THE EFIGENIA EJ-1B MOZART
An S/VTOL Autonomous UAV Unmanned Aircraft Autocontrolled with an Intelligent Adaptive Digital Reconfigurable Guidance, Navigation and Flight Control System

By: MARIO ANDRÉS CÓRDOBA G.

Aeronautical and Electronics Designer Engineer.
EFIGENIA Aerospace Robotics
www.efigenia-aerospace.com

THE EFIGENIA EJ-1B MOZART
An S/VTOL Autonomous UAV Unmanned Aircraft Autocontrolled with an Intelligent Adaptive Digital Reconfigurable Guidance, Navigation and Flight Control System

By: MARIO ANDRES CORDOBA G.
Aeronautical and Electronics Designer Engineer.
EFIGENIA Aerospace Robotics
E-Mail: cordoba@efigenia-aerospace.com
www.efigenia-aerospace.com

ABSTRACT

This paper describes the EFIGENIA EJ-1 Short or Vertical take-off and Landing (S/VTOL) autonomous intelligent unmanned aerial vehicle (UAV). The EFIGENIA EJ-1 is an advanced aerodynamics design vehicle and avionics system which I developed as a personal research project that I designed, builded and actually conducting a series of flight test. A Digital neural network combined with a Fuzzy Logic System perform the best flight guidance, navigation and flight control condition operation.

1. **Introduction**

Short or vertical take-off and landing (S/VTOL) unmanned aerial vehicles are just one class of pilotless aircraft that captured my imagination. In particular, a personal predilection for Aeronautics and Electronics Engineering combination propitiated the birth of a robotic flying idea named EFIGENIA EJ-1 Mozart.

The EFIGENIA UAV Aircraft S/VTOL project start in December 1991. I worked as in the Aeronautical areas as in the Electronics (hardware and software) areas, designing, building, and conducting the EFIGENIA UAV flight test.

The basic idea was to create an exceptional autonomous robotic flying machine that be capable of perform special and high risk tasks such as Rescue Works, Scientist Research support, in particular, collect environmental data to asses climatic change, atmospherical pollution analysis and geological survey.
EFIGENIA also carry a small Forest surveillance and Fires prevention equipment, News transmission "in live" system, and a traffic monitoring report.

EFIGENIA S/VTOL unmanned aerial vehicle requirements was an enormous challenge for me, because of the variety objectives in this research project. This included topics such as:

- The design and introduction of the S/VTOL Rotor and Tailless Forward Swept wing Concept unmanned aerial vehicle.
- The design and development of an intelligent adaptive reconfigurable (on hardware) digital neural network guidance and navigation computer.
- Design and development of multiprocessor DSP embedded Fuzzy Logic flight control system.
- Air vehicle sensor instrumentation development (Real-time airborne control system, data acquisition, and video).
- ADPCM telemetry and telecontrol system based on Reconfigurable Computation devices.
- Neural networks fuzzy logic system integration for EFIGENIA intelligent avionics system architecture.

2. EFIGENIA UAV System Overview

The EFIGENIA UAV System configuration join important topics of Aeronautics and Electronics technology. Every EFIGENIA UAV aircraft component was designed, build and tested in my own workshop laboratory, including wings, fuselage, electronics equipment (hardware and software), propulsion units and station control.

The EFIGENIA was designed and developed to validate and demonstrate the flying qualities and performance characteristics of a short or vertical take-off and landing (S/VTOL) unusual experimental unmanned aerial vehicle that gives to the aerial

vehicle the vertical flight capability and low speed flight characteristics of a helicopter and the horizontal cruise speed of a conventional aircraft (Figure 1).

Figure 1. EFIGENIA S/VTOL-UAV Airplane.

3. EFIGENIA UAV Airplane Design Philosophy

The EFIGENIA UAV is built of robust, lightweight, and high-strength materials.
EFIGENIA´s aerospace design introduces a ***S/VTOL Rotor and Tailless Forward Swept Wing Concept*** with the purpose of allowing to the air vehicle an excellent aeromechanical behavior.

