

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

4,800

Open access books available

122,000

International authors and editors

135M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Modelling and Control Prototyping of Unmanned Helicopters

Jaime del-Cerro, Antonio Barrientos and Alexander Martínez
*Universidad Politécnica de Madrid – Robotics and Cybernetics Group
Spain*

1. Introduction

The idea of using UAV's (Unmanned Aerial Vehicles) in civilian applications has created new opportunities for companies dedicated to inspections, surveillance or aerial photography amongst others. Nevertheless, the main drawback for using this kind of vehicles in civilian applications is the enormous cost, lack of safety and emerging legislation. The reduction in the cost of sensors such as Global Positioning System receivers (GPS) or non-strategic Inertial Measurement Units (IMU), the low cost of computer systems and the existence of inexpensive radio controlled helicopters have contributed to creating a market of small aerial vehicles within an acceptable range for a wide range of applications. On the other hand, the lack of safety is mainly caused by two main points: Mechanical and control robustness.

The first one is due to the platform being used in building the UAV in order to reduce the cost of the system, which is usually a radio controlled helicopter that requires meticulous maintenance by experts.

The second is due to the complexity of the helicopter dynamics since it is affected by variations in flying altitude, weather conditions and changes in vehicle's configuration (for example: weight, payload or fuel quantity). These scenarios disrupt the modeling process and, consequently, affect the systematic development of control systems, resulting to tedious and critical heuristic adjustment procedures.

Researchers around the World propose several modeling techniques or strategies for dynamic modeling of helicopters. Some works on helicopter modeling such as (Godbole et al or Mahony et al, 2000), (Gavrilets et al, 2001), (Metler et al and La Civita et al, 2002), and (Castillo et al, 2007) show broad approaches that have been done in this field of engineering. The lack of an identification procedure in some cases and the reduced field of application in others, make sometimes difficult to use them.

In this chapter, not only a modeling is described, but also the identification procedure that has been successfully tested. The proposed model has been defined by using a hybrid (analytical and heuristic) algorithm based on the knowledge of flight dynamic and by resolving some critical aspects by means of heuristic equations that allow real time simulations to be performed without convergence problems. Evolutionary algorithms have been used for identification of parameters. The proposed model has been validated in the different phases of the aircraft flight: hovering, lateral, longitudinal or vertical using a

Benzin Trainer by Vario which relies on a 1.5 m of main rotor diameter and a payload of about five kilograms.



Figure 1. Benzin trainer by Vario with GNC (Guidance Navigation & Control) system onboard

A full structure of control has been developed and tested by using a proposed fast design method based on Matlab-Simulink for simulation and adjustment in order to demonstrate the usefulness of the developed tool. The proposed architecture describes low level control (servo actuators level), attitude control, position, velocity and maneuvers. Thus there are commands such as straight flying by maintaining a constant speed or maneuvers such as flying in circles i.e.

The results have confirmed that hybrid model with evolutionary algorithms for identification provides outstanding results upon modeling a helicopter. Real time simulation allows using fast prototyping method by obtaining direct code for onboard controllers and consequently, reducing the risk of bugs in its programming.

2. Helicopters flight principles

The required thrust for flying helicopters (elevation and advance) is only provided by the main rotor. In order to obtain a comprehensive knowledge about the forces involved in the main rotor, an exhaustive explanation would be required. The forces involved in the main rotor generate twisting and bending in the blades, as well as elevation forces and different kinds of aerodynamic resistance.

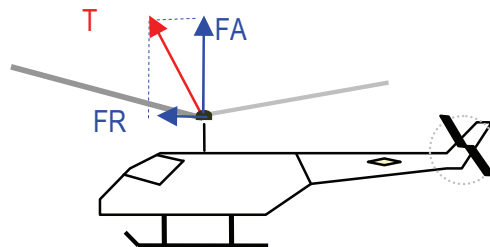


Figure 2. Basic Helicopter Thrust analysis

In a first approach, only a sustentation and a resistance force isolated from any other influence could be taken into account. The thrust (T) generated by the air pressure against the blade has an inclination in relation to the rotation plane. This force can be divided in vertical force (F_A) and resistance (F_R) that is applied in the horizontal plane against rotation direction (Figure 2).

Helicopters rely on mechanisms to modify the attack angle of the blade in the main rotor. It allows controlling the movement of the fuselage through the inclination of the rotation plane. The fact is that the attack angle of the blade is not constant neither in time nor space. It continuously changes while the blade is rotating as azimuth angle indicates. It can be assumed that the attack angle is the addition of two components: The first is an average attack angle during one complete rotation of the blade, called collective angle. The second component depends on the azimuth angle. When the azimuth angle is 0° or 180° , the blade has the roll cyclic angle. When 90° or 270° , the blade has the pitch cyclic angle (Figure 3).

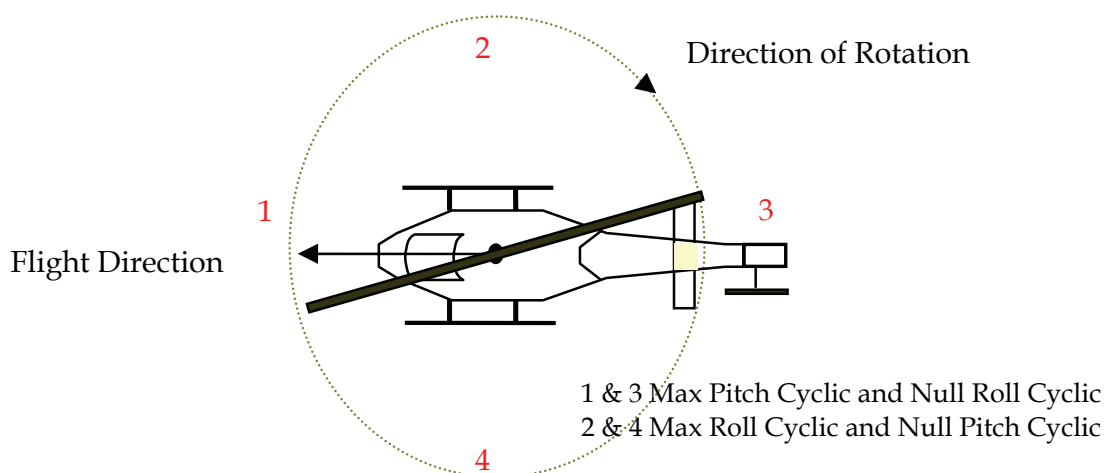


Figure 3. Attack angle during a blade revolution

Using these three signals (collective, roll and pitch cyclic), a pilot is able to control the main rotor. In addition to these signals, the pilot also controls the attack angle of tail rotor blades and the engine throttle.

Typically, radio-controlled helicopters rely upon a commercial control system to maintain the speed of the main rotor constant. The vertical control of the helicopter is done by changing the collective attack angle in the main rotor.

On other hand, the mission of the tail rotor is to compensate the torque that main rotor creates on the helicopter fuselage. The compensation torque can be adjusted by changing the attack angle of its blades. The tail rotor typically requires values between 5 to 30 per cent of the total power of the helicopter.

A lot of physical principles such as ground effect, downwash, flapping or atmospheric effects have to be considered in an in-depth study of helicopter flight dynamics. Taking into account the application scope for the proposed model, which is a small helicopter with small capabilities, no change of air density is considered. Moreover, the blades of the proposed model are also considered as solid bodies.

3. Model Description

Mathematical models of helicopter dynamics can be either based on analytic or empirical equations. The former applies to the physical laws of aerodynamics, and the latter tries to define the observed behavior with simpler mathematical expressions.

The proposed model is a hybrid analytic-empirical model that harnesses the advantages of both: high-velocity and simplicity of the empirical method, as well as fidelity and the physical meaning of the analytic equations.

3.1 Inputs and outputs

The proposed model tries to replicate the behavior of a small radio controlled helicopter, therefore the inputs and outputs have been selected as the controls that the pilot relies when using a commercial emitter. Cyclic (Roll and Pitch) and collective controls have been considered as inputs.

Denomination	I/O	Symbol	Units
Collective	Input	θ_{col}	Degrees
Roll Cyclic	Input	θ_{Roll}	Degrees
Pitch Cyclic	Input	θ_{Pitch}	Degrees
Rotational speed over a main rotor shaft.	Input	ω_z^h	Degrees/s
Acceleration (Helicopter reference frame)	Output	\bar{a}	m/s ²
Velocity (Helicopter reference frame)	Output	\bar{v} (u_a, v_a, w_a)	m/s

Table 1. Model inputs and outputs

Radio controlled helicopters usually rely on electronic systems based on gyroscopes to tail stabilization. Based on this fact, the yaw angle is controlled by giving rotational speed commands. Thus, the yaw rate has been considered as one of the inputs to the model.

It is also common that helicopters rely on a main rotor speed hardware controller. In such manner, the rotor maintains the speed and consequently, the vertical control is then performed by the changing of the collective angle. The assumption in considering constant speed reduces the complexity of the model and maintains its quality. Furthermore, the use of this hardware controller decreases the number of inputs since no throttle command is required.

Accelerations and rotational speeds are the outputs of the model. Table 1 summarizes the inputs and outputs of the model.

3.2 Model block diagram

A block diagram of the proposed model is described in Figure 5. A brief definition of every part is also shown in the following sections.

3.2.1 Main rotor

It is modeled with analytic equations, derived from research on full-scale helicopters [Heffley 2000], which can be used to model small helicopters without fly-bars. The iterative algorithm computes thrust and induced wind speed while taking into account geometrical parameters, speed of the blades, commanded collective, roll and pitch cyclic.

One of the most important concepts to be known is the relationship among the Torque, Power and Speed. Such response arises from the induced velocity of the air passing through the disk of the rotor.

