Tiriba – A New Approach of UAV based on Model Driven Development and Multiprocessors

Kalinka R. L. J. C. Branco, Jorge Marques Pelizzoni, Luciano Oliveira Neris, Onofre Trindade Junior,
Fernando Santos Osório, Denis Fernando Wolf

***Abstract*— This paper presents the technical details of Tiriba, which is a small autonomous electrical airplane used into pre-defined missions and applications such as agricultural and environmental monitoring. This class of aircrafts has taken advantage of the miniaturization of electronic components and modules such as GPS receivers, digital cameras, wireless communication equipment, and other sensors. One of the main components of Tiriba is the autopilot module, which is capable to control the aircraft and keep it in a predefined route. This paper addresses the use of model driven development of the system and its multiprocessor platform to support the four components that compose the UAV control software architecture.**

I. Introduction

BASED on the fast growth of the computational power available in low power microprocessors and microcontrollers, the miniaturization of electronic components, and improvements in reliable GPS receivers, it is now possible to develop UAVs capable of performing autonomous missions at a very low cost in comparison with the same missions carried out by manned aircrafts [1] [2] [3].

AGX [4] started its UAV projects with project ARARA (Autonomous and Radio-Assisted Reconnaissance Aircraft), further known commercially as AGPlane, which has been extensively used for agricultural and environmental monitoring. Its main objective is the replacement of conventional aircrafts used to obtain aerial imagery of crops and areas under environmental stress. One of the ARARA´s drawbacks is its relatively large size (3m. wing span) that currently requires a ground launching vehicle to the take off (Fig. 1).

Another important question related to the deployment of commercial UAVs is the training time for their operation. UAVs are non-standard aerial platforms hence some non conventional proceedings can be applied. In this context, an important capability of UAVs is the autopilot. Its function is providing the navigation operation of the UAV in pre-defined flight conditions (e.g. keep the velocity and wings leveled), and with route control. The AGPlane aircraft is able to follow autonomously a pre-defined GPS waypoint.

Manuscript received December 20, 2010. This work was supported in part by the MCT, FAPESP and CNPq..

J. M. Pelizzoni and L. O. Neris are with AGX Tecnologia Ltda, São Carlos, Brazil, Phone/FAX: +55(16)3372-8185 (e-mail: jorge.pelizzoni @gmail.com, luciano.neris@agx.com.br).

Kalinka C. Branco, O. Trindade Jr., F. S. Osório, D. F. Wolf are with USP – Universidade de São Paulo, ICMC - Instituto de Ciências Matemáticas e de Computação (Av. Trabalhador Sãocarlense, 400 - São Carlos, Brazil. Phone:+55(16)3373-8174 - Fax: +55(16)3371-2238, e-mail: otjunior, fosorio, denis, kalinka@icmc.usp.br).

Fig. 1. Take-off of the AGPlane UAV (an ARARA Aircraft).

The autonomous control system is divided into control and navigation units that have different tasks and can be executed at different frequencies [5] [6] [7] [8], allowing the distribution of the autopilot system tasks over multiple processors. Its code is automatically generated using the Matlab/Simulink tool through Model-Driven Development (MDD) [11]. The use of MDD allows code reuse and decreases time spent in code maintenance and development, then reducing the final cost of the aircraft [9].

An important point in the development of Tiriba, is the focus on the simplicity of the operation. This characteristic eliminates the requirement of a human pilot or an expert in aero-photography and flight. Anyone after a very brief training should be able to collect geo position referenced images using Tiriba. The take-off is hand launched, and its landing is based on a parachute to keep its operation simple and easy. Also this UAV only operate in autonomous mode, not allowing a radio controlled (R/C) assisted mode as its predecessor ARARA, making it simpler and safer.

The base station, used to send the mission data (mission planner) to the aircraft is also simple and easy to use (Figure 2). Tiriba´s base station is a Smartphone with Bluetooth capability and WindowsMobile OS.

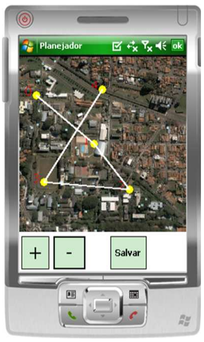

Fig. 2. Tiriba's base station –Smartphone interface.