The EFIGENIA is powered by two 2.0 HP engines located each one in the nose and tail fuselage respectively, and one more 2,25 HP engine inside the aerial vehicle body. In contrast, the tail engine has been adapted for conforming a thrust vectoring unit to aimed high performance flight control system, maneuverability and agility at low speeds.

The air vehicle is capable of taking-off with a maximum weight of 8 Kg, endurance of 1,0 Hrs and reaching a maximum altitude of 7.000 Ft.

The air vehicle control in Hover and transition modes is accomplished using a thrust vectoring unit which works in yaw and pitch axes. The control of the vehicle during forward flight is accomplished using split ailerons, small canard wing and flaps. Again, the thrust vectoring system remains active during forward flight mode; they contribute to the control power of the vehicle in this mode.

The EFIGENIA do not have vertical tail, hence, the control is provided by two split ailerons, canard mobile surface control and a thrust vectoring unit which works in yaw and pitch axes.

3.1 System Operating Modes

The EFIGENIA S/VTOL-UAV can be operated in two modes. This include:

- Fully Autonomous aerial vehicle in which the EFIGENIA has a complete autonomous operation.

- Semi Autonomous in which augmented stability assisting to a pilot-operator in the control station.

3.2 Telemetry and Telecontrol Communication Systems

The communication systems are capable to transport data from the EFIGENIA UAV to the control station, and in the contrary way (control station to UAV).
The Telecontrol commands are sent from the

control station to the EFIGENIA as in remotely piloted mode as in autonomous flight mode. The Telemetry system includes two communication channels:

- The uplink channel which operates from the control station to the EFIGENIA UAV
- The Downlink channel which operates from the air vehicle to the control station

For this purpose I decided to develop an Adaptive Differential Pulse Code Modulation (ADPCM) Telemetry and Telecontrol System based on a reconfigurable hardware. This solution offer high performance for the telemetry and telecontrol digital processing data information. In this way, the data are encoded in each channel for the transmission over a UHF band data link, and decoded at the receiver to recover the individual data.

Additionally, the vision system consists of a CCD video camera onboard the EFIGENIA which uses an individual transmission channel for transfer the video signal between the vehicle and the control station, in Real-time (Figure 2).

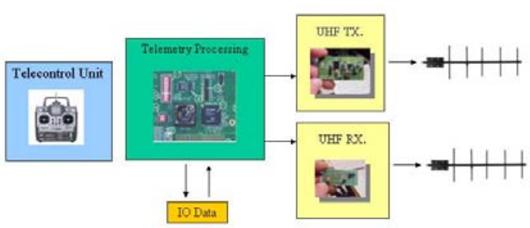

Figure 2. Telemetry and Telecontrol block diagram.

3.3 The Control Station

The flight operations of EFIGENIA UAV are specified by control station which because of its small physical dimensions could be resided onboard card, ship, airplane or ground. The control station continuously maintain communication with the airborne platform and payload.

This has been designed to operating under concept of " virtual Cockpit" which allows to the operator the possibility of feeling the realism of flight operations, flight conditions and its performance.

The pilot control unit consists of a instruments screen panel, a control stick and a keyboard, which are used for selecting and monitoring the aerial vehicle operation.

On the other hand, the mission control unit generates all the information about the EFIGENIA mission objective task (Figure 3 a,b).

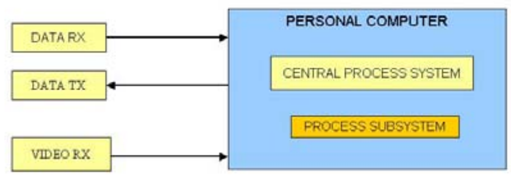

Figure 3 a. Station Control block diagram.

