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Test Platform and Graphical User Interface Design for Vertical Take-Off and Landing Drones

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Abstract. We present a novel test system for pre-flight control and test of *Vertical Take-Off and Landing* (VTOL) drones. This system includes a test platform consisting of nested circles in three different dimensions, a graphical user interface, and wireless communication modules. Thanks to this proposed test platform, basic axis tests (yaw, pitch, roll, elevation) can be done before the flight of a VTOL multi rotor drone, thus the problem or crash will be obstructed in the flight of a VTOL multi rotor drone. In addition to this test platform, we present a *graphical user interface* (GUI) for sending the test commands and receiving values from all sensors on the VTOL multi rotor drone board. The graphical analysis of all data, such as motor rpm value, velocity, angular value, etc., can be observed by the proposed test GUI. Also, the desired flight control parameters can be sent via a graphical interface to the VTOL multi rotor drone's board on the test platform. The wireless communication modules have been used between the VTOL multi rotor drone board and the computer consisting of the test GUI. In this study, the test system designed for VTOL multi rotor drone is given in detail. To show the performance of the UAV test system, some pre-flight tests are represented for the VTOL multi rotor drones with six rotors.

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Key-words: Drone. flight control, GUI, test system, unmanned aerial vehicle, VTOL.

[1]text

1. Introduction

There has been remarkable progress in research about *unmanned aerial vehicles* (UAV) during the last 20 years. UAVs have gotten a big potential for military and civilian applications where human intervention is risky, expensive, or impossible. These UAVs are mostly used in many areas such as traffic monitoring [1, 2], border control [3], border surveillance [4], monitoring harvesting [5, 6], search and rescue [7], and support during forest fires [8]. There are two different UAV designs: fixed wing and rotary-wing known as drone. Both of them have some advantages and disadvantages according to each other [9, 10].

The UAV has more advantages than the fixed wing UAV while performing inspection and surveillance tasks. A drone or rotary wing UAV is capable of VTOL (vertical takeoff and landing) and it has the potential to fly where the fixed wing UAVs do not fly, due to its high maneuver capability. The VTOL multi-rotor drone can fly in restricted and tight spaces, take off vertically and, most importantly, hover; it can also have complex control structures according to flight missions.

Due to poorly tuned parameters of the flight controller in the VTOL multi rotor drones, it may induce failure or crash during the flights. Therefore, these control parameters need to be tuned well before the flight missions. The simulations give the results different from real-time experiments of UAVs, so a range of control parameters obtained by simulation is adjusted by the test bench. To avoid a UAV flight crash or failure, some tests must be done before the flight. Suitable control parameters need to be set for a stable flight. [10-11].

In recent years, various test platforms have been presented in the literature to adjust the control parameters of VTOL multi rotor drones. Some of these are shown in Fig. 1. In the study presented by mrl and his friends, a variable DOF flight control system was designed as shown in Fig. 1 (a) for a quadrotor. This test structure is set to be lockable by some of the connection parts, such as universal joints and roller bearings. The proposed system was tested separately for roll, pitch, yaw, and elevation motions [12].

The proposed test platform has limitations in rotation around the x, y, and z axes and in elevation movements along the z axis. As seen in Fig. 1 (b), Grzonka et al. realized one axis control tests for a quadrotor [13]. This simple device allows only one axis of the quadrotor to be monitored using the IMU. In the study of Azfar et al. [14], the parameters of a classical PID controller are set on a single axis-based test bench platform (Fig. 1 (c)). This test platform was used for independent adjustment of PID values in a limited range in one direction for a quadrotor UAV mounted on it. In the work presented by Baran *et al.*, a test platform (Fig. 1 (d)) was proposed for flight control of unmanned helicopter [15]. Abdelhamid Tayebi *et al.* designed an experimental setup including a stationary ball joint base (Fig. 1 (e)) to test the attitude controller [16]. This base provides unlimited yaw and around $\pm 30°$ of pitch and roll motions. In Fig. 1 (f), Hanford et al. used a test platform known as Whiteman training stand for flight test of a rotary-wing unmanned air vehicle with four rotors [17].

The quadrotor can be rotated around its yaw, pitch, and roll axes and moved vertically by this test platform. The test stand was modified to allow a quadrotor UAV to rotate around its pitch and roll axes. In [18], an experimental test bench for small helicopters which is able to hold the helicopter, allowing the helicopter to perform hovering and altitude flight, was presented as shown in Fig. 1 (g). Alexis *et al.* proposed the safe flight test stand (Fig. 1 (h)) to modify the attitude freely while keeping the position of UAV [19]. UAV was attached to a slightly modified Heli-Safe flight test stand. In Fig. 1 (i), Albayrak and Arsoy presented the controller design with an artificial neural network for VTOL drone with four motors. For testing the performance of their proposed controller, a test stand was designed [20]. This test stand has gotten a similar design to the design in Fig. 1 (a) and Fig. 1 (e).

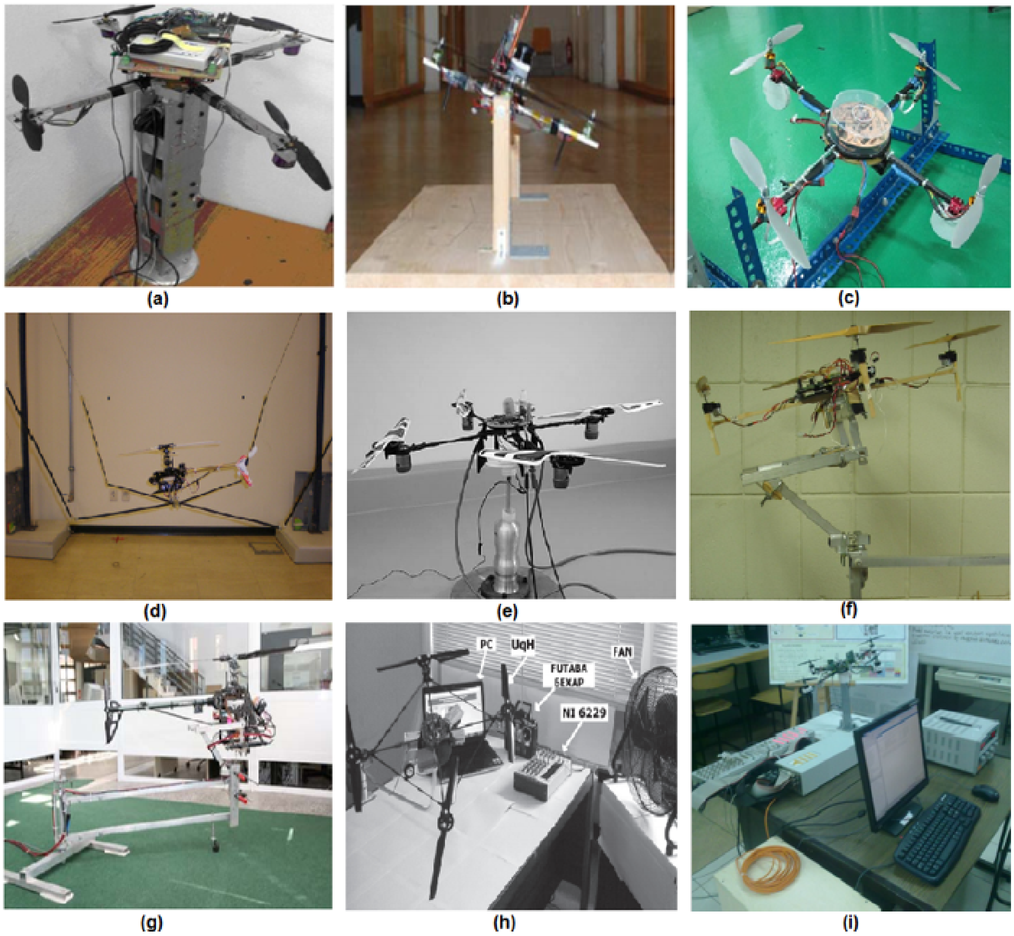


Fig. 1. Different test platforms for VTOL multi rotor drones.