978-1-61284-380-3/11/$26.00 © 2011 IEEE

The main goal of this paper is to present Tiriba, an electrical, small and low cost UAV including the following items: main board composed by the four processing units, the inertial, pressure and others units that compose the system architecture, and the applications of the aircraft. The aircraft design should also incorporate different aspects related to: modularity, software reuse, easy-of-use, rapid application development, safety and fault tolerance. This paper is organized as follows. The next section presents Tiriba´s hardware and software components, including: main board, processors, microcontrollers, sensors and navigation software. Section III presents current applications of Tiriba. Section IV concludes the paper and discusses about further research directions in small and low cost UAVs.

II. The Tiriba Project

A. Tiriba Overview

The main goal of the Tiriba project is the development and manufacturing of an Automatic Guidance Unit for lightweight UAVs based on inertial and barometric pressure sensors and Global Position Systems (GPS). The system should be as simple and easy of use as possible, once the mission is defined using a regular cell phone. The operation must be totally automatic and intuitive.

The advantages of the system are: the attractive price of the end product, due to a reduced price of development and manufacturing using only simple and low cost components. The price of the product is considerably lower than similar airplanes available commercially. The fully autonomous system can be used by any person without extensive training. This system certainly contributes to the agribusiness with the introduction of a new technology with a low cost product; and low cost of operation (U$ 10/hour of use ~ U$ 0,01 for captured image).

The system also provides a flight zone security scheme. When the Tiriba is delivered to a specific user, the space (region) where it will be used is hard coded. This is called flight envelope, keeping the aircraft in a safe and controlled zone. Tiriba also provides cryptography to avoid unauthorized access to aircraft data and control information.

When the mission is finished, Tiriba returns to the base and use the parachute to autonomously land. If a problem occurs during the mission, the autopilot also sends Tiriba back to the base.

Once Tiriba is an Unmanned Aerial Vehicle it has a on-board system to control all the functions performed by a pilot in a conventional aircraft. These functions include: navigation, control, sensors and actuators. Figure 3 presents the on-board system block diagram.

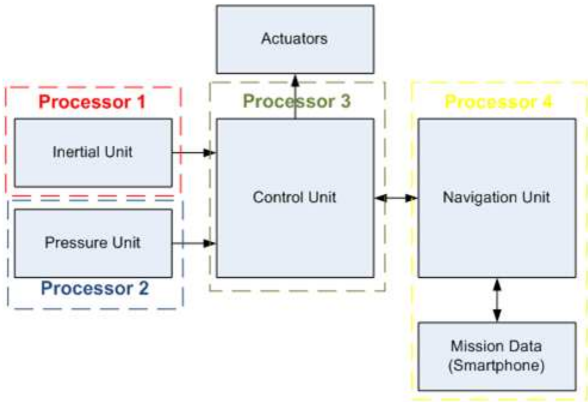

Fig. 3. Tiriba on-board system block diagram.

The on-board system is composed by four subsystems: Navigation, Control, Inertial and Pressure units, and each unit was assigned to a dedicated microprocessor (microcontrollers PIC32 80 MHz).

Table 1 presents the basic specifications of Tiriba.

TABLE 1
BASIC SPECIFICATIONS OF TIRIBA AIRCRAFT

Propulsion	Electric, 1.2KW
Max Takeoff weight	3 Kg
Payload	0.7 Kg
Endurance	40min/1h30min
Cruiser speed	100Km/h /60Km/h
Takeoff	hand launch/catapult
Landing	Automatic, parachute
Missions	Autonomous
Ground Station	Smartphone based
Assembly time	10 min

B. Hardware Components

The hardware is based on a main monolithic printed circuit board (Figure 4) including the following items:

- four processors (navigation, control, inertial and pressure units);
- Voltage regulator providing stabilized energy;
- Analog sensors and accelerometers, providing angular speed, absolute and relative pressure;
- EEPROM memory;
- logic circuits;
- interfaces and communication bus.

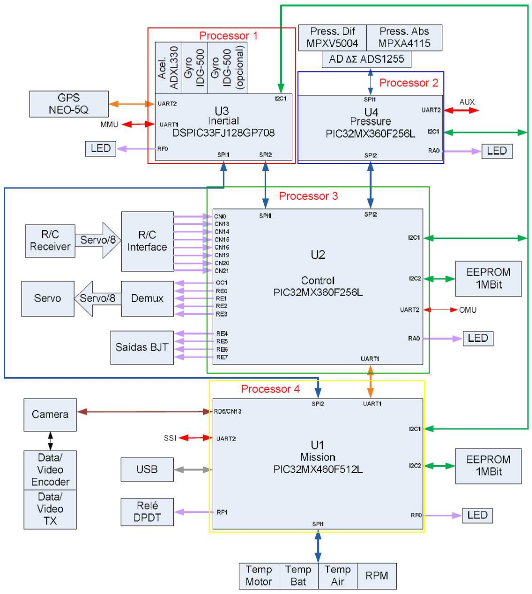

Fig. 4. On-board System block diagram

The actual main board is illustrated in Figure 5.