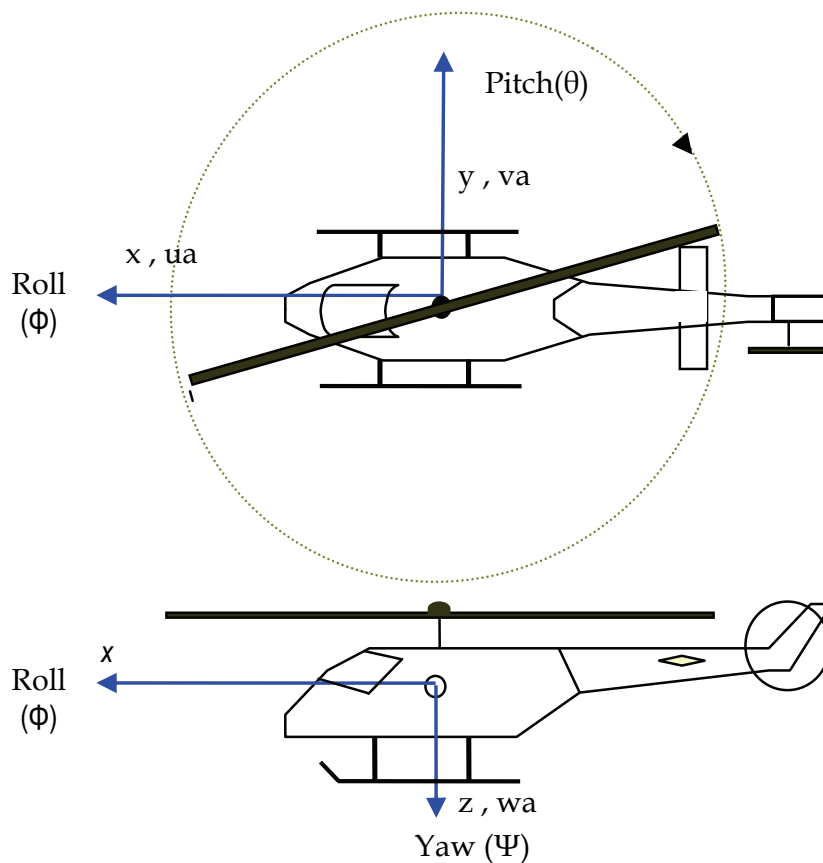


Figure 4. Outputs of the model

The airflow goes downward, and due to the action-reaction principle, it generates a vertical force that holds the helicopter in the air. The engine provides the torque to make the blades rotate and create the airflow.

Although there are many factors that make difficult to exactly determination of the relative speed between the helicopter and the airflow through the disk that the rotor creates when rotating, it is possible to work with a first order approach. In this way, it is possible to model using the momentum classic theory and estimating the force and induced velocity using an feedback aerodynamic block. Nevertheless, calculus turns to be difficult because the feedback is highly non-linear.

Another aspect regarding the induced speed is its influence on the surrounding surfaces, thus it can be affected by the ailerons and others fuselage parts and it changes depending on the speed and direction of the flight. In this model, torque and induced speed have been modeled assuming a uniform distribution of the air passing through the rotor disk.

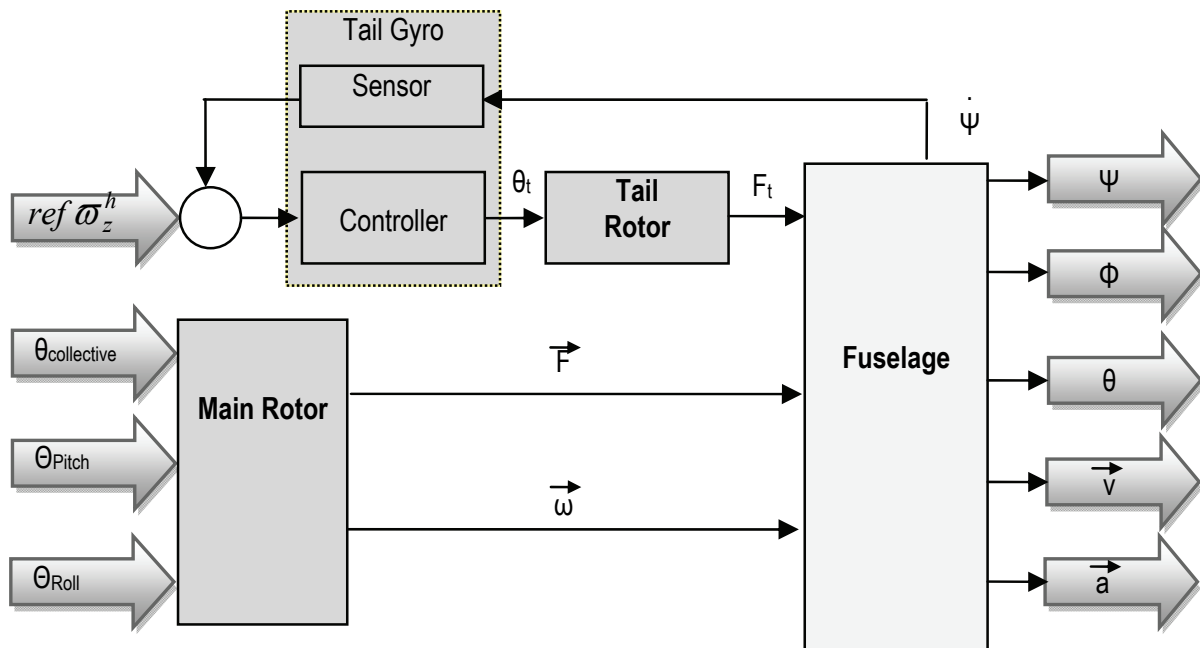


Figure 5. Model Block Diagram

The computation of the torque and induced speed is based on the classic momentum theory but using a recursive scheme that allows to reach a fast convergence. The equations used to model the main rotor have two groups of inputs, as Figure 6 shown.

The collective step (θ_{Col}) and the blade torsion (θ_{Twist}), compose the first branch. The rotor axis inclination (I_s) and the cyclic roll and pitch the second one.

The attack angles a_1 and b_1 are derived from the cyclic roll and pitch references. The wind speed relative to the helicopter is present through its three components: u_a , v_a , and w_a .

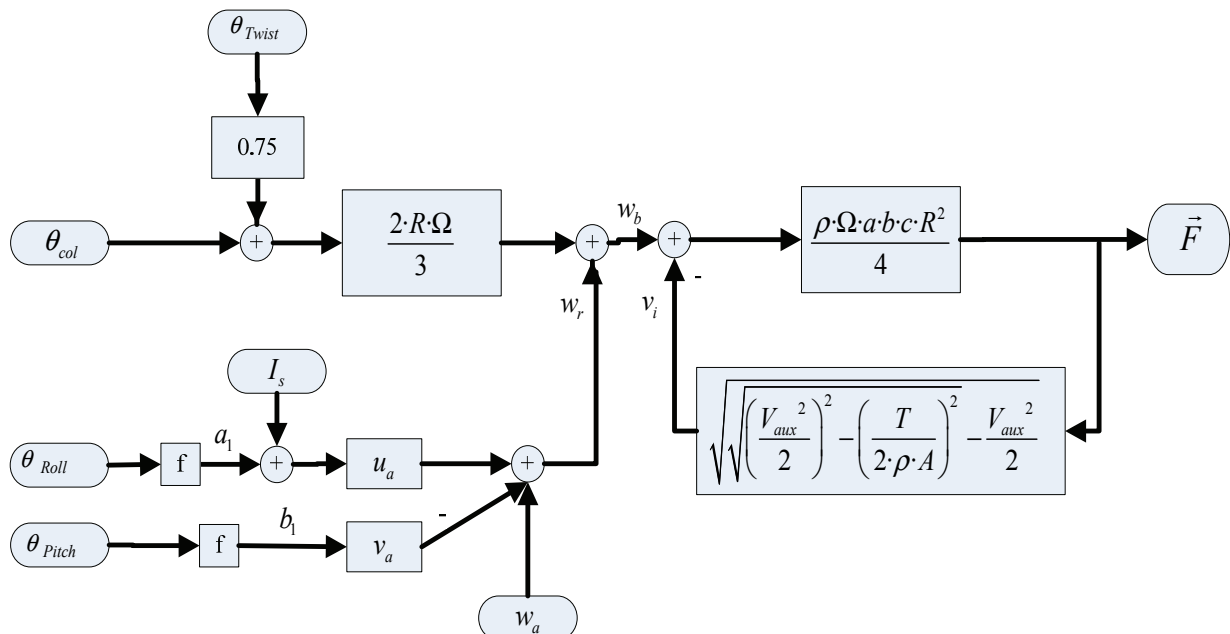


Figure 6. Main rotor block diagram

The equations corresponding to this part are:

$$w_r = w_a + (a_1 + I_s)u_a - b_1 \cdot v_a \quad (1)$$

$$w_b = w_r + \frac{2 \cdot \Omega \cdot R}{3} (\theta_{col} + \frac{3}{4} \theta_{twist}) \quad (2)$$

The output of the block is the rotor's thrust (F). R and Ω represent the radius of the rotor and its angular speed respectively; ρ is the air density, and a, b and c are geometrical blade factors. The relationship between thrust and angular rates has been derived from observation; therefore the model is also empirical.

$$V_{aux}^2 = u_a^2 + v_a^2 + w_r(w_r - 2v_i) \quad (3)$$

$$T = (w_b - v_i) \frac{\rho \cdot \Omega \cdot R \cdot a \cdot b \cdot c \cdot R}{4} \quad (4)$$

$$v_i^2 = \sqrt{\left(\frac{V_{aux}^2}{2}\right)^2 - \left(\frac{T}{2 \cdot \rho \cdot \Pi \cdot R^2}\right)^2} - \frac{V_{aux}^2}{2} \quad (5)$$

When the helicopter flies close to the ground (distances less than 1.25 times the diameter of the rotor) the ground effect turns to be very important. This effect has been modeled using the parameter η defined in (6) where h is the distance from the helicopter to the ground.

$$\eta = \frac{h}{2R} \quad (6)$$

In these cases, the thrust is modified using (7) where T_h' is the resulting thrust after correcting T_h . Values of T_0 , T_1 and T_2 have been calculated for no creating a discontinuity when h is 1.25 times the diameter of the rotor.

$$T_h' = T_h (T_0 + T_1 \eta + T_2 \eta^2) \quad (7)$$

By other hand, the commanded Roll and Pitch cyclic have been considered as reference for rotations in x and y axes considering the helicopter frame. In addition to this, a coupling effect has been considered for simulating real coupling in the helicopter.

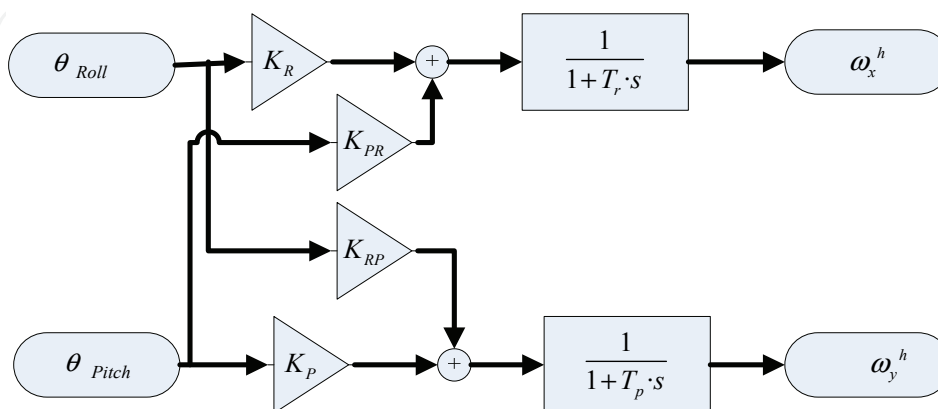


Figure 7. Roll and Pitch dynamic

As it was mentioned in the last section, RC helicopters usually rely upon commercial speed controllers in the main rotor. These devices have been modeled using an ideal dynamic response. On the other hand, engine has been modeled as a first order system. Therefore, variations in the speed of the rotor have been considered only due to changes in the collective angle as

Figure 8 shows.