The different test platforms presented in Fig. 1 are designed for different purposes and different types of UAVs. There is a significant shortcoming in these test platforms. During flight tests, VTOL multi rotor drones may not move freely along the axis due to the limit ranges of test platforms. For that reason, the tests done by these test platforms don't reflect the flight of UAVs completely.

It is very important in a VTOL multi rotor drone test that all flight scenarios are performed without any constraints from the test platform. In this paper, a novel test platform created from nested circles in three different dimensions is presented. This test platform has some key advantages. First is the fact that this test platform is suitable for VTOL multi rotor drones with a different number of rotors. The second advantage is that the fundamental tests can be done safely for the control parameters adjusted by the proposed GUI. The third is the fact that simply all sensor data of the VTOL multi rotor drone can be monitored in real-time via wireless communication. The last but the most important advantage is that this test platform has no motion limitation along all axes without elevation motion in comparison with the other existing test platforms.

The paper is organized as follows. The VTOL multi rotor drone is presented briefly in Section 2. Section 3 includes the test platform design for VTOL multi rotor drones in detail. The graphical user interface for monitoring the test data taken from the UAV on the test platform and sending commands to it is given in Section 4. The experimental results obtained by this test system are discussed in Section 5 for the VTOL multi rotor drones with six rotors. Finally, the paper is concluded in Section 6.

2. Vertical Take-Off and Landing (VTOL) Multi Rotor Drones

This section consists of the basic working concept of the rotary-wing *unmanned aerial vehicle* (UAV). Rotary wing UAVs have gotten different types according to the number of rotors and frame design. In Fig. 2, different types of VTOL multi rotor drones are shown.

Quad1 or QuadX has four motors that are placed in a cross or a plus frame. The motion of the VTOL multi rotor drone with four rotors is controlled by changing the velocity of rotation of each motor. To hover and fly this type of VTOL multi rotor drone, while the two reciprocal rotors rotate in a counterclockwise direction, the other two reciprocal rotors rotate in a clockwise direction.

All axis motions of the VTOL multi rotor drone with four rotors (Quad1) are shown in Fig.3. To control the roll and pitch movement of Quad1 or QuadX, the relative speed of the reciprocal rotors is varied [10, 17]. The yaw motion of the VTOL multi rotor drone with four rotors is realized by changing the relative speed of the rotors with respect to clockwise and counterclockwise. The ascent movement of VTOL multi rotor drone is realized by increasing the speed of all the rotors together. The other VTOL multi rotor drone designs, such as hexacopter, octocopter, etc., work same way. The VTOL multi rotor drone system's hardware consists of the flight board, IMU (*Inertial Measurement Unit*) sensors, *Electronic Speed Controllers* (ESCs), brushless DC motors, batteries, propellers, RC transmitter/receiver, etc.

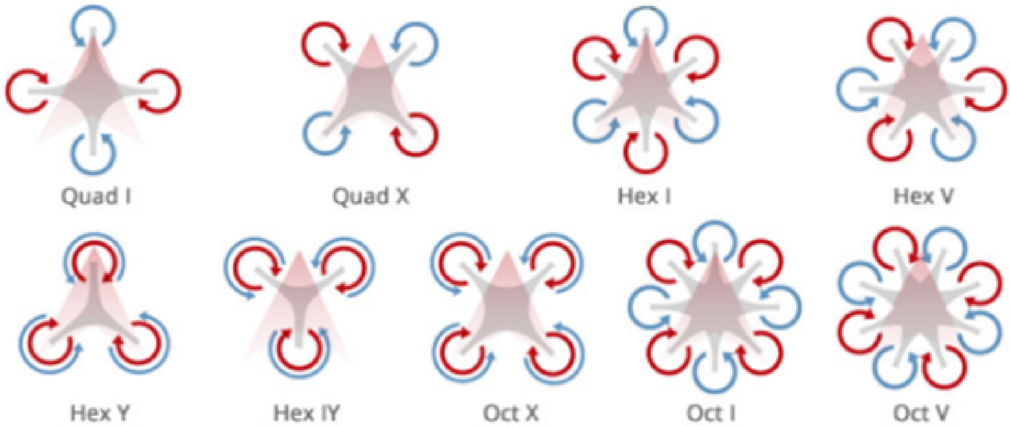


Fig. 2. Different types of VTOL multi rotor drones [21].

PI and PID controllers are widely used in the majority of industrial applications worldwide today, due to their simple and effective control [23]. In addition to this classical method, there are studies in the literature on different control approaches such as fuzzy controllers [23], sliding mode controllers [26], and hybrid controllers (PI-fuzzy, heuristic-based fuzzy controllers) [24, 25]. These control approaches are used in many different areas, from speed control of a DC motor [27] to power control in wireless sensor networks [28]. In the control of VTOL multi rotor drones, PI and PID controllers are preferred because of their simple and effective controls, as well as their ease of use in embedded systems.

For a stable flight of VTOL multi rotor drones, double PID controllers per axis (pitch, yaw, and roll) have been used in its software. This control structure is shown in Fig. 4. The first controller produces the desired rotational rate to hold stable at the desired angle. The motor torques are adjusted by the second controller. This controller's inputs are the desired rotational rate produced by the first controllers and the rotational rate from the gyro sensor [22]. The fundamental motion tests have to be realized before the flight to adjust the most suitable PID parameters. Thanks to the test platform proposed in this study, all pre-flight tests of VTOL multi-rotor drones can be done.

3. Test Platform Design for Rotary-Wing UAVs

The test platform is inspired by the gyroscope and it is composed of three circles, pulleys, the balance weight, and a strain prevention system as shown in Fig 5. The main purpose of this test platform is to enable the testing of VTOL multi rotor drones in different types and sizes in the x, y, and z axes without any angular restrictions. In the test platform design, first of all, VTOL multi rotor drone tests and existing test setups were examined. Unlike the other test platforms presented in the literature, the VTOL multi rotor drone placed on this test platform can move easily at all axis. In the second step, the dimensions of the test platform were determined and the drawings were made in the computer environment. In the third step, the test platform prototype was created and different trials were realized. Later, due to the problem in altitude test, pulley system and balance weights were added to the design.