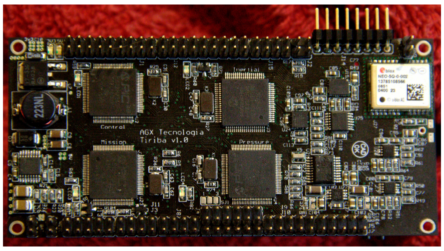

Fig. 5. Tiriba Autopilot main board.

C. *Software Components*

Some important characteristics of the on-board system are: low-level communication within hardware devices, extended operation time without intervention, capable of operating in hostile environments, and able to operate with limited resources like memory, processing, and power.

In order to obtain certified quality software, the Tiriba software development was based on Matlab/Simulink to generate all the source code and validate it in a simulated hardware [9].

As mentioned before, the four subsystems are:

1) Navigation Unit: was developed to guide the aircraft along a route, following some rules defined by the mission planner, such as the accomplishment of tasks associated to each waypoint (e.g. take pictures from a specific GPS location) . Figure 6 shows the Navigation System in details;

2) Control Unit: in charge of maintain the speed, the roll angle, the angle of sideslip and the altitude or the engine speed. In summary, the control unit has three main functions: start the flight mode (direct, stabilized and autonomous), process flight and setup commands; keep the flight conditions and perform commands sent by the navigation system;

3) Inertial Unit: This unit is responsible for estimating the aircraft pose in real time. For that, the unit receives information from the inertial sensors and from the GNSS (Global Navigation Satellite System);

4) Pressure Unit: provides altitude, vertical speed and aero-dynamical speed based on air pressure.

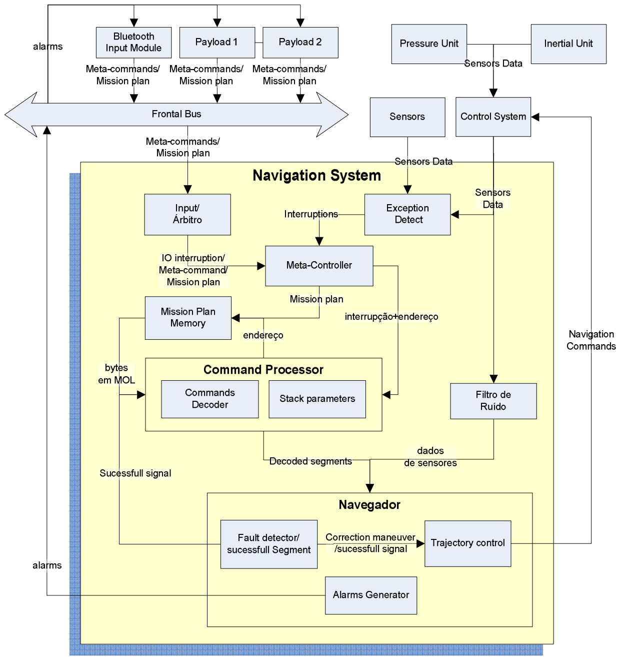

Fig. 6. Navigation Unit block diagram.

III. APPLICATIONS

As main applications performed by Tiriba we can list agricultural, environmental monitoring, security, and civil defense. AGX Company has an extended expertise in agricultural applications [10]. The Tiriba UAV can capture images of cultures and after these images can be processed to obtain important information about the field, as can be seem in Figures 7 and 8. The information obtained can be used to improve productivity.

Nowadays AGX is focusing in environmental applications. The fact that Brazil has continental dimensions facilitates illegal practices due to difficulties in monitoring, especially related to environmental damages. Figure 9 shows an old satellite image of the Mogi Mirim River. In recent images captured by Tiriba (Figure 10) it is possible to notice considerable environment degradation. It demonstrates that Tiriba can help to preserve the environment.

Fig. 7. Soil culture image captured using the UAV (100km/h cruiser speed).

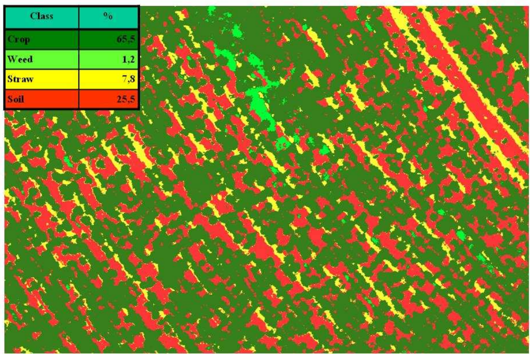

Fig. 8. Image processing showing irregular culture problems.