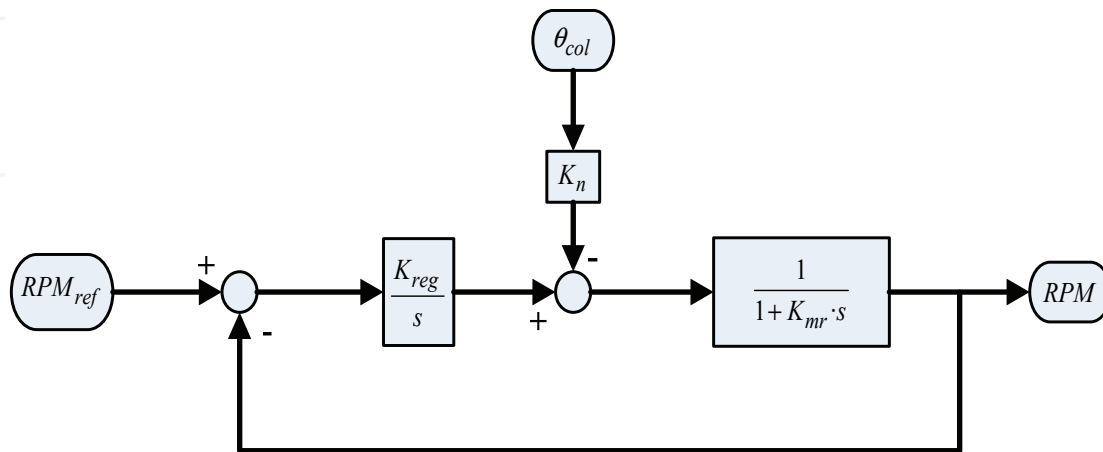


Figure 8. Engine model

3.2.2 Tail rotor

The algorithm for estimating the thrust provided by tail rotor is similar to the main one but only the pitch angle of the blades has been considered as input. This signal is provided by the hardware controller that is in charge of stabilization of the tail. A PI classical controller has been used to model the controller and the sensor has been considered as no dynamic as Figure 9 shows.

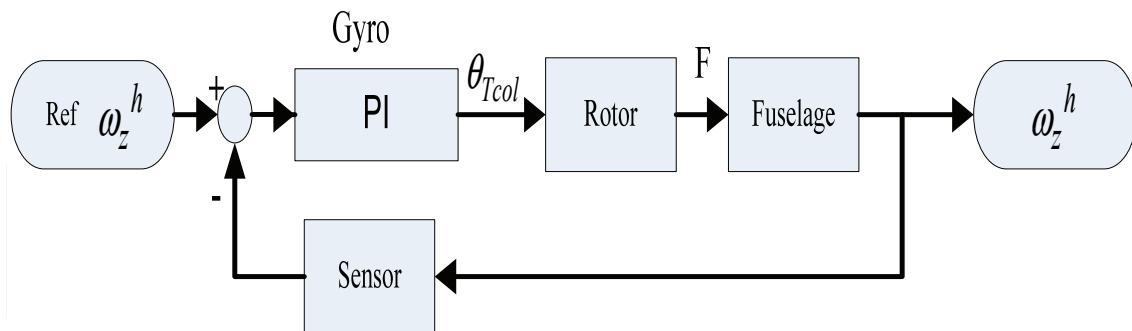


Figure 9. Tail rotor model

3.2.3 Fuselage

In a first step, all the forces (main and tail rotor, gravity, friction and aerodynamic resistances) have to be taking into account for computing the movement of the fuselage of the helicopter. After that, accelerations and velocities can be estimated.

Forces due to the aerodynamic frictions are estimated using the relative velocity of the helicopter with respect to the wind applying (8), where A_r is the equivalent area and v_w is the wind velocity.

$$F = \frac{1}{2} A_r \rho v_w^2 \quad (8)$$

The resulting equations are summarized in (9).

$$\begin{aligned} F_x^h &= G_x^h + Fus_x^h \\ F_y^h &= G_y^h + Fus_y^h \\ F_z^h &= G_z^h + Fus_z^h + T^h \\ M_z^h &= M_d^h + M_t^h + M_{vt}^h \end{aligned} \quad (9)$$

Where the prefix Fus means aerodynamic forces on fuselage and T the main rotor thrust. The prefix M means Torque where suffix d denotes main rotor, the t denotes tail rotor and the v is the effect of the air in the tail of the helicopter. The prefix G means the gravity components.

Once forces and torques have been calculated, accelerations can be obtained and therefore velocities. Once the velocity referred to helicopter frame (v^h) is calculated, a transformation is required in order to obtain an absolute value by using (10).

$$\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \begin{bmatrix} \cos\theta\cos\psi & -\cos\phi\sin\psi + \sin\theta\sin\phi\cos\psi & \sin\phi\sin\psi + \cos\phi\sin\theta\cos\psi \\ \cos\theta\sin\psi & \cos\phi\cos\psi + \sin\theta\sin\phi\sin\psi & -\sin\phi\cos\psi + \cos\phi\sin\theta\sin\psi \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta \end{bmatrix} \begin{bmatrix} v_x^h \\ v_y^h \\ v_z^h \end{bmatrix} \quad (10)$$

Flybars are important elements to take into account in the dynamic model. In this work, they have been modeled by using empiric simple models, and the stabilization effect that they produced on the helicopter has been simulated using (11). A more realistic model of flybars can be obtained in [Mettler-2003].

$$\begin{aligned} \ddot{\phi} &= \dot{\phi} - k_1\phi \\ \ddot{\theta} &= \dot{\theta} - k_2\theta \end{aligned} \quad (11)$$

3.3 Identification of the parameters

Once the mathematic equations have been obtained, a procedure to give values to the parameters that appear into the model is required. Some of the parameters can be easily obtained by simple measurements or weighs but some of them turn to be very difficult to obtain or estimate.

Table 2 describes the parameter list to be identified.

Some methods have been studied for performing the parameters identification, such as multi-variable systems procedures (VARMAX), but they are difficult to apply because there is an iterative process into the model. Due to this, the selected method was evolutionary algorithms, after trying unsuccessfully stochastic methods.

Genetic algorithms may be considered as the search for a sub-optimal solution of a specific cost-based problem. The parameters are codified as chromosomes that are ranked with a fitness function, and the best fits are reproduced through genetic operators: crossover and mutation. This process continues until the fitness of the best chromosome reaches a preset threshold.

#	Name	Meaning
1	TwstMr	Main rotor blade twist.
2	TwstTr	Tail rotor blade twist.
3	KCol	Collective step gain.
4	IZ	Moment of inertia around the z axis.
5	HTr	Vertical distance from tail rotor to centre of mass of the helicopter.
6	WLVt	Vertical position of the aerodynamic centre of the tail.
7	XuuFus	Frontal effective area of the helicopter.
8	YvvFus	Lateral effective area of the helicopter.
9	ZwwFus	Effective area of the helicopter
10	YuuVt	Frontal area of the tail.
11	YuvVt	Lateral area of the tail.
12	Corr1	Correction parameter for Roll.
13	Corr2	Correction parameter for Pitch.
14	Tproll	Time constant for Roll response.
15	Tppitch	Time constant for Pitch response.
16	Kroll	Gain for Roll input.
17	Kpitch	Gain for Pitch input.
18	Kyaw	Gain for Yaw input.
19	DTr	Horizontal distance from centre of the tail rotor to mass centre of the helicopter.
20	DVt	Horizontal distance from the aerodynamic centre of the tail and mass centre of the helicopter.
21	YMaxVt	Saturation parameter (no physical meaning).
22	KGyro	Parameter of commercial gyro controller. (gain)
23	KdGyro	Parameter of commercial gyro controller. (derivative)
24	Krp	Cross gain for Roll and Pitch coupling.
25	Kpr	Cross gain for Pitch and Roll coupling.
26	OffsetRoll	Offset of Roll input (trimmer in radio transmitter).
27	OffsetPitch	Offset of Pitch input (trimmer in radio transmitter).
28	OffsetCol	Offset of Collective input (trimmer in radio transmitter).

Table 2. Parameter to identify list

The main steps of the process for identification using GA's have been:

3.3.1 Parameters codification

The parameters are codified with real numbers, as it is more intuitive format than large binary chains. Different crossover operations have been studied:

- The new chromosome is a random combination of two chains.

Asc1	0	1	2	3	4	5	6	7	8	9
Asc2	10	11	12	13	14	15	16	17	18	19
Desc	0	11	12	3	14	5	6	17	18	9

- The new chromosome is a random combination of random genes with values in the range defined by the ascendant genes.

Asc1	0	1	2	3	4	5	6	7	8	9
Asc2	10	11	12	13	14	15	16	17	18	19
Desc	6.5	7.6	2	13	4	15	9.2	8.5	8	19

The first operator transmits the positive characteristics of its ascendants while the second one generates diversity in the population as new values appear. In addition to the crossover operator there is a mutation algorithm. The probability of mutation for the chromosomes is 0.01, and the mutation is defined as the multiplication of random genes by a factor between 0.5 and 1.5.

When the genetic algorithms falls into a local minimum, (it is detected because there is no a substantial improvement of the fitness in the best chromosome during a large number of iterations), the probability of mutation have to be increased to 0.1. This improves mutated populations with increased probability of escaping from the local minimum.

3.3.2 Initial population

The initial population is created randomly with an initial set of parameters of a stable model multiplied by random numbers selected by a Monte-Carlo algorithm with a normal distribution with zero mean and standard deviation of 1.

The genetic algorithm has been tested with different population sizes, between thirty and sixty elements. Test results showed that the bigger population did not lead to significantly better results, but increased the computation time. Using 20 seconds of flight data and a population of 30 chromosomes, it took one hour to process 250 iterations of the genetic algorithm on a Pentium IV processor. Empirical data suggests that 100 iterations are enough to find a sub-optimal set of parameters.

3.3.3 Fitness function

The fitness function takes into consideration the following state variables: roll, pitch, yaw and speed. Each group of parameters (chromosome) represents a model, which can be used to compute simulated flight data from the recorded input commands. The difference between simulated and real data is determined with a weighted least-squares method and used as the fitness function of the genetic algorithm.

In order to reduce the effect of the error propagation to the velocity due to the estimated parameters that have influence in attitude, the global process has been decomposed in two steps: Attitude and velocity parameters identification.

The first only identifies the dynamic response of the helicopter attitude, and the genetic algorithm modifies only the parameters related to the attitude. Once the attitude-related parameters have been set, the second process is executed, and only the velocity-related parameters are changed. This algorithm uses the real attitude data instead of the model data so as not to accumulate simulation errors. Using two separate processes for attitude and velocity yields significantly better results than using one process to identify all parameters at the same time.

