, *Full Control of Quadrotor*, in IEEE/RSJ International Conference on Intelligent Robots and Systems, San Diego – CA, 2007, pp. 153-158.
[12] P.Pounds, R. Mahony, and P. Corke, *Modelling and Control of a Large Quadrotor Robot*, in Control Engineering Practice, vol. 8, issue 7, 2010, pp. 691-699.
[13] H. Meric, *Stabilization of a Four Rotors UAV*, Master Thesis, Institut Supérieur de l'Aéronautique et de l'Espace, National ICT Australia, 2002.
[14] P. Castillo, A. Dzul, and R. Lozano, *Real Time Stabilization and Tracking of a Four-Rotor Mini Rotorcraft*, in IEEE Transactions on Control Systems Technology, vol. 12, issue 4, 2004, pp. 510-516.
[15] Y.S. Daoud and R.K. Kadhim, *Linear Quadratic Regulator Control Technique for Stabilization A Quadrotor Aircraft*, in Електроніка та системи управління., no 1, 2012, pp. 31-38.
[16] S. Bouabdallah, A. Noth, and R. Siegwart, *PID vs LQ Control Techniques Applied to an Indoor Micro Quadrotor*, in Proc. of IEEE/RSJ International Conference on Intelligent Robots and Systems, vol. 3, 2004, pp. 2451-2456.
[17] Anonim, (2013), ATmega2560. Available: http://www.atmel.com/devices/atmega2560.aspx
[18] D. Gil de la Iglesias. (2013, 1, 28). 4ME103: Tangible User Interface. Available: http://194.47.95.238/~didac/4ME103/Materials/TUI_book_reduced.pdf
[19] Anonim. (2013, 10, 8). 8-bit Atmel Microcontroller with 64K/128K/256Kbytes In-System Programmable Flash. Available: http://www.control.auc.dk/~jdn/edu/courses/13-2/norway-cansat/litt/mega2560.pdf
[20] W.T. Higgins, *A Comparison of Complementary and Kalman Filtering*, in IEEE Transactions on Aerospace and Electronic Systems, vol. AES-11, issue 3, 1975, pp. 321-325.
[21] P. Ward, *QT Programming for Linux and Windows*, Prentice Hall, USA, 2000.
[22] M. Summerfield, *Advanced Qt Programming: Creating Great Software with C++ and Qt4*, Prentice Hall, USA, 2010.
[23] J.M. Domingues, *Quadrotor Prototype*, M.S. thesis, Universidad Técnica de Lisboa, Instituto Superior Técnico, Lisboa, 2009.
[24] López-Gutiérrez, R., Rodriguez-Mata, A.E., Salazar, S. et al. *Robust Quadrotor Control: Attitude and Altitude Real-Time Results*, J Intell Robot Syst, 2017, 88: 299.
[25] Ivan Gonzalez-Hernandez, Filiberto Munoz Palacios, Sergio Salazar Cruz, Eduardo Steed Espinoza Quesada, Rogelio Lozano Leal, *Real-time altitude control for a quadrotor helicopter using a super-twisting controller based on high-order sliding mode observer*, in International Journal of Advanced Robotic System, Volume 14, Issue 1, 2017.
[26] Jonay Toledo; Leopoldo Acosta; Daniel Perea; Nestor Morales, *Stability and performance analysis of unmanned aerial vehicles: Quadrotor against Hexrotor*. in IET Control Theory and Applications, Volume 9, Issue 8, p1190-1196, 2015
[27] Syed. F. Ahmed; D. Hazry; Kushsairy Kadir; Abadal Salam T. Hussain; Zuradzman M. Razlan; Shahriman AB, *Development of Automatic Take Off and Smooth Landing Control System for Quadrotor UAV*, International Conference on Artificial Life and Robotics (ICAROB 2017), 2017