# Simulation Platform for Quadricopter: Using Matlab/Simulink and X-Plane

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***Abstract*— The unmanned aerial vehicles (UAVs) has grown in military and civilian areas of application. Several industries (automotive, military, factories, space, etc.) use robots for dangerous and repetitive tasks. This paper is dedicated to a special type of aerial platforms, the quadricopter. This platform has been highlighted by having unique characteristics in flight and construction, for example, hovering flight, vertical takeoff and landing, high maneuverability, low speed flight, and simple mechanics. This work proposes a tool for simulation and visualization of an aerial air-type quadricopter robots, using the flight simulator X-Plane 9, Matlab and Simulink. The aircraft under study is control the so-called ITA-001, developed by the quadricopter study group the Aeronautical Institute of Technology – ITA.**

***Keywords- Quadricopter, Simulation, X-Plane, Matlab***

## I. INTRODUCTION

Currently, the use of unmanned aerial vehicles (UAVs) has increased both in military and civilian areas, especially in missions where human operation is unnecessary, repetitive or dangerous. These are employed in diverse areas such as surveillance, photography, traffic monitoring, identification of pests in agriculture and educational platforms [1].

UAVs can be divided into two groups: fixed-wing and rotorcraft. Fixed wing flight vehicles are suitable for outdoor use and can cover large area. The rotary-wing vehicles have features such as: increased maneuverability, vertical takeoff and landing and hovering flight, enabling flight at low altitudes and indoor application [2]. For the group of rotorcrafts, a configuration that is gaining prominence is the quadricopter, which consists of four independent blades arranged in a cross shape.

The concept of quadricopter appears in 1907 with Breguet brother's and professor Richet work [3]. Their aircraft concept was large and heavy, and it was not possible to make a flight with large payloads or large distance flights. Since then, rotorcraft research had been developed, but the concept of quadricopter was forgotten. In recent years, the development of lightweight building materials, the improvement of the relation between power and weight, and the miniaturization of the engine and control systems, has been factor that turned the quadricopter feasible. Since then, several civil and military institutions are researching and developing this type of aircraft [4].

The autopilot is a major component of a UAV. The design of automatic pilot systems requires many simulations and tests on real aircraft. The real aircraft tests present high risk of dangerous accidents. Therefore, before being embedded, autopilot systems must be thoroughly tested in the laboratory [5].

Several platforms have been developed for UAV simulation, but they are focused on complex vehicles and integration of their systems. Great effort and development time are required to build a custom configuration for specific integration of sensors and normally complex software is required to operate. Many of them do not support modifications of hardware or software, and to update or to modify it, one spends almost the same time necessary to develop a new UAV. Besides the simulation platform related problems, it is also difficult to know the actual meteorological conditions along the route [6].

Some authors have addressed the topic of simulation platform for UAVs. The reference [6] treats the problems of small fixed wing UAVs, analyzing the control and navigation algorithms. The reference [7] treats the problem of the ducted type fan UAVs, and proposes a concept of simulation platform based on the commercial flight simulator X-Plane 9 and Matlab \ Simulink. The reference [8] is a simulation platform for multi-UAV helicopters, and proposes a simulator for test and evaluation of control algorithms for stabilization of the aircraft and formation of the swarm. According to our knowledge, none of the recent works presents a simulation platform for quadricopter control and navigation and prepared for swarm research, at the point of view of its embedded system.

For the reasons mentioned above and for not having found a platform to quadricopters simulations, with support for autopilot tests, ability to customize features of the aircraft and to simulate real conditions (such as winds, turbulences, etc.), we propose in this article a platform for simulation and visualization of quadricopter type aircraft using the commercial simulator X-Plane 9 and Matlab Simulink. The main objective of this platform is to test and to help the development process of autopilot systems for quadricopter type aircraft. The quadricopter ITA-001 will be used as an object under test of this study.