Fig. 9. Image of the Mogi Mirim River captured by Google.

Fig. 10. Overlap of the UAV image mosaic and Google image showing the environmental degradation in the Mogi Mirim River.

These images and missions performed by the Tiriba Prototype UAV and others mission executed by AGX demonstrate that the use of small and electrical UAVs is beneficial for agriculture and other environmental applications. Therefore, the use of model driven development and multiprocessors allows the development of low cost, reliable, and efficient UAVs.

IV. CONCLUSION

This paper presented the description of Tiriba project, a small, electronic and low cost UAV. The system development using model driven development methodology accelerated the process by using automatic code generation and made easier the source code reuse. Important aspects related to communication, safety, security and fault tolerance were also discussed and represents a contribution to the field. The Tiriba prototype is currently in a final validation stage, and it should be available commercially in February 2011.

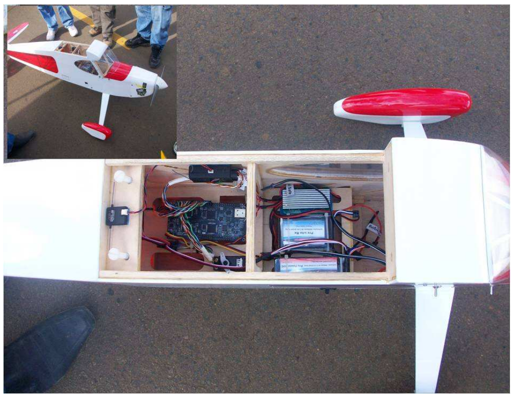

Fig. 11. Tiriba Prototype.

ACKNOWLEDGMENT

The authors acknowledge the support granted by CNPq and FAPESP to the INCT-SEC (National Institute of Science and Technology - Critical Embedded Systems - Brazil), processes 573963/2008-9 and 08/57870-9.

REFERENCES

[1] Y. S. Wang, X. P. Li, and Y. Huang, "Navigation system of pilotless aircraft via gps," IEEE Aerospace and Electronic Systems Magazine, vol. 11, no. 8, pp. 16-20, August 1996.

[2] D. P. Boyle and G. E. Chamito, "Autonomous maneuver tracking for self-pilot vehicles," Journal of Guidance, Control and Dynamics, vol. 22, no. 1, pp. 58-67, January 1999.

[3] O. Trindade Jr, L. O. Neris, L. Barbosa, K. R. L. J. C. Branco. A Layered Approach to Design Autopilots. In: IEEE-ICIT 2010 International Conference on Industrial Technology, 2010, Viña del Mar. IEEE-ICIT 2010 International Conference on Industrial Technology. Santiago, Chile : IEEE Press, 2010. v. v1. p. 1395-1400.

[4] AGX Tecnologia Ltda, www.agx.com.br, accessed in 12/19/2010.

[5] L. C. P., Barbosa, SiNaCoM – Sistema de Navegação e Controle de Missão do Projeto ARARA. in Portuguese, MSC Thesis, University of São Paulo, 2001.

[6] E. N. JOHNSON, S. Fontaine and A. D. Kahn, Minimum Complexity Uninhabited Air Vehicle Guidance and Flight Control System. AIAA Digital Avionics Conference, 2001.

[7] J. H. Kim, S. Wishart and S. Sukkarieh, Real-time navigation, guidance and control of UAV using low-cost sensors. In: International Conference on Field and Service Robotics (FSR 2003), Yamanashi, pp. 95-100, 2003.

[8] L. O. Neris, "Um Piloto Automático para as Aeronaves do Projeto ARARA"; in Portuguese, MSC Thesis, University of São Paulo, December 2001.

[9] O. Trindade Jr, R. T. V. Braga, L. O. Neris, K. R. L. J. C. Branco. Uma Metodologia para Desenvolvimento de Sistemas Embarcados Críticos com Vistas a Certificação. In: IX Simpósio de Automação Inteligente - IX SBAI, 2009, Brasília. Anais do IX Simpósio de Automação Inteligente IX SBAI, 2009. p. 1-6.

[10] O. Trindade Jr, L. A. C. JORGE, J. Aguiar. Field of Dreams – Using UAVs for Precision Farming. Unmanned Systems Magazine, pp 35-39, 2004.

[11] T. Stahl, M. Voelter, K. Czarnecki. Model-Driven Software Development: Technology, Engineering, Management. Wiley, 2006.