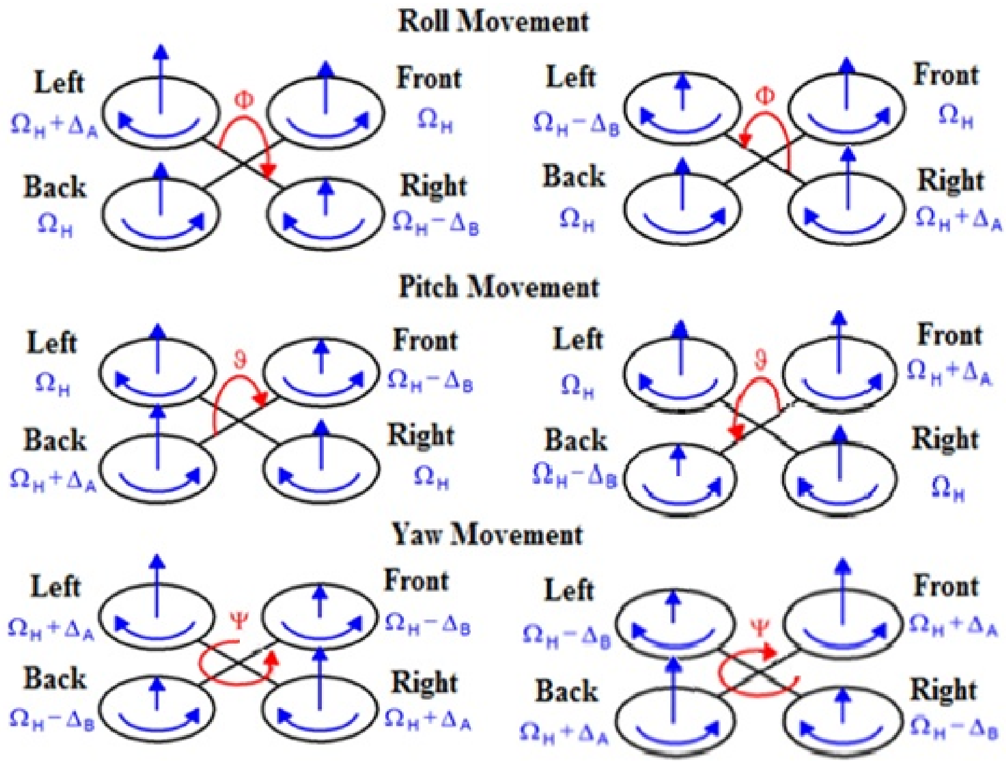


Fig. 3. Rotary wing UAV with four rotors (Quad1) axis movements [11].

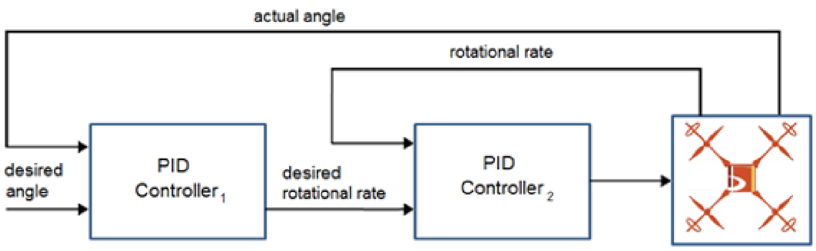


Fig. 4. PID control structure per axis for VTOL multi rotor drone.

As can be seen from this figure, the VTOL multi rotor drone on the test platform is simply able to move on every axis because of the fact that these three-circles mounted into each other. For testing the altitude motion, the balance weight is connected to these circles with the steel rope and four pulleys as given in Fig. 5, thus it is eliminated the extra weight of the circles on the test platform. The pre-flight tests, such as yaw, pitch, roll and altitude motions are realized by this proposed platform for the VTOL multi rotor drones. However, unlike the other three-axis motion tests, there is a restriction in the UAV motion in the altitude test. In the altitude test, the UAV on the platform can move 60 cm at most.

In Fig. 6, the proposed test platform draft was drawn by Solid Works, and the dimensions

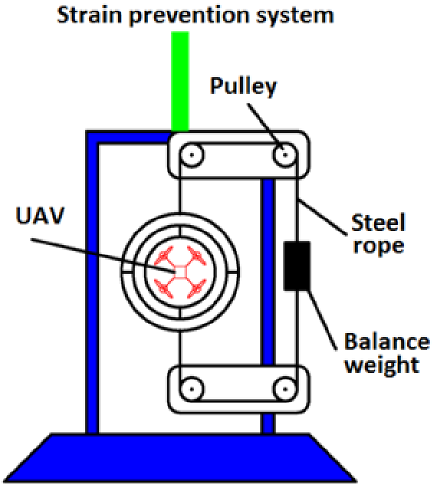
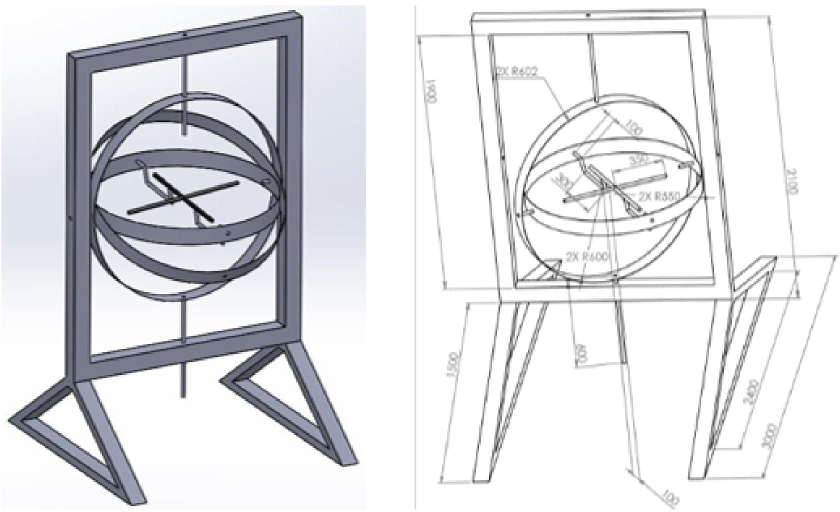


Fig. 5. The proposed test platform system for VTOL multi rotor drone.

of the test mechanism are shown. For the pre-flight tests, first, the VTOL multi rotor drone is placed tightly at the center of the test mechanism. Then the desired tests can be done by this test platform; thus, the control parameters can be adjusted easily without real flight outside. The realized test platform is presented in Fig. 7. The main parts of this platform are shown in this figure.



(a) (b)

Fig. 6. (a) Test mechanism draft by Solid Works and (b) its dimensions.

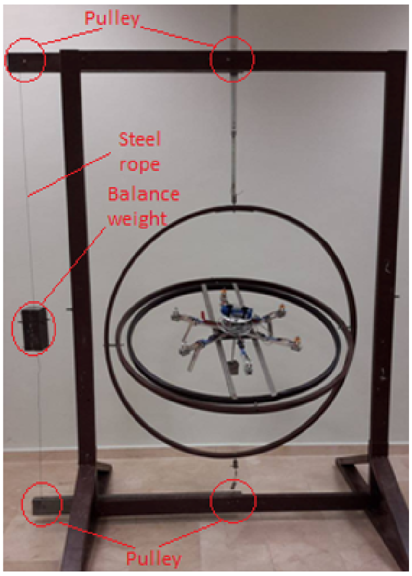


Fig. 7. The realized test platform and its main parts.