The parameters related to the attitude process are: TwstTr, IZ, HTr, YuvVt, YuvVt, Corr1, Corr2, Tproll, Tppitch, Kroll, Kpitch, Kyaw, DTr, DVt, YMaxVt, Kgyro, Kdgyro, Krp, Kpr,

OffsetRoll, OffsetPitch and OffsetYaw. The parameters related to the vehicle's speed are TwstMr, KCol, XuuFus, YvvFus, ZwwFus and OffsetCol.

The fitness functions are based on a weighted mean square error equation, calculated by comparing the real and simulated responses for the different variables (position, velocity, Euler angles and angular rates) applying a weighting factor.

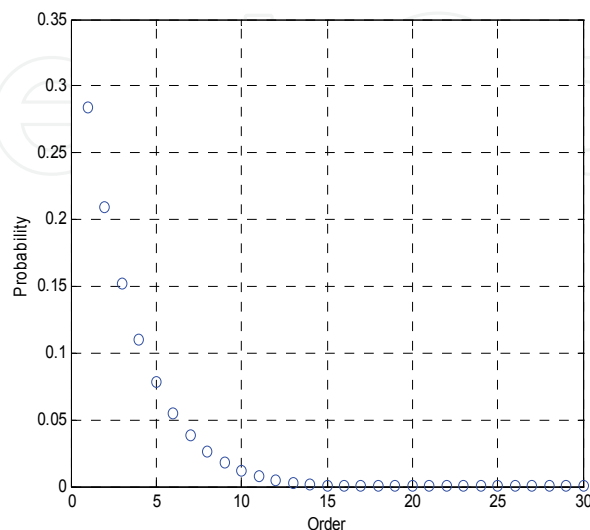


Figure 10. Probability function for selection of elements

The general process is described below:

- To create an initial population of 30 elements.
- To perform simulations for every chromosome;
- Computation of the fitness function.
- Classification the population using the fitness function as the index. The ten best elements are preserved. A Monte-Carlo algorithm with the density function shown in Figure 10. Probability function for selection of elements is used to determine which pairs will be combined to generate 20 more chromosomes. The 10 'better' elements are more likely (97%) to be combined with the crossover operators.
- To repeat from step 2 for a preset number of iterations, or until a preset value for the fitness function of the best element is reached.

3.3.4 Data acquisition

The data acquisition procedure is shown in Figure 11. Helicopter is manually piloted using the conventional RC emitter. The pilot is in charge to make the helicopter performs different maneuvers trying to excite all the parameters of the model. For identification data is essential to have translational flights (longitudinal and lateral) and vertical displacements.

All the commands provided by the pilot are gathered by a computer through a USB port by using a hardware signal converter while onboard computer is performing data fusion from sensors and sending the attitude and velocity estimation to the ground computer using a WIFI link.

In this manner inputs and outputs of the model are stored in files to perform the parameters identification.



Figure 11. Data acquisition architecture

4. Identification Results

The identification algorithm was executed several times with different initial populations and, as expected, the sub-optimal parameters differ. Some of these differences can be explained by the effect of local minimum. Although the mutation algorithm reduces the probability of staying inside a local minimum, sometimes the mutation factor is not big enough to escape from it.

The evolution of the error index obtained with a least-squares method in different cases is shown in Figure 12. The left graph shows the quick convergence of the algorithm in 50 iterations. On the other hand the right graph shows an algorithm that fell in a local minimum and had an overall lower convergence speed. Around the 50th step a mutation was able to escape the local minimum, and the same behavior is observed in the 160th step.

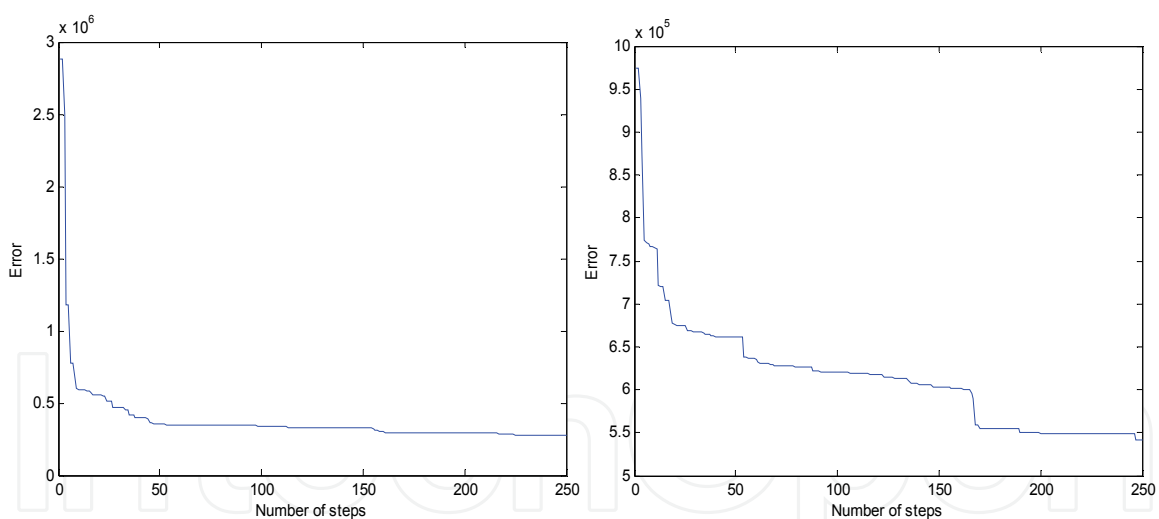


Figure 12. Error evolution for two different cases

The result may be used as the initial population for a second execution of both processes. In fact, this has been done three times to obtain the best solution.

The analysis of cases where mutation was not able to make the algorithm escaped from local minimum, led to the change of the mutation probability from 0.1 to 1 when detected.

On the other hand, not all the parameters were identified at the same time, actually two iterative processes were used to identify all parameters. The first process used 100 steps to identify the parameters related to the modeling of the helicopter's attitude, beginning with a random variation of a valid solution. The second process preserved the best element of the

previous process' population, and randomly mutated the rest. After 100 steps the parameters related to the helicopter's speed were identified.

The simulated attitude data plotted as a blue line against real flight data in red, is shown for roll, pitch, yaw angles in Figure 13. They give you an idea about how simulations follow real tendencies even for small attitude variations.

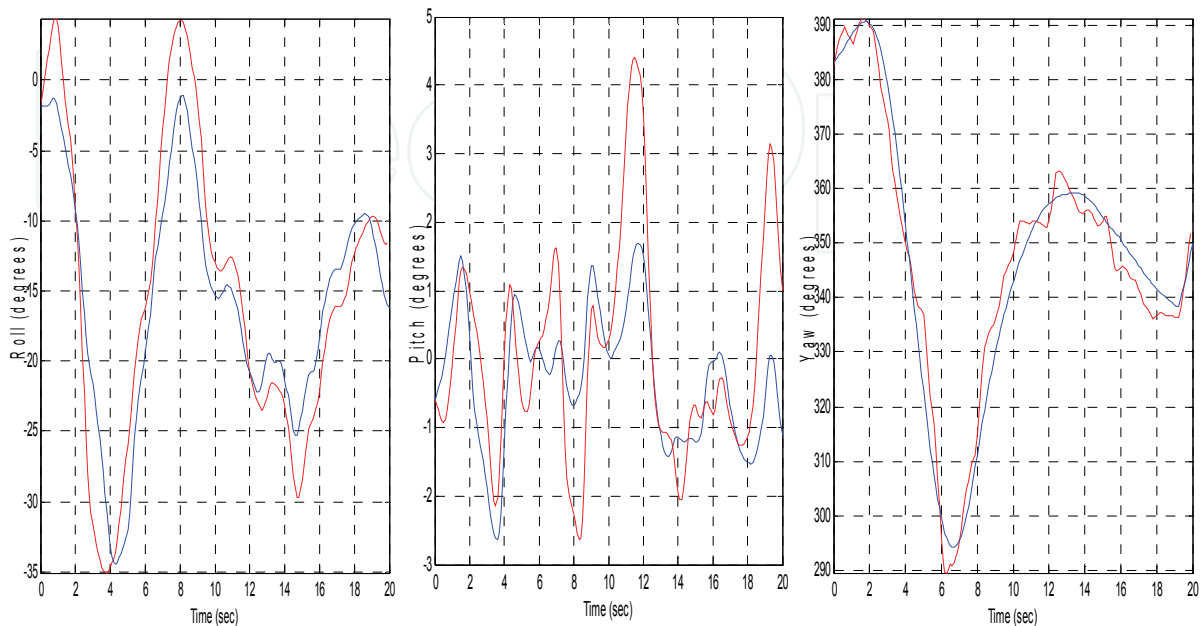


Figure 13. Roll, Pitch and Yaw real vs simulated

On the other hand, the results obtained for the velocity analysis are shown in Figure 14.

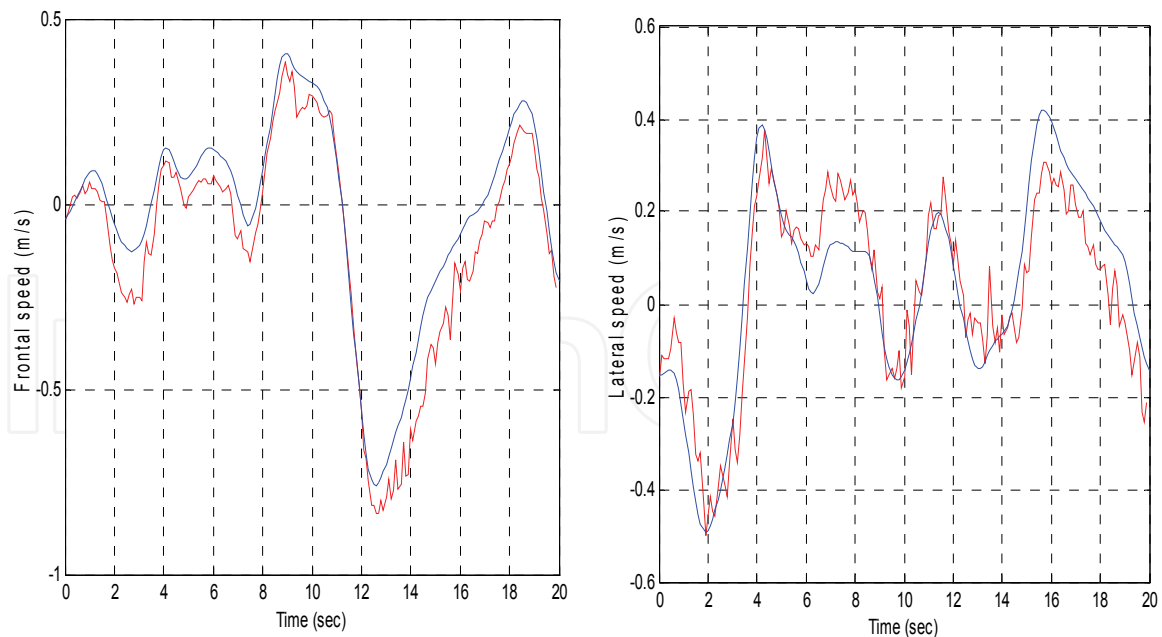


Figure 14. Velocity Simulation Analysis

The quality of the simulation results is the proof of a successful identification process both for attitude and speed.