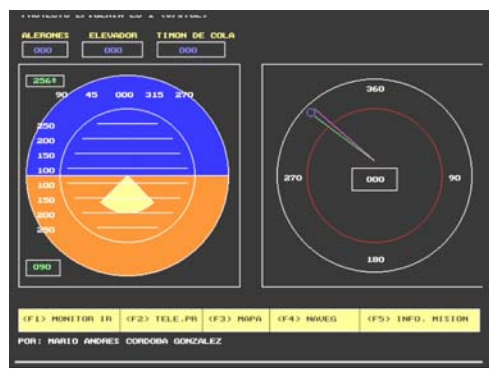

Figure 3 b. Flight instruments screen.

4. Adaptive Reconfigurable Intelligent Guidance, Navigation and Flight Control System for the EFIGENIA S/VTOL-UAV.

The combination of neural network and fuzzy logic expert system make possible to create an effective method for implement the EFIGENIA autonomous navigation and flight control technique. In this way, the system allows a massive parallelism, learning ability, fault tolerance, etc., capabilities.

This system is divided in two important subsystems: The Adaptive Reconfigurable (on hardware) Digital Neural Network Guidance and Navigation Computer and the Fuzzy Logic flight control system computer.

4.1 Adaptive Reconfigurable (on hardware) Digital Neural Network Guidance and Navigation Computer.

Artificial neural networks have been used in a wide variety of Robotics applications. The idea in the EFIGENIA adaptive Reconfigurable digital neural network guidance and navigation computer was to make an ideal technique for improving the aerial vehicle navigation process, obtaining as result high accuracy navigation data because of the adaptive nature of the system.

This navigation computer is designed based on multiple parallel interconnected digital neural network chips architecture system, that I designed specially for the EFIGENIA air vehicle.
During the flight, the system combines the navigation data information from multiple sensors such as GPS, Accelerometers, Gyros, and magnetic sensors. The objective of this process is to provide high accuracy and low cost reliable system solution that ensures to the EFIGENIA a enhanced navigation accuracy and removes common errors from the system.

For this purpose, I used a multilayer digital neural network as on-line learning estimator because of its high performance in multivariable and non-linear systems. In this way, The first step in the development of the guidance and navigation computer was the design and development of a ***digital neural network chip.***

This chip is based on a reconfigurable logic devices, which contains an important amount internal neurons (process elements). Each neuron process a 8 bits inputs, and 4 bits wide weights. All weights are stored in a external chip memory.

Due to the parallel distributed processing properties of the artificial neural networks, the chip developed for this guidance and navigation computer allows that multiple chips can be interconnected to expand the network, taking advantage on important system characteristics such as high digital processing speed, and fault-tolerance.

The EFIGENIA UAV reconfigurable guidance and navigation digital neural network computer employ a GPS receiver, inertial sensors, and magnetic sensors as inputs to the system which allow to compute the most effective positioning operation and obtain high accuracy outputs enhancing the navigation performance (Figure 5).

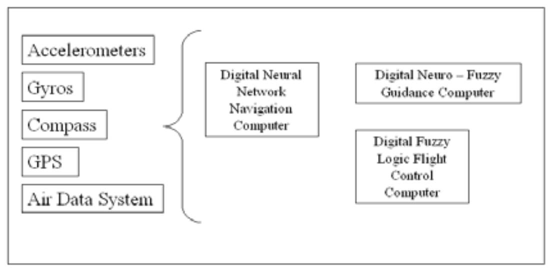

Figure 5. Reconfigurable guidance and navigation digital neural network computer block diagram.

4.2 The Fuzzy Logic DSP Multiprocessor Flight Intelligent Control System Computer.

The EFIGENIA's digital flight control system architecture is implemented using fly-by-wire techniques.

All control laws computations are performed by a multiprocessor system computer based on nine DSP controllers which run a Fuzzy Logic flight-control software at 90 million instruction per second (MIPS). For facilitate the flight control tasks, the EFIGENIA has a wide amount of sensors placed over the body and wings, which allow collect data for its proper functioning.

Hence, the system uses all this data information for the digital fuzzy logic processing and compute commands to the servoactuators that provide the desired surface deflection and/or engines parameters control obtaining the aerial vehicle response.