This article is organized as follows: section 2 describes the quadricopter ITA-001, section 3 presents the simulation platform, section 4 describes the data interface for the simulation, section 5 describes the implementation platform, section 6 is about platform application and section 7 contains conclusions and suggestions for future works.

## II. QUADRICOPTER ITA-001

The quadricopter is an aircraft with four independent rotors, fixed at the end of each axle as shown in Figure 1

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[4]. In order to cancel the moment generated by the rotating blades, a pair of propellers rotates clockwise and the second pair in a counterclockwise direction.

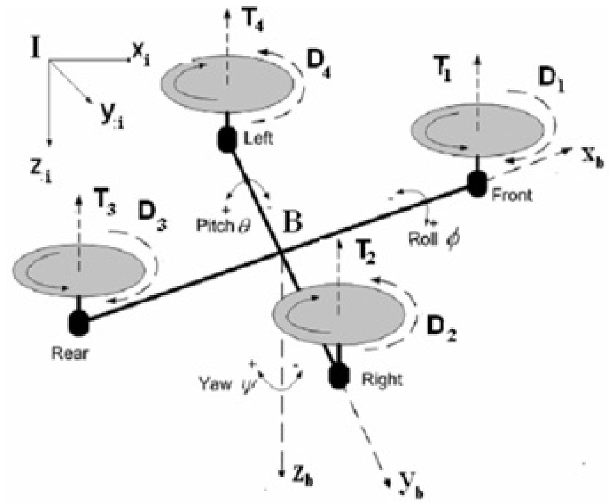


Figure 1. Configuration quadricopter withdrawal [4]

## A. *ITA-001 Description*

The model ITA-001 was based on an experimental structure, assembled from parts of commercial RC (Remote Controlled) airplanes, as shown in Figure 2. Its structure is made of aluminum rods, together with pieces of acrylic. It contains four brushless motors located on the ends of the rods, four controllers engine and a controller for stabilization.

Figure 2. ITA-001

## B. *ITA-001 Control System*

The quadricopter ITA-001 features two control problems: glide control and path control. The first control system is used to obtain a stable operation hover. The second control system is to perform missions that require to travel certain paths. Figure 3 shows the control system for a quadricopter.

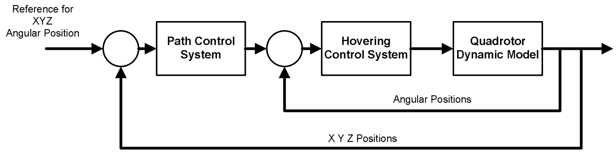


Figure 3. Control System

# III. SIMULATION PLATFORM

This platform has been implemented using the flight simulator X-Plane 9 and Matlab. The chosen means of communication between software is UDP (user datagram protocol). The Matlab/Simulink runs the autopilot and processes data flight for analysis. The X-Plane simulates the dynamics of the aircraft and displays the 3D view of the Simulation. The Simulation Platform concept is presented in Figure 4.

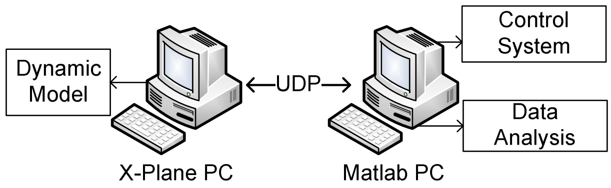


Figure 4. Simulation Platform Concept

## A. *X-Plane flight Simulator*

This simulator was chosen for the following characteristics:

- Certification by Federal Aviation Administration (FAA).
- Plane Maker: tool for drawing and modifying aircraft.
- Has been used as the basis for designing and testing control algorithms.
- Has a god interface for data injection and data extraction.
- Accurate flight models.

The X-Plane uses the geometric shape modeled in Plane Maker to see how the aircraft will fly. He uses an engineering method called blade element theory, which means to divide the aircraft into small elements and then find the forces acting on each element several times per second [9].