The simulated roll and yaw fit accurately the registered helicopter response to input commands. The simulated pitch presents some problems due to the fact that the flight data did not have a big dynamic range for this signal. Nevertheless the error is always below three degrees.

For the simulation of the vehicle’s velocity good performance was obtained for both frontal and lateral movement. The unsuccessful modeling of vertical velocity can be linked to the sensors available onboard the helicopter. Vertical velocity is registered only by the differential GPS, and statistical studies of the noise for this sensor show a standard deviation of 0.18 meters per second. In other words, the registered signal cannot be distinguished from the noise because the registered flight did not have a maneuver with significant vertical speed; therefore modeling this variable is not possible.

It is important to analyze the values of the obtained parameters since the parameters are identified using a genetic algorithm. The dispersion of the value of the parameters for five different optimization processes was analyzed. Most of the parameters converge to a defined value, which is coherent with the parameter’s physical meaning, but sometimes, some parameters were not converged to specific values, usually when no complete set of flights was used. Thus, if no vertical flights were performed, the parameters regarding vertical movements turned to be with a great dispersion in the obtained values.

This conclusion can be extended to different optimization processes for different groups of flight data. In other words, several flights should be recorded, each with an emphasis on the behaviors associated to a group of parameters. With enough flight data it is trivial to identify all the parameters of the helicopter model.

5. Control Prototyping

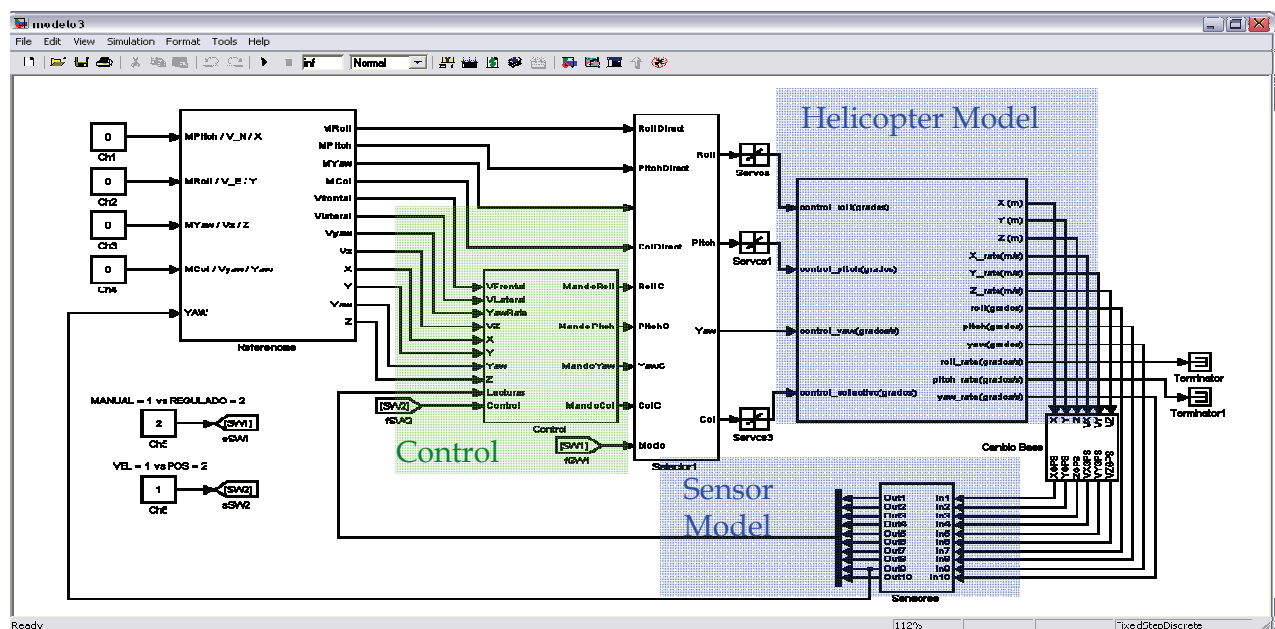


Figure 15. Control Developing template

In order to develop and test control algorithms in a feasible way, the proposed model has been encapsulated into a Matlab-Simulink S-Function, as a part of a prototyping template as Figure 15 shows. Others modules have been used for performing realistic simulations, thus

a sensor model of GNC systems has also been created. Auxiliary modules for automatic-manual switching have been required for testing purposes.

The proposed control architecture is based on a hierarchic scheme with five control levels as Figure 16 shows. The lower level is composed by hardware controllers: speed of the rotor and yaw rate. The upper level is the attitude control. This is the most critical level for reaching the stability of the helicopter during the flight. Several techniques have been tested on it (classical PI or fuzzy controllers). The next one is the velocity and altitude level. The fourth is the maneuver level, which is responsible for performing a set of pre-established simple maneuvers, and the highest level is the mission control.

Following sections will briefly describe these control levels from the highest to the lowest one.

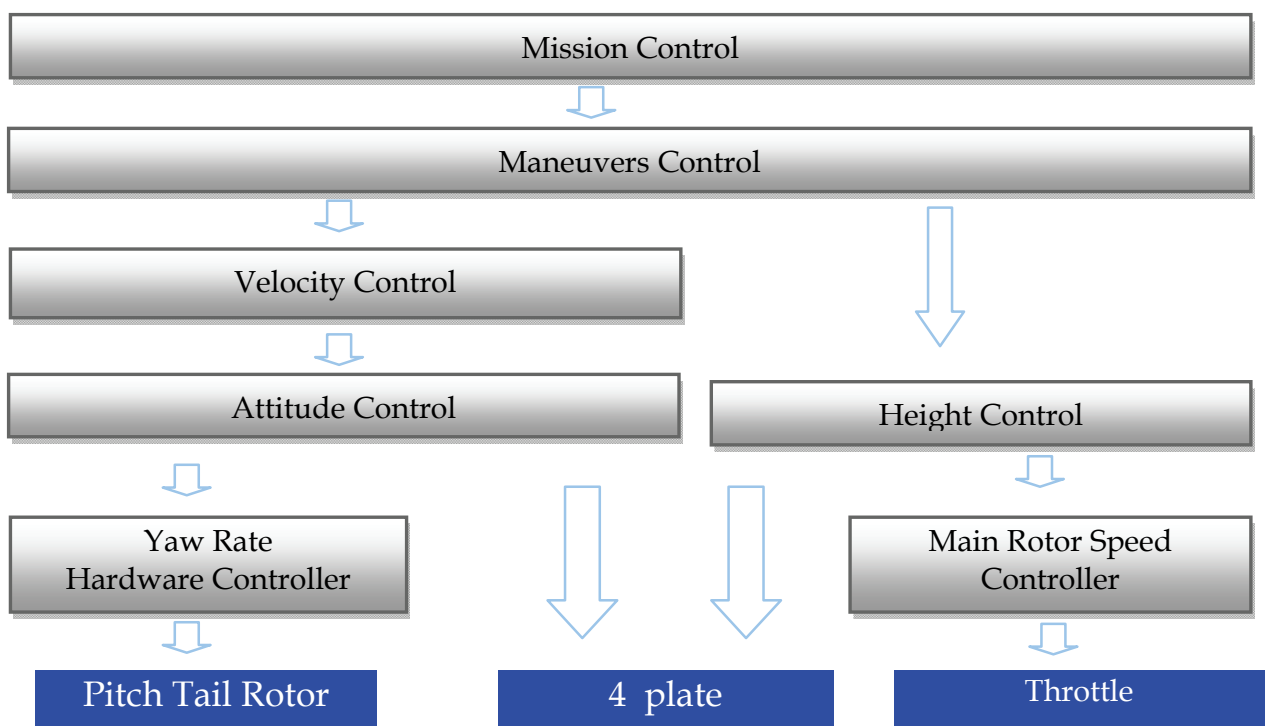


Figure 16. Control Architecture

5.1 Mission control

In this level, the operator designs the mission of the helicopter using GIS (Geographic Information System) software. These tools allow visualizing the 3D map of the area by using Digital Terrain Model files and describing a mission using a specific language. (Gutiérrez et al -06). The output of this level is a list of maneuvers (parametric commands) to be performed by the helicopter.

5.2 Maneuver Control

This control level is in charge of performing parametric manoeuvres such as flight maintaining a specific velocity during a period of time, hovering with a fix of changing yaw, forward, backward or sideward flights and circles among others. The output of this level are velocity commands.

Internally, this level performs a prediction of the position of the helicopter, applying acceleration profiles (Figure 17).

Velocity and heading references are computed by using this theoretical position and the desired velocity in addition to the real position and velocity obtained from sensors.

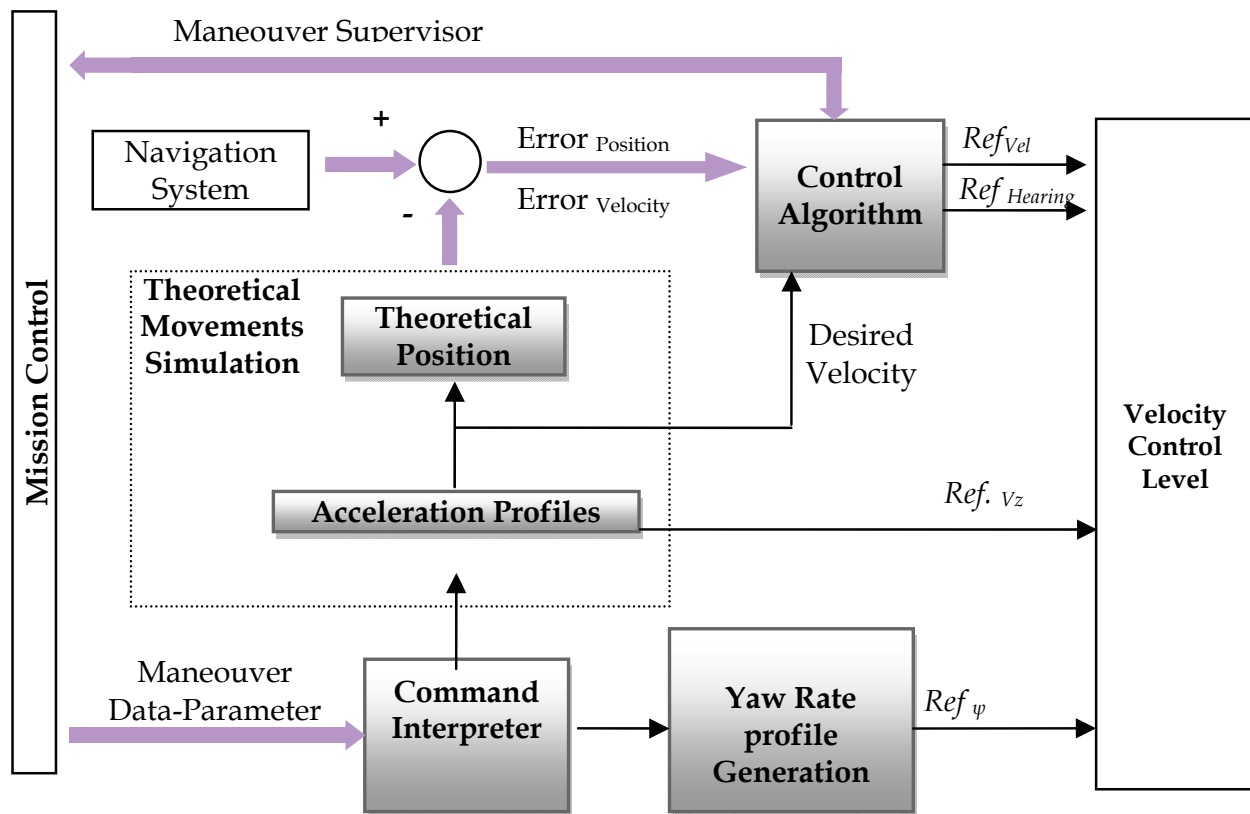


Figure 17. Maneuvers Control Scheme

A vertical control generates references for altitude control and Yaw control.