4. Graphical User Interface (GUI) for Pre-Flight Tests

A GUI has been designed to view the data received from the sensors of the VTOL multi rotor drone on the test platform and to initiate test commands from the computer. GUI design consists of two phases: back-end and front-end. In the front-end, there are buttons, combo boxes, and an information panel. In the back-end part, there are codes for wireless connection with the UAV board, receiving data from the sensors on the board, editing and visualizing the data. To obtain the data of the sensors from the microcontroller board on the VTOL multi rotor drone and to send test commands, to edit control parameters of the VTOL multi rotor drone, a graphical user interface has been built by the Matlab framework. Thanks to this interface, the data taken from all sensors can be seen on the graphical windows. Also, all desired control parameters can be sent to the VTOL multi rotor drone's flight board on the test platform via wireless transmission. From the menu on the graphical interface, the desired pre-flight tests can be selected easily, then obtained test results are shown in the figures, such as pitch, yaw, and roll angle changes during tests. By the test platform, fundamental pre-flight tests are realized for the different types of VTOL multi rotor drones and the test results are observed or analyzed in real-time on the designed graphical user interface.

In this study, sensor data, motor speed values, and flight board information have been taken by wireless transmission, then this information has been processed by the designed graphical interface and this processed data is shown graphically according to the user's request. The startup screen of the designed graphical interface is presented in Fig. 8. Related port connection information is selected from the "Port Number" and "Baud Rate" section under the heading of Connection Options on the upper left corner of this screen then the connection between the VTOL multi rotor drone. When pressing the "Connect" button after the selection of the related port information, if the selected port information is right, the connection will be successful. Otherwise, the connection is failed. In Fig. 8, the main screen of the graphical interface is presented after a successful connection.

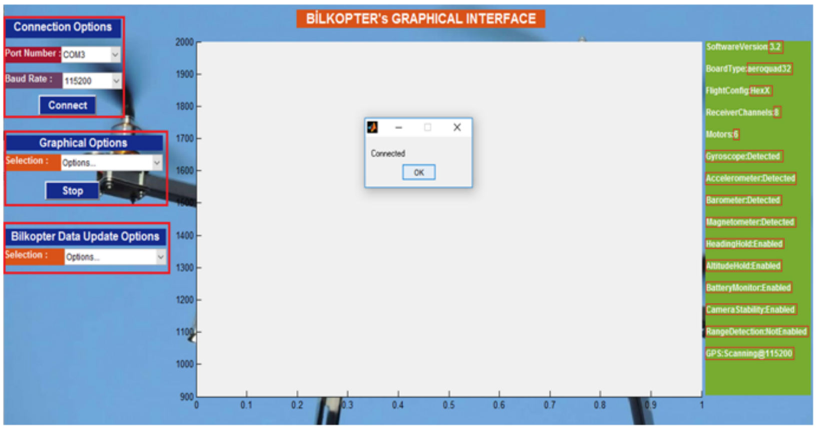


Fig. 8. The main screen of test graphical interface [11].

On the left side of the main screen, there are two sections whose names are "Graphical Options" and "Data Update Options". In the middle of the main screen, there is a drawing section for presenting the graphics. Information on the UAV's controller board and the states of the sensors (gyroscope, magnetometer, accelerometer, barometer, etc.) are located on the right side of the main screen. In the combo box section, whose name is Graphical Options, some options can be selected such as reading sensor information, the motor speed values, and the remote controller signal. To receive the desired information from the flight controller board, some characters are sent to the board and the requested acknowledgment information is taken from this board. The requested graphics are shown on the plot screen of the proposed GUI. In this section, all sensor data, barometers and range finder graphic, motor speed graphic, remote controller data, gyro graphic, accelerometer graphic, and magnetometer graphic options can be chosen.

In Fig. 9, the combo box section, which is used for reading and updating the PID coefficient values, range finder values, camera stabilization values, and battery monitor values from the flight controller board, is shown. The fundamental tests can be performed in this section. For taking the information from the flight controller board, first, a character is sent to this board via serial communication, and the requested information is taken from this board.

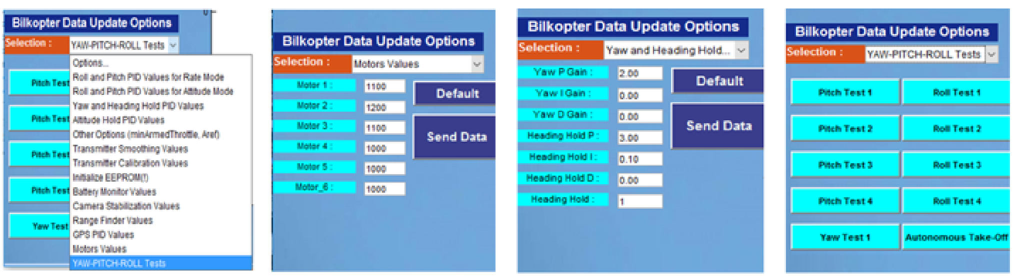


Fig. 9. Data Update Options Section on the designed GUI [11].

5. Experimental Results

In this section, a VTOL drone with six motors from the Department of Computer Engineering at Bilecik Seyh Edebali University has been used to evaluate the performance of the proposed test mechanism. This VTOL multi rotor drone has the open source AeroQuad 32 V2 Flight Control Board including STM32F405VGT6 CPU with 168MHz Cortex M4 32 bit core, 1MB flash ROM, 192KB RAM. AeroQuad board has 6 analog inputs and 20 PWM outputs. The sensors on this board are MS5611-01BA03 barometer, MPU6000 gyro/accelerometer, and HMC5983-TR magnetometer. Data and system parameters from these sensors are recorded at 40 Hz. At the same time, the necessary data is saved in the computer environment with the wireless communication module and transferred to the GUI. The reason we prefer this flight board is that it is open source. Therefore, the data collection process is solved in a simpler way compared to flight boards with closed software. Fig. 10 shows the hardware block diagram of open-source AeroQuad board. In this study, Hitec Aurora 9 channel radio transmitter/receiver was used. Other materials connected to the AeroQuad board used in this study are 10x4.5 APC propellers, 18 Amp ESCs and 750KV motors.

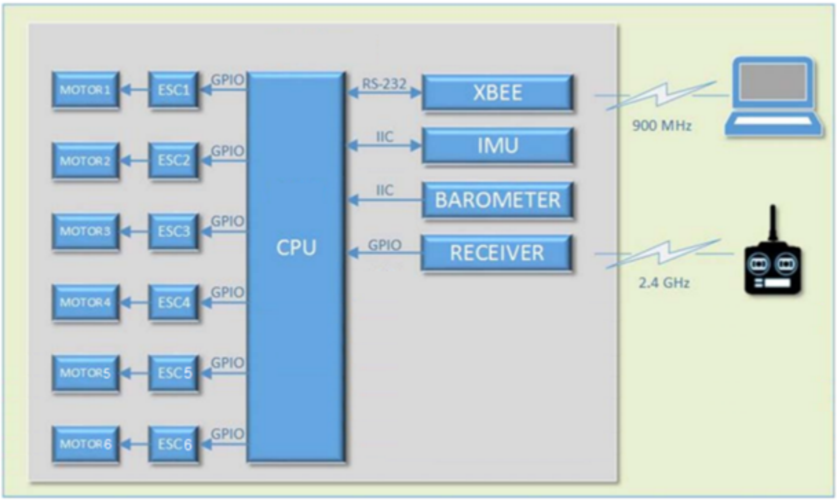


Fig. 10. The block diagram of AeroQuad with six motors.