X-Plane native method of communication (import and export data) is the UDP protocol. This protocol is a non-guaranteed protocol and gives no assurance that data packets arrived in order or didn't arrive at all, so it may present a possible problem resulting from data corruption. [8]

This simulator has configurations where it is possible to view the various forces acting on the aircraft, the path traveled by the aircraft and, also, allows the introduction of in-flight failures.

## B. *Matlab/Simulink*

Matlab/Simulink® is an environment for multi-domain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing [10].

Simulink is integrated with MATLAB®, providing immediate access to an extensive range of tools that let you develop algorithms, analyze and visualize simulations, create batch processing scripts, customize the modeling environment, and define signal, parameter, and test data [10].

In the simulation platform, the software Matlab / Simulink is responsible for processing the UDP data, control system for glide and post processing of data simulation.

## IV. DATA INTERFACE

The UDP protocol is chosen because it is the standard system for sending and receiving data from the X-plane and, also, it is compatible with Matlab / Simulink.

The speed of communication is a point of great importance, because the control commands must be synchronized with the simulation in X-plane. The X-Plane has capacity to send 99.9 packets per second, but most of the inertial measurement systems operate at a rate of 40 to 60 times per second. Therefore, we chose to work with 40 packets per second.

The type and size of the UDP packet depends on the amount and types of data to be exported. The X-Plane has a interface to set the output and receiving data, which is shown in Figure 5.

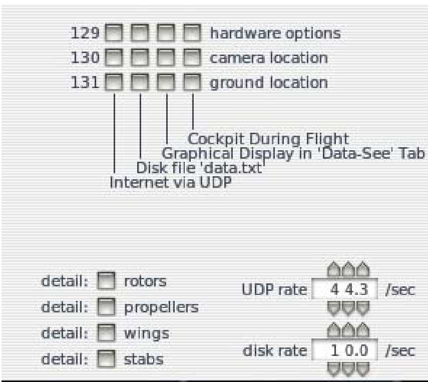


Figure 5. UDP Configuration X-Plane 9

The data packet sent by the X-plane follows this pattern: the first four bytes represent the type of packet, the fifth byte is an internal policy, the next four bytes indicate what type of parameter is being sent, the following four bytes represent the value in single-precision float. An example of packet data is shown in Figure 6.

| | DATA | | | | I | Label | | | | GROUP 1 | | | | ... | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Byte | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| | | | | | | Speeds | | | | Vind(Kias) | | | | Vind(keas) | | | |

Figure 6. UDP Pack

## V. PLATFORM IMPLEMENTATION

This platform has been implemented using two desktop computers. The first computer runs the first flight simulator X-Plane and the second one runs control system and processing, and also analysis of simulation data. The computers communicate through Ethernet port via UDP protocol.

For the implementation it was necessary to build the quadricopter ITA-001 model for X-Plane 9. To this implementation the tool Plane-Maker was used. For the modeling process, we made use of the Plane-Maker Manual [11], and Tutorial Plane-Maker [12].

Making ingenious use of Plane-Maker special options, and also taking advantage of symmetry existing in the system, the modeling was performed successfully, as illustrated in Figures 7 and 8.

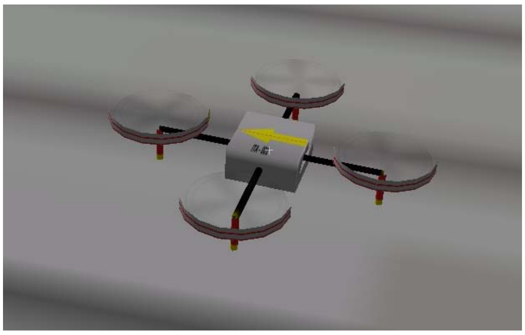

Figure 7. ITA-001 X-Plane model

Figure 8. ITA-001 Cockpit Vision

## VI. APPLICATION

To demonstrate the use of this as a development tool for autopilot systems, control system for hovering was designed and implemented in simulation platform, The high level hovering control system block diagram is shown in Figure 9.