In manoeuvres that no high precision of the position is required, i.e. forward flights, the position error is not taken into account, because the real objective of the control is maintain the speed. This system allow manage a weighting criteria for defining if the main objetive is the trajectory or the speed profile. The manoeuvres that helicopter is able to perform are an upgradeable list.

5.3 Velocity Control

The velocity control is in charge of making the helicopter maintains the velocity that manoeuvres control level computes.

The velocity can be referred to a ENU (East-North-Up) frame or defined as a module and a direction. Therefore, a coordinate transformation is required to obtain lateral and frontal velocities (v_l , v_f) that are used to provide Roll and Pitch references. This transformation is very sensitive to the yaw angle estimation.

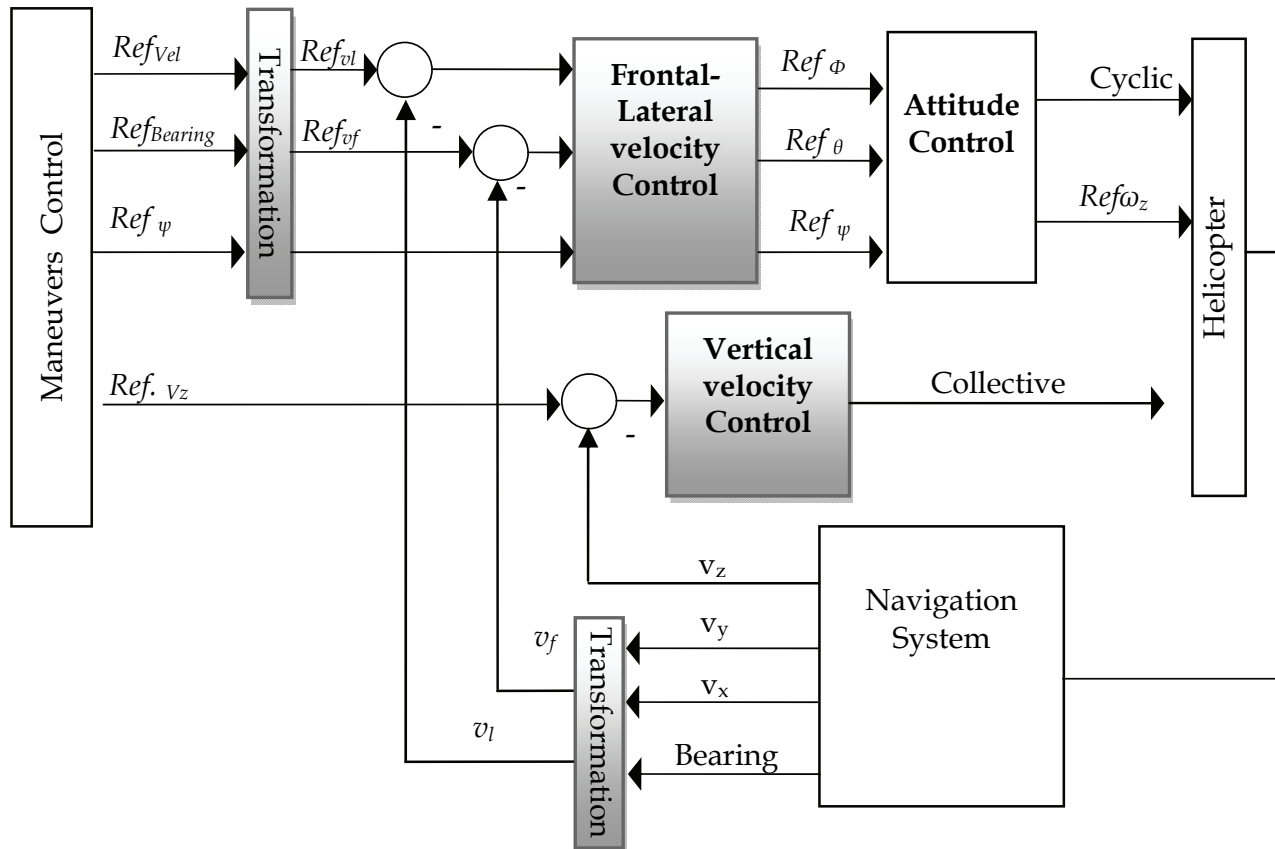


Figure 18. Velocity control structure

Control maneuver has also to provide with the yaw reference due to the capability of helicopters for flying with derive (different bearing and heading).

Vertical velocity is isolated from the horizontal because it is controlled by using the collective command.

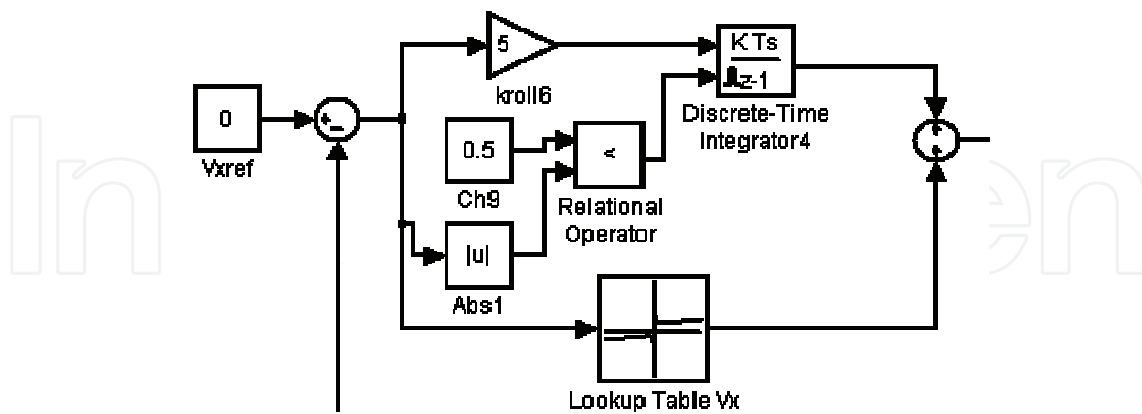


Figure 19. Velocity control example

Concerning to the control algorithms used to test the control architecture, two main problems have been detected and solved:

The first one is based on the fact that the speed is very sensitive to the wind and payload. Due to this, a gain-scheduler scheme with a strong integration effect has been required in PI algorithm. (Figure 19)

The second one arises from the solution of the first problem. Thus, when operator performs a manual-automatic switching by using channel nine of the emitter, integral action needs to be reset for reducing the effect of the error integration when manual mode is active.

5.4 Attitude Control

The attitude control is in charge of providing with commands to the servos (or hardware controllers). Several control techniques were tested in this level, but probably fuzzy controllers turned out to have the best performance. Figure 20 shows the proposed architecture and Figure 21 the control surfaces used by fuzzy controller.

As it can be observed, the Yaw have been isolated from the multivariable Roll-Pitch controller with a reasonable quality results.

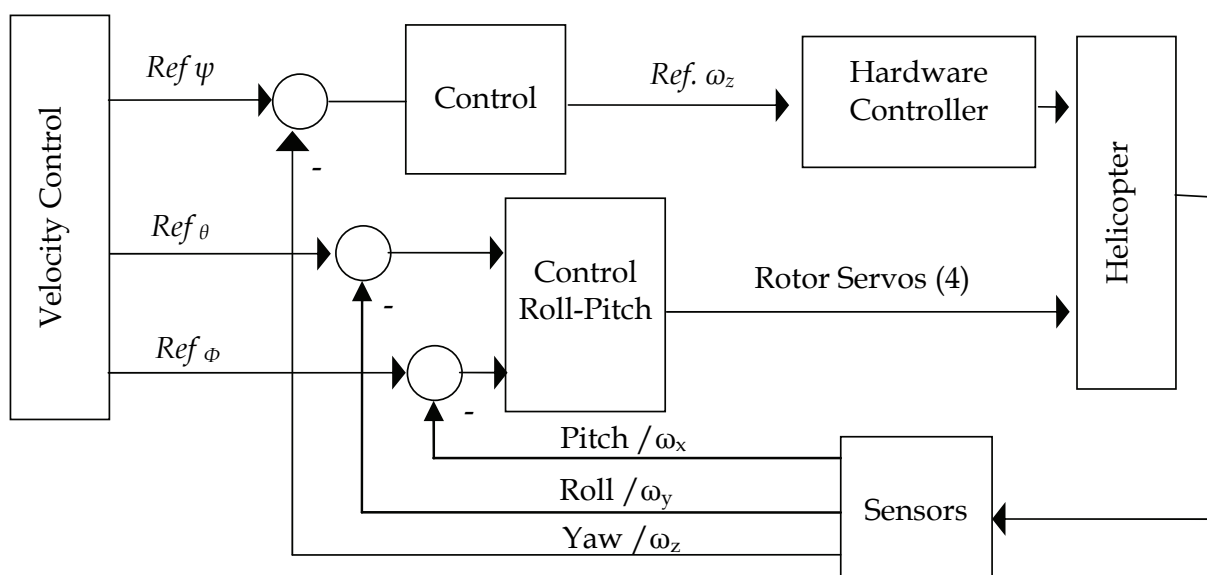


Figure 20. Attitude control structure

Once the control structure has been designed, the first step is to perform simulations in order to analyze if the control fulfills all the established requirements.

Considering the special characteristics of the system to control, their main requirements to be taken into account are:

- No (small) oscillations for attitude control. In order to transmit a confidence in the control system to the operator during the tests.
- No permanent errors in velocity control. This is an important concept to consider for avoiding delays in long distance missions.
- Adjustable fitness functions for maneuvers control. This allows characterizing the mission where position or velocity is the most important reference to keep.