Each DSP controller perform its own independently real-time task aimed a high process speed, and optimizing the fuzzy logic flight control algorithm performance.

The modular architecture and construction of the EFIGENIA guidance and digital flight control system provides a number of benefits, including accommodation for future growth or configuration changes because the system architecture is capable
of working with multiple chips in parallel offering massive parallelism, learning ability, fault tolerance, etc, capabilities.

5. **FLIGHT TEST.**

The performance of ***EFIGENIA EJ-1B MOZART S/VTOL UAV*** aircraft and UAV system is investigated in a series of flight tests.

This experimental flights are made to verify and validate that the UAV aircraft and UAV system design and construction is operating as specified in the design requirements.

6. **EFIGENIA S/VTOL-UAV Applications**

The EFIGENIA is ideally suited for a high number applications, in particular, in situations where it is too dangerous or expensive to have a human pilot on aircraft. The system is designed to be man-carried and easily transported in a vehicle, and minimize the need for operator training. According to the mission objective, I designed some electronic equipment to use onboard first prototype vehicle that help to the vehicle to do specific task. This include:

- Rescue works equipment.
- A small remote sensing of earth topography.
- Meteorological data collection.
- Transmission of news “in live” in both TV and radio stations.

7. **Conclusions**

This paper has presented the EFIGENIA EJ-1 short or vertical take-off and landing (S/VTOL) Autonomous Intelligent Unmanned Aerial Vehicle development and implementation in which the use of new technologies as in the Aerospace as in the Electronics sciences offer a high performance solution in the unmanned systems scientific research field.

At the same time, EFIGENIA S/VTOL-UAV is an attempt to contribute with the enhancement of human kind quality life level.

MARIO ANDRES CORDOBA G received his engineering degree with honors in Electronics and Telecommunications Engineering from the **University of Cauca**, *Laureates Thesis: DSP-FPGA Embedded Fuzzy Logic Flight Control and Stability Augmented System For Unstable Autonomous Unmanned Aerial vehicles UAVs.*

Engineer Córdoba has study Aerospace Engineering courses about Airplane Design in the **University of Kansas**, Department of Aerospace Engineering, Lawrence, Kansas, USA.

He has been Visiting Scholar Student in the **Massachusetts Institute of Technology MIT**, Department of Aeronautics and Astronautics, Cambridge, Massachusetts, USA, and he has been Short Term Visiting Scientist in **NASA Langley Research Center,** ICASE, Applied & Numerical / Computer Science. Hampton, Virginia, USA.

Engineer Córdoba scientist research interest is in all aspect of design, development and operation of Unmanned Aerial Vehicles (UAVs) Systems since 1991, UAV aircraft design, airframes, aerospace instrumentation and telemetry design, Multi-sensors data fusion and GPS / IMU attitude determination using neural network, Design, development and implementation of PCM – RF telemetry system using reconfigurable computing based on programmable logic devices (FPGA's) for data processing, UAV airplane instrumentation design and development, DSP multiprocessor Fuzzy Logic flight control system architectures, Digital Neural Network and Fuzzy Logic integration for guidance and flight control
systems, Design and implementation of digital neural network chip using programmable logic devices (FPGAs).

Acknowledgments

I want to thank to:

- General: José Manuel Sandoval. ***Colombian Air Force***.
- Drs. Eduardo Sanchez. ***Swiss Federal Institute of Technology***, Laboratoire de Systemes Logiques.
- Sergio Abramoff, ***ANALOG DEVICES*** Sensor Products.
- Carol Popovich, ***MICROCHIP*** Technology, Inc.
- Sr. Gerardo Maya and Cesar Caicedo, Popayán Air Model Plane Club.

References

[1] M. A. Córdoba, "Introduction to Digital Signal Processors, Technology for the new Century", Electronics and Computers Magazine, vol 46, pp 14-18, 1998.

[2] W. Z. Stepniewski, C. N. Keys, Rotary-Wing Aerodynamics, Dover Publications, Inc. New York, 1984.