The AeroQuad board works with onboard PID controllers that use the onboard sensors to keep the VTOL drone stable during flight. The AeroQuad includes the PID software which is a modified version of the Bare Bones (PID) Coffee Controller. The PID controllers in AeroQuad do not normalize the inputs and have a standard reset-windup mitigation code.

There are nine PID controllers to decrease error for pitch, roll, yaw, and altitude using inputs from the sensors on the AeroQuad board. These controllers are Roll PID, Pitch PID, Yaw PID, Altitude PID, Heading PID, Level Roll PID, Level Pitch PID, Level Gyro Roll PID, and Level Gyro Pitch PID, respectively. The default values of 27 control parameters, three for each PID controller (Kp, Ki, and Kd), are stored on the AeroQuad board's EEPROM. However, these default values vary according to different hardware materials such as frame sizes, motor features, and propeller sizes. In short, the default PID values are generally useless for a good flight at the beginning; it must be fine-tuned before the flight. Here, the test platform proposed in this study comes into play. We initially got the default PID values on the AeroQuad, then we experimented with the pitch and roll PID values. Test results for the best PID values obtained are presented in this study for three different set signals. The hardware tools used in the test platform are shown in Fig. 11.

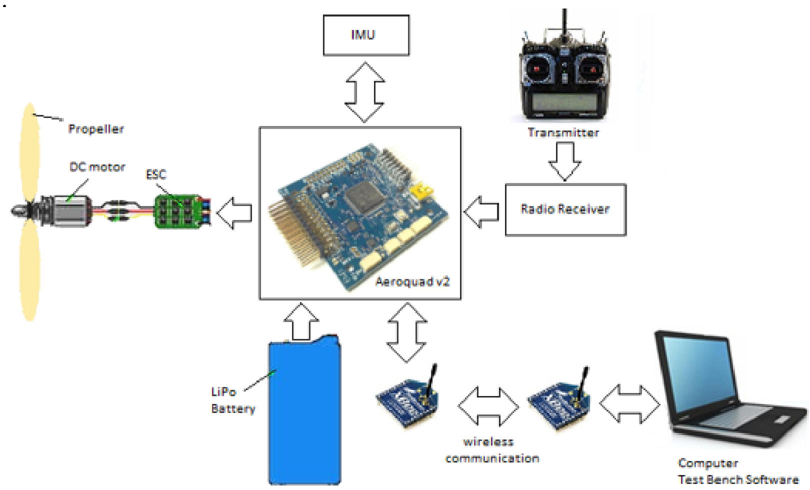


Fig. 11. The hardware tools used in test platform.

Fig. 12 shows a photo taken at the time of reading sensors' values of the VTOL multi rotor drone by the proposed test system. For data transfer between the computer that includes the test GUI and the test platform two Xbee wireless communication modules have been used in this work. Thanks to the proposed test platform and GUI, all the sensor data of VTOL multi rotor drones can be easily received via wireless communication. Fig. 13 presents three-axis data taken from the gyroscope and accelerometer. The roll angle test result obtained using the PID controllers including the unsettled control parameters that are reset, is presented in Fig 14.

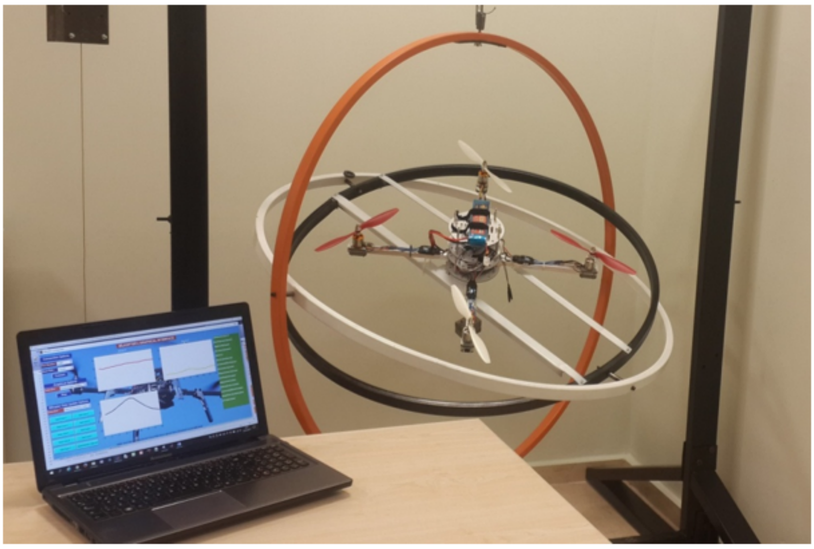


Fig. 12. The VTOL multi rotor drone's pre-flight tests at Computer Engineering Laboratory.

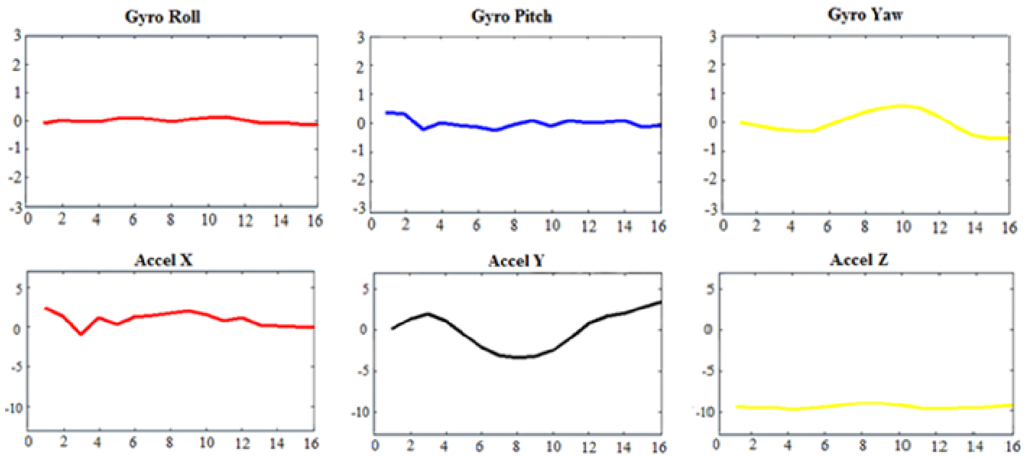


Fig. 13. GUI data taken from the gyroscope and accelerometer.