The operator relies upon all the tools that Matlab-Simulink provides and an additional 3D visualization of the helicopter as Figure 22 shows for test performing.

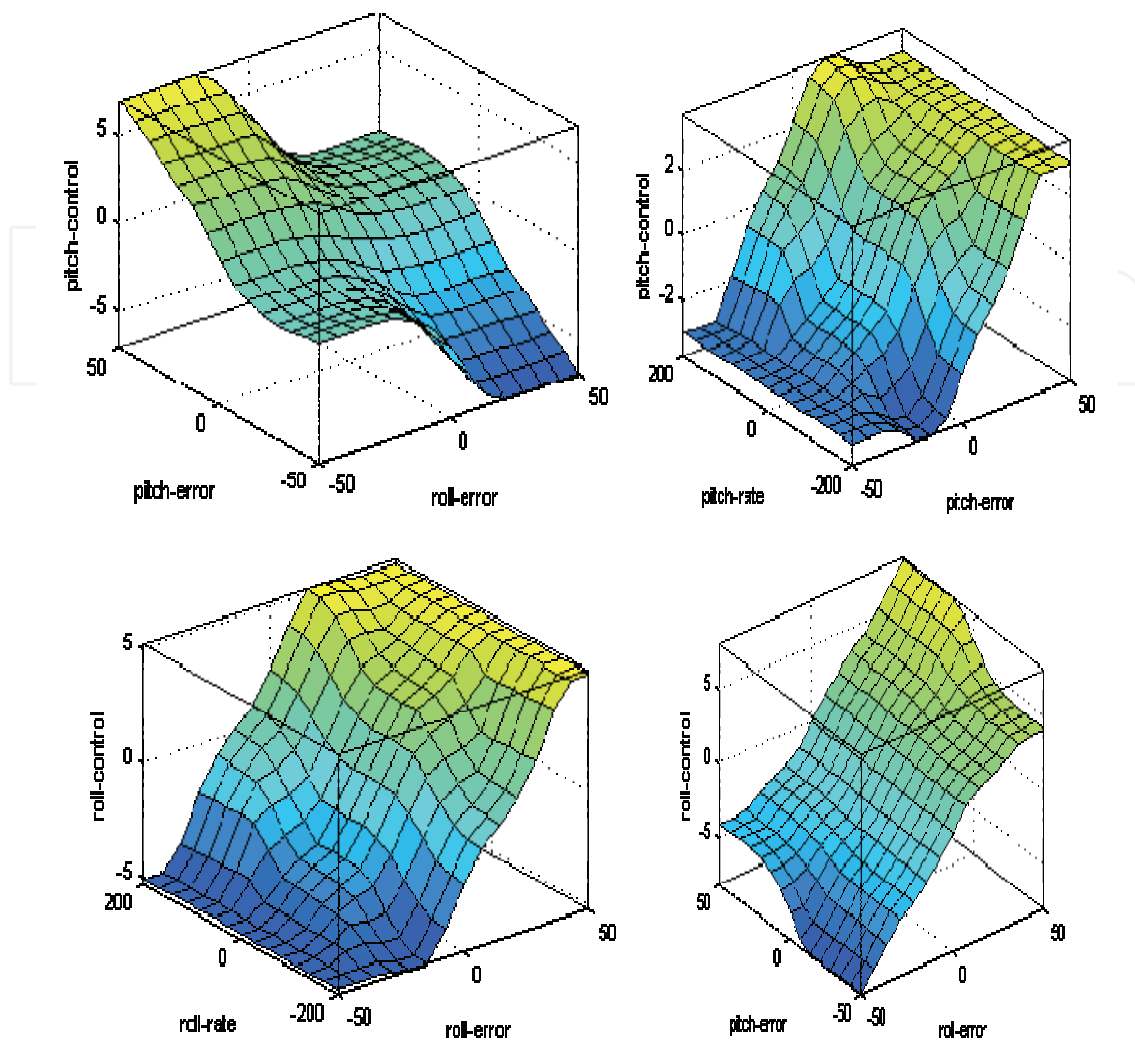


Figure 21. Control surfaces for aAttitude level

The controller block has to be isolated for automatic C codification by using the embedded systems coder of Matlab-Simulink when simulation results are satisfactory. Then, the obtained code can be loaded into onboard computer for real testing (Del-Cerro 2006).

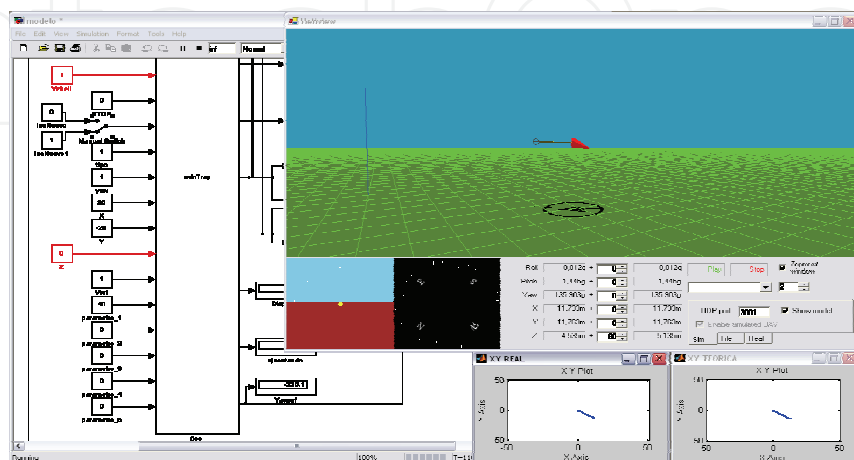


Figure 22. Simulation framework

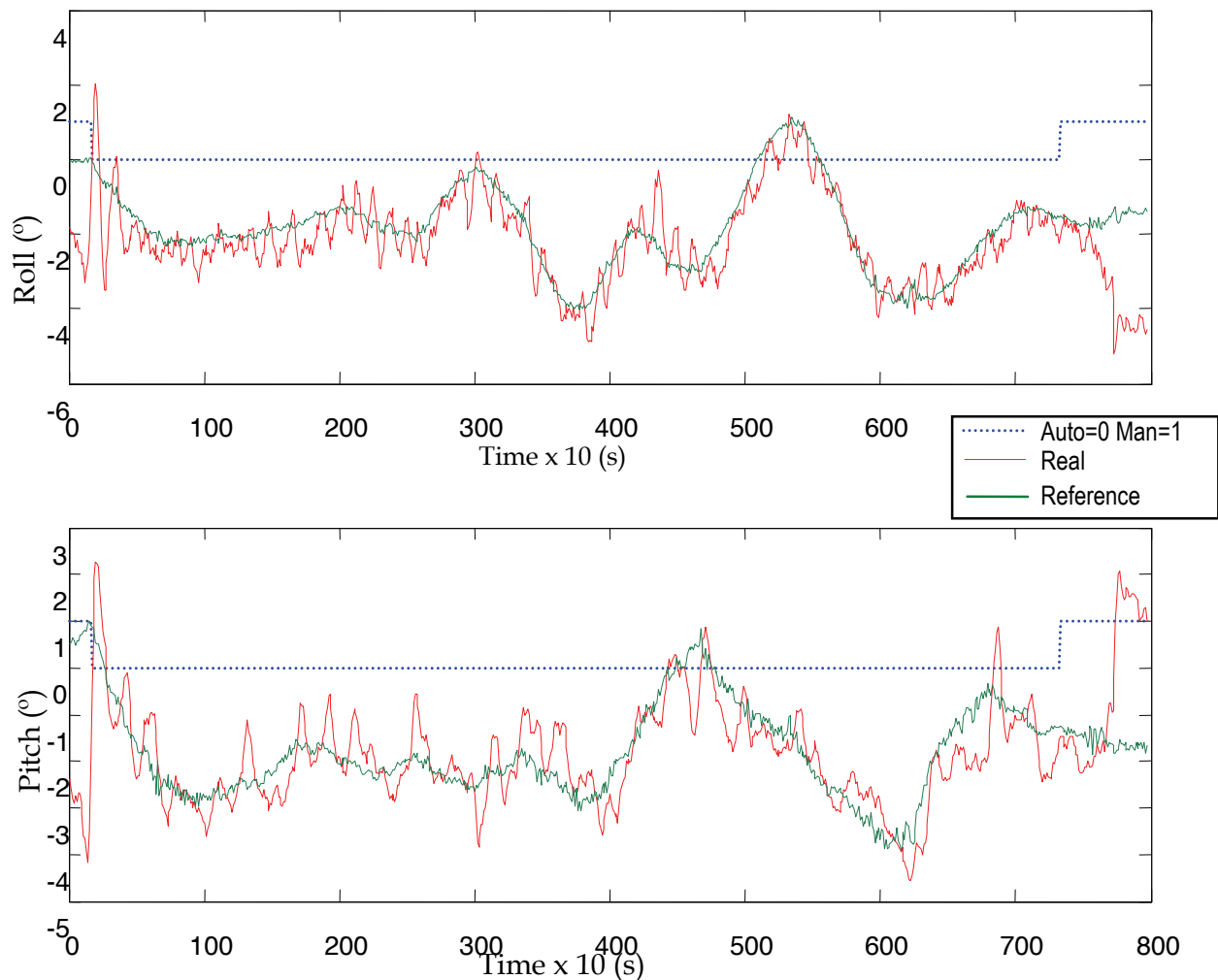


Figure 23. Roll and pitch Control results during real flight

6. Control Results

Figure 23 shows the results obtained for attitude control during an eighty-seconds real flight with the Vario helicopter.

Lines in red show the real attitude of the helicopter while green ones are the references provided by the velocity control level.

Dotted blue line indicates when the helicopter is in manual (value of 1) or automatic (value of 0). It can be observed that, when helicopter is in manual mode, the red line does not follow the references of the automatic control, because the pilot is controlling the helicopter.

Figure 24 shows the obtained results for velocity control. The same criteria that in last graphic has been used, thus red line indicates real helicopter response and green means references from maneuvers control level. Dotted blue line is used to show when the helicopter flies autonomously or remote piloted. Small delays can be observed.