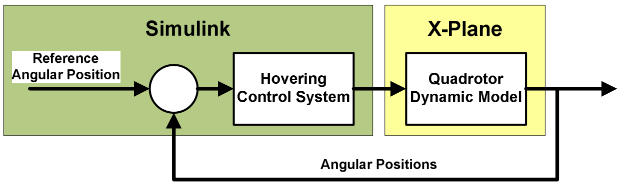


Figure 9. High Level Hovering Control

The quadricopter dynamics is simulated at X-Plane, and the autopilot blocks are inserted in the block control system. Figure 10 presents a detailed vision of the control system block.

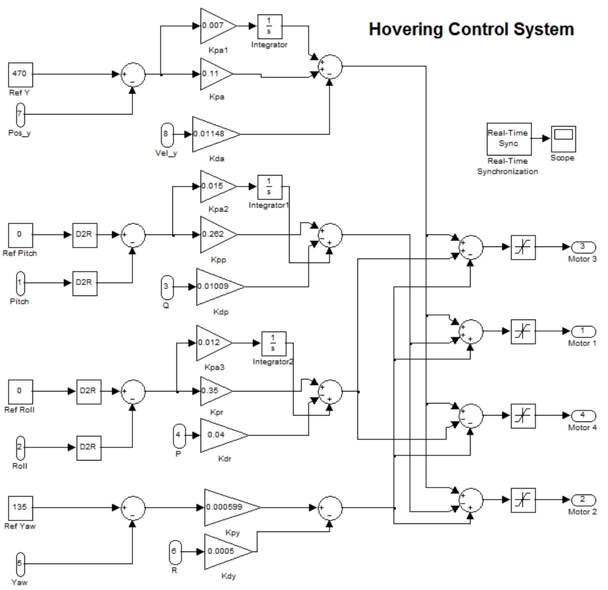


Figure 10. Detailed view of the control system

The reference signal applied to the system and the response to this stimulus is presented in Figure 11. For hovering, the reference signals of the angular positions were set to zero, the reference altitude is set to 476 meters. Altitude response is shown in Figure 12.

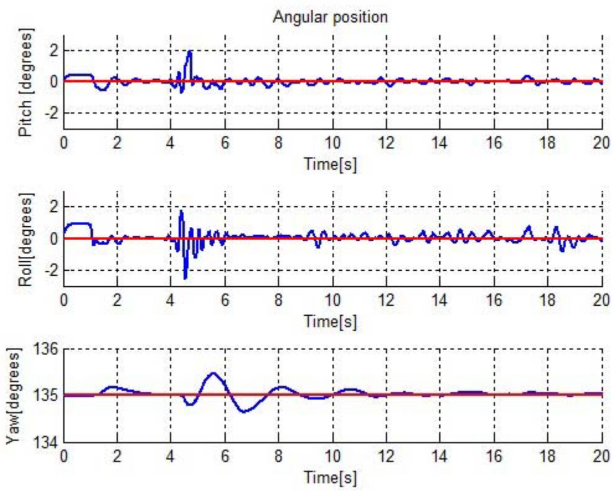


Figure 11. Angular Positions response

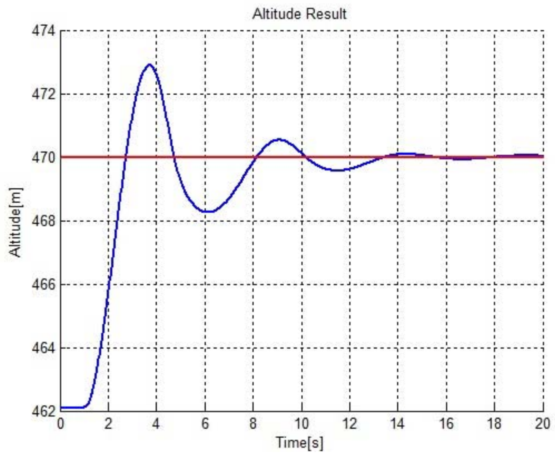


Figure 12. Altitude response

For this simulation, the quadricopter starts from the ground, and then put the reference signals to hover in 470 meters. The control loops gain were tuned empirically. In order to ease this work, we designed a graphical user interface shown in Figure 13.