The VTOL multi rotor drone has two modes: RC and test modes. In RC mode, the drone onto the test platform can be controlled by a RC receiver/transmitter. Test mode consists of roll and pitch tests. Each test has fixed set angle, fixed two-level set angle, and sinusoidal set angle cases. In the test mode, the default PID coefficients on the AeroQuad board were used first. However, these coefficients need to be adjusted, as can be seen from the experiment performed in RC mode for the roll angle in Fig. 14. Cohen-Coon method, Yuwana-Seborg method, Ziegler-Nichols method and trial-error method are available in the literature for setting PID parameters. Since we started with the predetermined PID coefficients in AeroQuad, we adjusted the PID parameters by trial and error on the test platform.

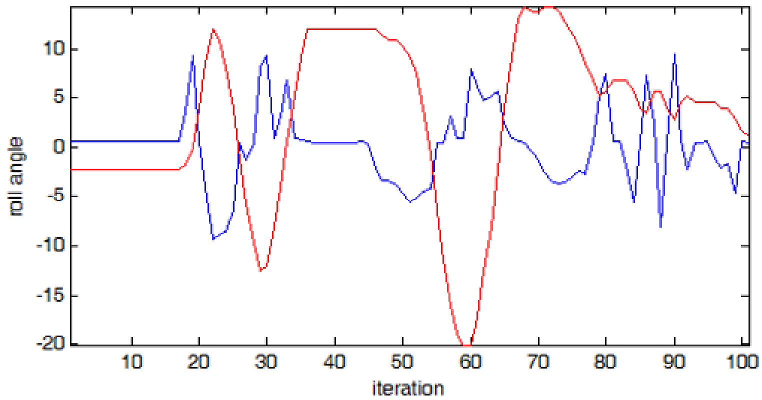


Fig. 14. The results of the roll angle test for VTOL multi rotor drone with unsettled control parameters (red line: measured roll angle, blue line: remote control signal).

In this study, Roll PID and Pitch PID values from a total of 9 PID controllers in AeroQuad were changed from their default values and adjusted slowly. Here, first the Kp coefficient, then the Kd and Ki coefficients are adjusted. The control structure of the VTOL drone is shown in Fig. 15. In this closed-loop model, I_{lat}, I_{lon}, I_{dir}, I_{ver} represent the pilot commands; I_{ail}, I_{ele}, I_{rud}, I_{thr} stand for the axis commands. The VTOL multi rotor drone response consists of linear accelerations $(a_x,\ a_y,\ a_z)$, Euler angles $(\theta,\ \phi,\ \psi)$, and angular rates $(p,\ q,\ r)$.

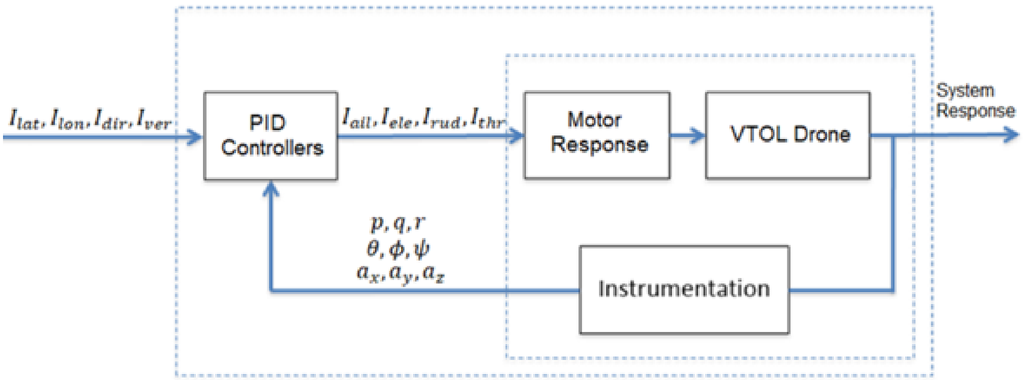


Fig. 15. The control block diagram of VTOL multi rotor drone.

All necessary data in the control model is obtained by the *Inertial Measurement Unit* (IMU) on the AeroQuad board. In this study, the pitch and roll tests of the VTOL drone are considered. In this study, pitch and roll tests are discussed. According to the test option selected over the GUI, the necessary set signal values are sent to the VTOL drone mounted on the test platform with the wireless communication module, and the angular information of the vehicle is displayed on the GUI by processing the data received from the IMU during the test period. Roll and Pitch PID values are wirelessly set to the AeruQuad board by entering the desired values via the GUI before the test. The pseudo code of the test software is given below:

Case Initialize Option of

condition 1 : initialize in RC mode
condition 2 : initialize in Test mode
End Case
If (initial thrust command thrust command)
Case Test Number of
condition 1 : run pitch test for fixed angle case
condition 2 : run pitch test for fixed two-level angle case
condition 3 : run pitch test for sinusoidal angle case
condition 4 : run roll test for fixed angle case
condition 5 : run roll test for fixed two-level angle case
condition 6 : run roll test for sinusoidal angle case
End Case
ElseIf
Stop the UAV Test
End If

To show the performance of the test system developed for the VTOL multi rotor drones, two basic pre-flight tests are discussed such as pitch and roll angle tests. For all test works, three set angle signals, x(t) have been used as given below:

$$x_1\,(t) = 20\,[u\,(t) - u(t - 100)] \tag{1}$$

$$x_2\,(t) = 20.u\,(t) - 40u\,(t - 50) + 20u\,(t - 100) \tag{2}$$

$$x_3\,(t) = 30.\sin(2\pi t/100) \tag{3}$$

The first signal is a constant amplitude signal; the second signal consists of two levels with 20 and –20. The last test signal is a sinusoidal signal whose amplitude is 30 and its period is 100. The total test time for each test signal has been determined as 100 seconds. The experimental setup consists of the VTOL multi rotor drone on the test mechanism, wireless XBee modules and a personal computer, and all of them are shown in Fig. 16.

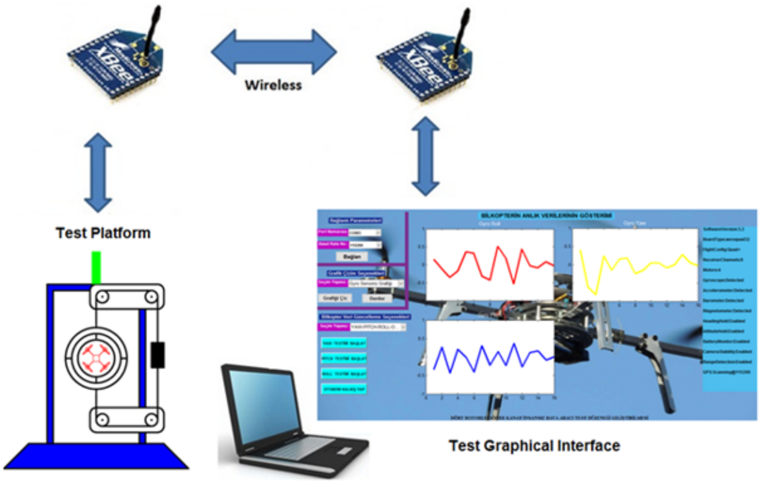


Fig. 16. Experimental setup for VTOL multi rotor drone's pre-flight tests.