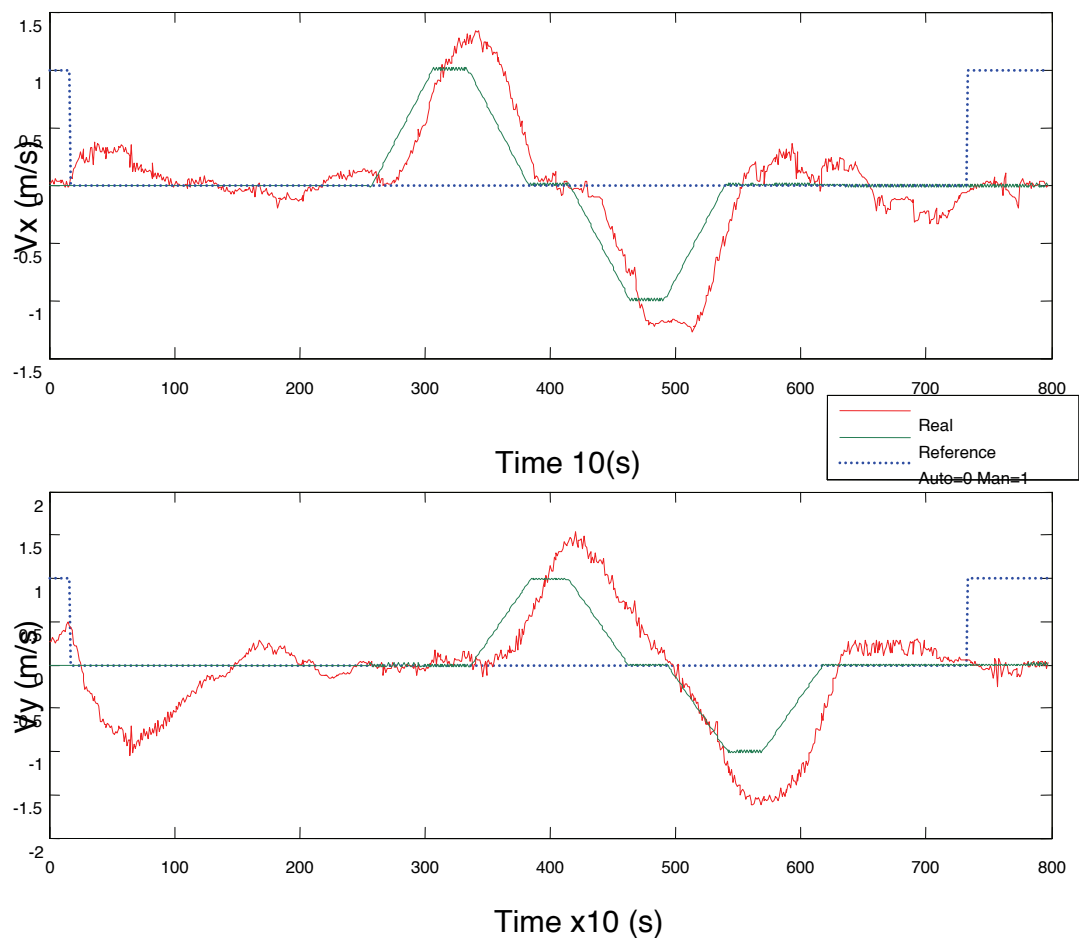


Figure 24. Velocity control results

Figure 25 shows two examples of the maneuvers control performance.

The right side graph shows the position when helicopter is moving in a straight line. It can be observed that maximum error in transversal coordinates is less than one meter. This result can be considered as very good due to is not a scalable factor. The precision of the position control reduces the error when trajectory is close to the end by weighting the error position against the velocity response.

On the other hand, the left side shows a square trajectory. The speed reference performs smooth movements and therefore the position control is less strong that in the first case. Even in this case, position errors are smaller than two meters in the worst case.

In general, a high precision flight control has been developed, because sub-metric precision has been reached during the tests with winds slower than twenty kilometers per hour.

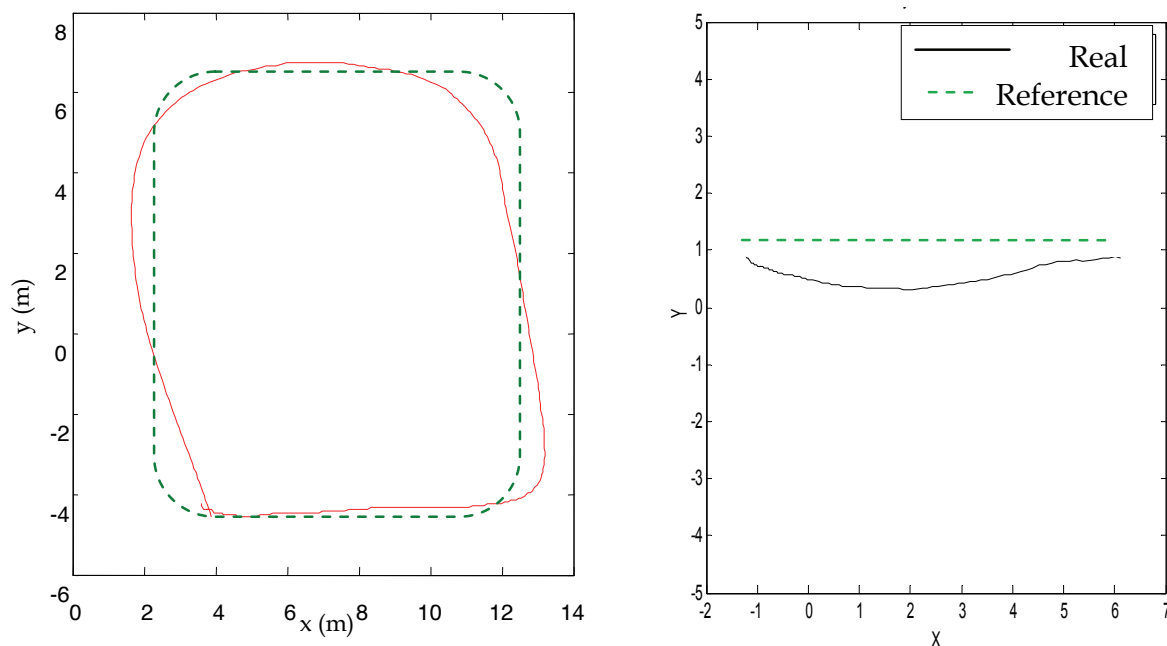


Figure 25. Maneuvers control results

7. Final Observations and Future Work

The first part of this chapter describes a procedure for modeling and identification a small helicopter. Model has been derived from literature, but changes introduced in the original model have contributed to improve the stability of the model with no reduction of the precision.

The proposed identification methodology based on evolutionary algorithms is a generic procedure, having a wide range of applications.

The identified model allows performing realistic simulations, and the results have been validated.

The model has been used for designing real controllers on a real helicopter by using a fast prototyping method detailed in section 4.

The model has confirmed a robust behavior when changes in the flight conditions happen. It does work for hover and both frontal and lateral non-aggressive flight.

The accuracy and convenience of a parametric model depends largely on the quality of its parameters, and the identification process often requires good or deep knowledge of the model and the modeled phenomena. The proposed identification algorithm does away with the complexity of model tuning: it only requires good-quality flight data within the planned simulation envelope. The genetic algorithm has been capable of finding adequate values for the model's 28 parameters, values that are coherent with their physical meaning, and that yields an accurate model.

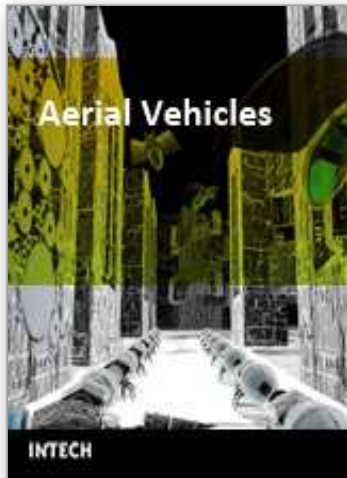
It is not the objective of this chapter to study what the best control technique is. The aim is to demonstrate that the proposed model is good enough to perform simulations valid for control designing and implementation using an automatic coding tool.

Future work will focus on the following three objectives:

- To develop a model of the engine in order to improve the model behavior for aggressive flight maneuvers.
- To compare this model with others in the literature in a wide range of test cases.
- To validate the proposed model with different helicopters.

8. References

- Castillo P, Lozano R, Dzul A. (2005) Modelling and Control of Mini-Flying Machines. Springer Verlag London Limited 2005. ISBN:1852339578.
- Del-Cerro J, Barrientos A, Artieda J, Lillo E, Gutiérrez P, San- Martín R, (2006) Embedded Control System Architecture applied to an Unmanned Aerial Vehicle International Conference on Mechatronics. Budapest-Hungary
- Gavrilets, V., E. Frazzoli, B. Mettler. (2001) Aggressive Maneuvering of Small Autonomous Helicopters: A Human Centered Approach. *The International Journal of Robotics Research*. Vol 20 No 10 , October 2001. pp 795-807
- Godbole et al (2000) Active Multi-Model Control for Dynamic maneuver Optimization of Unmanned Air Vehicles. *Proceedings of the 2000 IEEE International conference on Robotics and Automation*. San Francisco, CA. April 2000.
- Gutiérrez, P., Barrientos, A., del Cerro, J., San Martín., R. (2006) Mission Planning and Simulation of Unmanned Aerial Vehicles with a GIS-based Framework; *AIAA Guidance, Navigation and Control Conference and Exhibit*. Denver, EEUU, 2006.
- Heffley R (1988). Minimum complexity helicopter simulation math model. *Nasa center for Aerospace Information* . 88N29819.
- La Civita M, Messner W, Kanade T. Modeling of Small-Scale Helicopters with Integrated First-Principles and System-Identification Techniques. *American Helicopter Society 587h Annual Forum*, Montreal, Canada, June 11-13,2002.
- Mahony-R Lozano-R, Exact Path Tracking (2000) Control for an Autonomous helicopter in Hover Manoeuvres. *Proceedings of the 2000 IEEE International Conference on Robotics & Automation*. San Francisco, CA. APRIL 2000. P1245-1250
- Mettler B.F., Tischler M.B. and Kanade T.(2002) System Identification Modeling of a Model-Scale Helicopter. *T. Journal of the American Helicopter Society*, 2002, 47/1: p. 50-63. (2002).
- Mettler B, Kanade T, Tischler M. (2003) System Identification Modeling of a Model-Scale Helicopter. *Internal Report CMU-RI-TR-00-03*.



Aerial Vehicles

Edited by Thanh Mung Lam

ISBN 978-953-7619-41-1

Hard cover, 320 pages

Publisher InTech

Published online 01, January, 2009

Published in print edition January, 2009

This book contains 35 chapters written by experts in developing techniques for making aerial vehicles more intelligent, more reliable, more flexible in use, and safer in operation. It will also serve as an inspiration for further improvement of the design and application of aerial vehicles. The advanced techniques and research described here may also be applicable to other high-tech areas such as robotics, avionics, vetronics, and space.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Jaime del-Cerro, Antonio Barrientos and Alexander Martinez (2009). Modelling and Control Prototyping of Unmanned Helicopters, Aerial Vehicles, Thanh Mung Lam (Ed.), ISBN: 978-953-7619-41-1, InTech, Available from:

http://www.intechopen.com/books/aerial_vehicles/modelling_and_control_prototyping_of_unmanned_helicopters

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2009 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](#), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.

IntechOpen

IntechOpen