[3] J. Katz, A. Plotkin, Low Speed Aerodynamics, Mc-Graw Hill, 1991.

[4] M. A. Córdoba, "Digital signal processors, Architecture and Performance", Electronics and Computers magazine, vol 47, pp 38-42, 1998.

[5] M. A. Córdoba, "Aerospace Vehicles, Aerodynamics the key of Design", Aeronautics Magazine, vol 218, pp 10-16, January 1999.

[6] H. Ashley, Engineering Analysis of Flight Vehicles. Dover publications, Inc., 1992.

[7] J. D. Anderson, JR, Fundamentals of aerodynamics. Mc Graw-Hill, Inc., 1991.

[8] R. C. Nelson, Flight Stability and automatic Control. Mc Graw-Hill, Inc., 1989.

[9] C. R. Spitzer, Digital Avionics Systems, principles and practice. Mc Graw-Hill, Inc., 1993.

[10] M. A. Córdoba, “Digital Signal Processing, Application with the TMS320 DSP family, first part”, Electronics and Computers Magazine, vol 48, pp 25-29, 1999.

[11] M. A. Córdoba, “Digital signal Processing, Application with the TMS320 DSP family, second part”, Electronics and Computer Magazine, vol 49, pp 30-34, 1999.

[12] M. A. Córdoba, “Multiprocessor Systems, Applications with the TMS320 DSP family”, Electronics and Computer Magazine, vol 50, pp 26-30, 1999.

[13] M. A. Córdoba, “Digital signal processing, Application with the TMS320 DSP family, third part”, Electronics and Computers Magazine, vol 51, pp 18-21, 1999.

[14] M. A. Córdoba, “Digital signal Processing, Application with the TMS320 DSP family, fourth part, Instruction Set”, Electronics and Computer Magazine, vol 52, pp 18-21, 1999.

[15] M. A. Córdoba, “Telemetry and Telecontrol, an RF application to Unmanned Vehicles and mobile robots” Electronics and Computer Magazine, vol 52, pp 24-27, 1999.

[16] M. A. Córdoba, “Telemetry and Telecontrol, RF modulation techniques”, Electronics and Computers Magazine, vol 53, pp 20-23, 1999.

[17] M. A. Córdoba, “Telemetry and Telecontrol, Antennas and fields propagation”, Electronics and Computers Magazine, vol 54, pp 62-65, 1999.

[18] W. Tomasi, Electronics Communications Systems, 2th edition. Prentice Hall Publications, 1996.

[19] J. G. Proakis, D. G. Manolakis, Digital Signal Processing, 3th edition. Prentice Hall Publications, 1998.

[20] D. Mange, M Tomassini, Bio-Inspired Computing Machines, Towards novel computational architectures. Presses Polytechniques et Universitaires Romandes, 1998, Switzerland.

[21] A. Cobrasi, Sistemas de Navegación, Desde el Compass Magnético a la Navegación por Satélite. Mc-Graw Hill, Inc., 1998.

[22] M. A. Córdoba, “Expert Systems in artificial Intelligence”, Electronics and Computers Magazine, vol 56, pp 54-57, 1999.

[23] M. A. Córdoba, “Expert Systems Operation”, Electronics and Computers Magazine, vol 57, pp 63-65, 1999.

[24] M. A. Córdoba, “Aerodynamics, the lift elements” Aeronautics Magazine, vol 222, pp 44-47, may 2000.

[25] M. A. Córdoba, “The wing lift theory “, Aeronautics Magazine, vol 223, pp 44-47, July 2000.

[26] M. A. Córdoba, “The Wings in the airplane design”, Aeronautics Magazine, vol 224, pp 44-47, October 2000.

[27] M. A. Córdoba, “The Airplane wings and its aerodynamics design”, Aeronautics Magazine, vol 225, January 2001.

[28] M. A. Córdoba, “Programmable Logic Devices, FPGAs and CPLDs, first part”, Electronics and Computers Magazine, vol 66, 2001.