5.1. Pitch Angle Tests

The pitch angle tests have been realized for the different parameters of PID controller. The VTOL multi rotor drone has been set tightly in the center of the test platform during the pitch tests. In Fig. 17, the results of the pitch angle test for a VTOL drone with six motors, and an image from this test run are shown. The results obtained here are obtained for a proportional gain coefficient of 5.5, a derivative gain coefficient of 1.5, and an integral gain coefficient of 0.5 for the pitch PID controller.

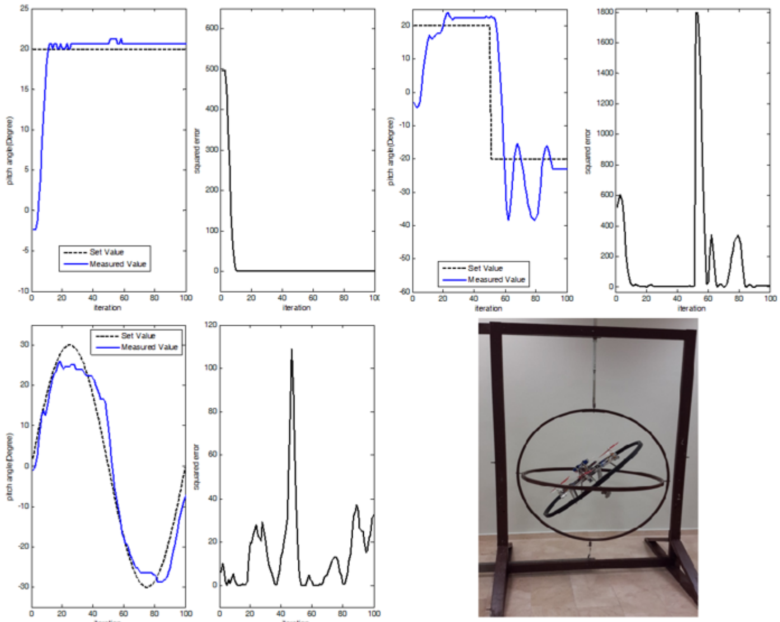


Fig. 17. The results of the pitch angle test for VTOL multi rotor drone with six rotors.

As can be understood from these test results, it is shown that the measured pitch angle values follow the set angle signal and the squared error is decreased by PID controller for predetermined control parameter. The pitch angle values are obtained from the kinematic angle values calculated by the sensors data on the VTOL multi rotor drone. The second set signal consists of 20 degrees in the time range of [0 50] and -20 degree in the time range of [51 100]. The response of the VTOL multi rotor drone includes an excessive overshoot and oscillation for the second interval. By adjusting the parameters of the pitch PID controller using the proposed test GUI, this response has little steady error and overshoots. The last set angle is a sinusoidal signal. The results show that the response of the VTOL multi rotor drone follows the sinusoidal test signal successfully.

5.2. Roll Angle Tests

In the roll angle tests, the VTOL drone with six motors has been used for the different parameters of PID controller. Fig. 18 shows the results of the roll angle test for a VTOL multi rotor drone with six rotors. Also, a photo from this test run is presented in the same figure. Roll PID values were used as in the previous test (Kp=5.5, Kd=1.5, and Ki=0.5).

The roll angle test results show that the VTOL drone with six motors tries to follow the set signals for the predetermined roll PID control parameters by test GUI. Looking at the results in detail, it can be seen that the target roll angle of 20 for the first set signal settles with a decreasing oscillation. In the second two-stage set signal, it is seen that when the set value decreases from 20 to -20, it misses the set value at first, but then the system settles to the new set value in a short time. It is understood that the drone roll angle successfully follows the set signal for the sinusoidal signal with a frequency of 10e-2 Hz, which is the last test signal. In short, as a result, for the all-set signals, the developed test system has been used successfully in the roll movement tests.

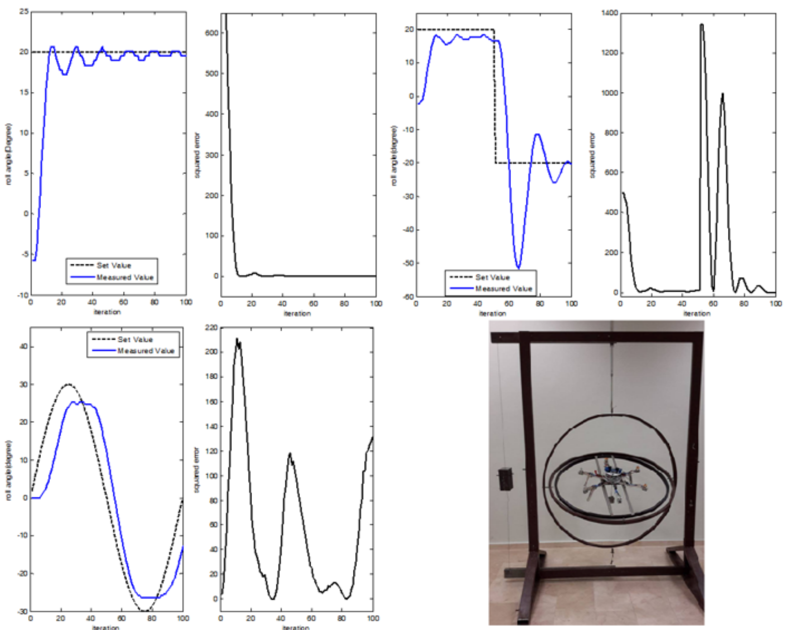


Fig. 18. The results of the roll angle test for VTOL multi rotor drone with six rotors.

6. Conclusions

In this study, a new test platform system has been proposed for the different VTOL multi rotor drones. This test mechanism, which is inspired by the gyroscope movement, consists of the three different sized circles that lie one inside the other, steel rope, pulleys, balance weight, and a strain prevention system. Thanks to the proposed test platform, the some axis tests, such as pitch, yaw, roll, and altitude, can be done before the flight of VTOL multi rotor drone. The most vital advantage of this developed test mechanism is that it has no motion restriction along all axes without altitude motion in comparison with the other existing test mechanisms. This test platform is suitable for preflight tests of the VTOL multi rotor drones and all tests can be done safely for the adjusted control parameters.

In the scope of this work, a test graphical user interface has been built to acquire the data of the sensors from the microcontroller board on the VTOL multi rotor drone and to send test commands, to edit control parameters of the VTOL multi rotor drone. By this proposed GUI, axis motion tests, such as altitude, yaw, pitch, and roll, the sensor data, the angle values of all axes, the position information of the VTOL multi rotor drone on the test platform are shown on the screen.

During the test process, all data has been received and sent by XBee wireless modules which are connected between VTOL multi rotor drone and the user computer. With the help of GUI, the data taken from VTOL multi rotor drone can be sent to VTOL multi rotor drone again after updating. The other advantage of this test system is the fact that all sensor data of the VTOL multi rotor drone can be monitored via wireless communication in real time. The experimental results show that the responses of the VTOL multi rotor drones with six rotors follow the three different set signals with steady state error and a small overshoot.

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References

[1] K. KANISTRAS, G. MARTINS, M. J. RUTHERFORD and K. P. VALAVANIS, *Survey of unmanned aerial vehicles (UAVs) for traffic monitoring*, Proceedings of 2013 IEEE International Conference on Unmanned Aircraft Systems, Atlanta, GA, USA, pp. 221–234, 2013.