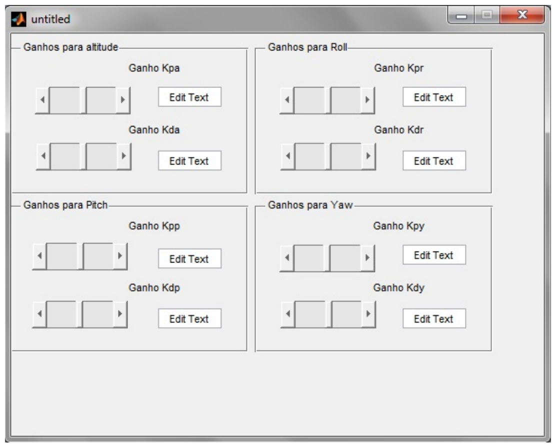


Figure 13. Adjust interface

A method to obtain better answers is to do more simulations for making fine adjustments in the controller.

An example of the utilization of this platform as a design tool for an autopilot system in context of an embedded autonomous system is the analysis of the frequency control loop. This analysis is important because for small aircrafts, such is the case of quadricopters, power is supplied by batteries and payload are very restricted, making critical the choice of sensors and microcontrollers that will be embedded. The frequency control loop can be limited by the speed of data acquisition for feedback or the processing capacity of the microcontroller where the control system was embedded.

As a design tool we could use this platform and test the control system in various frequencies. As an example we use the hovering control system previously proposed, and the response of the system at various frequencies, generated by the computer. Figure 14 presents the system response to altitude.

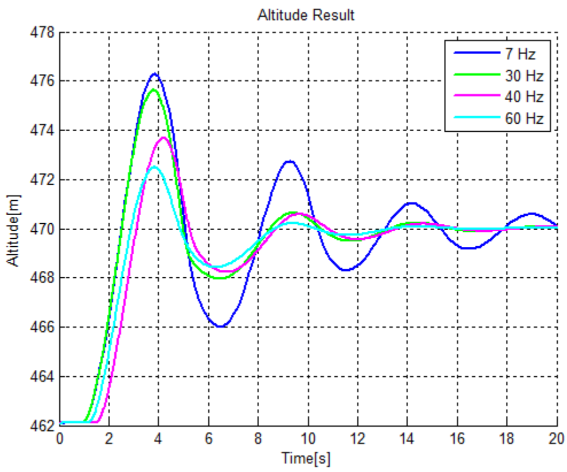


Figure 14. Altitude Response

Analyzing the resultant curves of Figure 14, we find that for low frequencies the system shows a larger overshoot and longer accommodation. Increasing the frequency of operation, we can observe that the maximum peak and the settling time are both lowering with the increase of frequency. This experiment is an example of how this simulation platform can generate the minimum requirements for the design of a prototype, given appropriate conditions.

This platform is also a good tool for design and analysis of algorithms for navigation, because it allows the test of these algorithms without the utilization of real aircraft, thus reducing the development time and system costs.

## VII. Conclusion

This test platform is a great tool for design and study systems for quadricopter type UAV autopilot. Also it is possible to monitor the response of the aircraft in a variety of flight conditions.

This simulation tool is useful also to try easily various techniques of control and navigation algorithms for hardware-in-the-loop tests. This architecture also enables simulating quadricopter swarms and interactions with vehicles on the ground.

To continue this work, the simulation results will be compared with the non-linear model of quadricopter, then with the real quadricopter, thus increasing the reliability of the results obtained in the simulation.

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