[2] B. COIFMAN, M. MCCORD, R. G. MISHALANI, M. ISWALT and J. YUXIONG, *Roadway traffic monitoring from an unmanned aerial vehicle*, IEE Proceedings-Intelligent Transport Systems, IET Digital Library **153**(1), pp. 11–20, 2006.

[3] C. C. HADDAL, C. CHAD and G. JEREMIAH, *Homeland security: Unmanned aerial vehicles and border surveillance*, Library of Congress Washington DC Congressional Research Service, 2010.

[4] A. R. GIRARD, A. S. HOWELL and J. K. HEDRICK, *Border patrol and surveillance missions using multiple unmanned air vehicles*, Proceedings of 43rd IEEE Conference on Decision and Control, Atlantis, Bahamas, pp. 620–625, 2004.

[5] E. R. HUNT, W. D. HIVELY, S. J. FUJIKAWA, D. S. LINDEN, C. S. DAUGHTRY and G. W. MCCARTY, *Acquisition of NIR-green-blue digital photographs from unmanned aircraft for crop monitoring*, Remote Sensing **2**(1), pp. 290–305, 2010.

[6] F. A. VEGA, F. C. RAMÍREZ, M. P. SAIZ and F. O. ROSÚA, *Multi-temporal imaging using an unmanned aerial vehicle for monitoring a sunflower crop*, Biosystems Engineering **132**, pp. 19–27, 2015.

[7] P. RUDOL and P. DOHERTY, *Human body detection and geolocalization for UAV search and rescue missions using color and thermal imagery*, Proceedings of 2008 IEEE Aerospace Conference, Big Sky, MT, USA, pp. 1–8, 2008.

[8] G. ZHOU, C. LI and P. CHENG, *Unmanned Aerial Vehicle (UAV) real-time video registration for forest fire monitoring*, Proceedings of 2005 IEEE International Geoscience and Remote Sensing Symposium, Seoul, South Korea, pp. 1803–1806, 2005.

[9] J. P. HOW, B. BETHKE, A. FRANK, D. DALE and J. VIAN, *Real-time indoor autonomous vehicle test environment*, IEEE Control Systems Magazine **28**(2), pp. 51–64, 2008.

[10] U. YÜZGEÇ, İ. ÖKTEN, H. ÜÇGÜN, A. R. GÜN, T. TÜRKYILMAZ, M. KESLER, C. KARAKUZU and G. UÇAR, *Development of the test platform for rotary-wing unmanned air vehicle*, Bilecik Seyh Edebali University Science Journal **3**(2), pp. 18–24, 2016.

[11] H. ÜÇGÜN, İ. ÖKTEN, U. YÜZGEÇ and M. KESLER, *Graphical interface design and implementation for flight tests of the rotary-wing unmanned aerial vehicles*, Proceedings of 2016 UBMK International Conference on Computer Science and Engineering, Tekirdag, Turkey, pp. 671–676, 2016.

[12] V. E. ÖMÜRLÜ, A. KIRLI, U. BÜYÜKŞAHIN, . N. ENGIN and S. KURTOĞLU, *A stationary, variable DOF flight control system for an unmanned quadrocopter*, Turkish Journal of Electrical Engineering and Computer Sciences **19**(6), pp. 891–899, 2011.

[13] S. GRZONKA, G. GRISETTI and W. BURGARD, *A fully autonomous indoor quadrotor*, IEEE Transactions On Robotics **28**(1), pp. 90–100, 2011.

[14] Z. A. AZFAR and D. HAZRY, *A simple approach on implementing IMU sensor fusion in PID controller for stabilizing quadrotor flight control*, Proceedings of IEEE 7th International Colloquium on Signal Processing and its Applications, Penang, Malaysia, pp. 28–32, 2011.

[15] E. A. BARAN, C. HANÇER, E. ÇALIKOĞLU, E. DUMAN, E. ÇETINSOY, M. ÜNEL and M. F. AKŞIT, *Design and production of test equipment for unmanned aerial vehicle*, Automatic Control Meeting TOK'08, İstanbul, Turkey, 2008.

[16] A. TAYEBI and S. MCGILVRAY, *Attitude stabilization of a VTOL quadrotor aircraft*, IEEE Trans. Control System Technology **14**(3), pp. 562–571, 2006.

[17] S. D. HANFORD, L. N. LONG and J. F. HORN, *A small semiautonomous rotary-wing unmanned air vehicle (UAV)*, Proceedings of 2005 AIAA InfoTech Aerospace Conference, Washington DC, USA, pp. 1–7, 2005.

[18] N. I. VITZILAIOS and N. C. TSOURVELOUDIS, *An experimental test bed for small unmanned helicopters*, Journal of Intelligent and Robotic Systems **54**(5), pp. 769–794, 2000.

[19] K. ALEXIS, G. NIKOLAKOPOULOS and A. TZES, *Design and experimental verification of a constrained finite time optimal control scheme for the attitude control of a quadrotor helicopter subject to wind gusts*, Proceedings of 2010 IEEE International Conference Robotic Automation, Anchorage, AK, USA, pp. 1636–1641, 2010.

[20] M. ALBAYRAK and A. ARISOY, *Controller design with real time neural networks for four rotor aerial vehicle*, Journal of Aerospace Technologies **6**, pp. 1–7, 2013.

[21] *Different types of VTOL multi rotor drones*, Accessed: May 1, 2019 [Online]. Available: http://www.birdseyeofbigsky.com/through-the-birds-eye/3tipssuccessfuldroneflight.

[22] Y. YU and X. DING, *A quadrotor test bench for six degree of freedom flight*, Journal of Intelligent and Robotic Systems **68**(3–4), pp. 323–338, 2012.

[23] S. PREITL, R.-E. PRECUP, J. FODOR and B. BEDE, *Iterative feedback tuning in fuzzy control systems. Theory and applications*, Acta Polytechnica Hungarica **3**(3), pp. 81–96, 2006.

[24] T. CHEN, A. BABANIN, A. MUHAMMAD, B. CHAPRON and C. CHEN, *Modified evolved bat algorithm of fuzzy optimal control for complex nonlinear systems*, Romanian Journal of Information Science and Technology **23**(T), pp. T28–T40, 2020.

[25] R.-E. PRECUP and S. PREITL, *PI-fuzzy controllers for integral plants to ensure robust stability*, Information Sciences **177**(20), pp. 4410–4429, 2007.

[26] S. LABDAI, N. BOUNAR, A. BOULKROUNE and B. HEMICI, *Sliding mode control via fuzzy multi-level switching control scheme for DFIG based WECS*, Romanian Journal of Information Science and Technology **21**(4), pp. 429–445, 2018.

[27] R.-E. PRECUP and S. PREITL, *PI and PID controllers tuning for integral-type servo systems to ensure robust stability and controller robustness*, Electrical Engineering **88**(2), pp. 149–156, 2006.

[28] B. PRIYA and S. S. MANOHAR, *Adaptive power control and duty cycle based medium access control protocol for cluster based wireless sensor network*, Romanian Journal of Information Science and Technology **23**(1), pp. 38–54, 2020.