How design an unmanned aerial vehicle with great efficiency in the use of existing resources

Javier Bilbao, Andoni Olozaga, Eugenio Bravo, Olatz García, Concepción Varela and Miguel Rodríguez

***Abstract*—**At a time of economic recession, the selection of means necessary for the development of research projects takes high importance because, among other reasons, the premature end of the project depends on this selection. The use of existing solutions and the merger among similar projects allows greater efficiency in the use of existing resources. This paper is a synthesis of work done so far in the Department of Applied Mathematics of the Engineering School of Bilbao about the design of Unmanned Aerial Vehicles (UAVs) for water bombing.

***Keywords*—** UAV, design, water bombing, project management, efficiency.

I. Introduction

A UAV is an aircraft with no onboard pilot. Instead, it is remotely-controlled or can fly autonomously based on pre-programmed flight plans or more complex dynamic 'self-thinking' systems. While to some extent such unmanned aircraft resemble cruise missiles1, they differ in that they return to base for further use once they have fulfilled their mission.

UAVs are often categorized based on performance (linked often to size). There are several categorizations from producers, users and researchers.

UAVs can be classified according to the way their flight is controlled, of which there are three methods: pre-programmed; remote control; self-thinking (which can be combined). Each means of control provides both challenges and opportunities.

The most basic control is by pre-programmed flight. This is simple, does not need technically difficult and disturbance-sensitive data-links for control, and gives ranges beyond the line-of-sight. However, the system is inflexible.

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Once airborne the UAV follows a fixed path. It cannot 'take a second look' at something that seems interesting. If the UAV needs to fly as low as possible, it is also dependent on good information of the terrain.

Remote-control is the most common control system for UAVs. By radio, the operator receives flight data from the UAV and sends flight commands back. The weak points of this system lie in the vulnerability of the continuous radio links, which reveal the positions of both the controller and the UAV, and the fact that radio links limit the UAV's range. More advanced, less vulnerable radio links and indirect radio links (e.g. via satellites or relay UAVs) are a partial solution.

Self-thinking UAVs are still a futuristic option. The technical challenges to develop a fully autonomous UAV are still insurmountable. Nevertheless, an element of self-thinking has been achieved in as much as UAVs are able to react to threats, for example, when attacked by an air-defence missile.

UAVs and UCAVs are themselves just 'aircraft' with onboard systems. However, they are usually linked to additional equipment outside, such as the remote-control and launching equipment.

In addition, UAVs often have an interchangeable 'mission package', which includes the sensors and, if necessary, the link for transferring data collected by the sensors. Together, this equipment forms the UAV system.

Sometimes, UAVs are classified in seven categories:

- Tactical - the catch-all for the ubiquitous 50 to 1000 lb deployable air vehicle;
- Endurance - capable of extended duration flight, typically 24 hrs or greater;
- Vertical Takeoff & Landing (VTOL) - self explanatory, typically rotary wing;
- Man Portable - light enough to be back-packed by an individual and launched by hand-throwing or sling-shot mechanism, larger than micro air vehicles;
- Optionally Piloted Vehicle (OPV) - capable of manned or unmanned flight operations, typically an adaptation of a general aviation aircraft;

- Micro Air Vehicle (MAV) - defined as having no dimension larger than 15 cm (6 in);

- Research - developed for specific investigations, typically with no production intent.

The main components of these vehicles are listed below:

Airborne part – aircraft:

- Airframe – wings and body.

- Engine – most UAVs are powered by a piston (reciprocating) engine driving a propeller. Faster and higher flying UAV use turboprop or jet engines. Electric, battery or fuel-cell powered, engines are becoming usual on micro- and mini-UAVs.

- Sensors – radar, photo or video camera, IR scanners or ELINT are most common. Sensors may include a (laser) target designator to provide guidance for stand-off guided missiles and shells.

- Control system – used to fly the UAV. Either a two-way data link (radio) for remote control or an onboard computer (generally with GPS navigation) connected to the aircraft control system.

- Data link – One-way (radio) link transmitting data collected by sensors.

- Recovery system – optional; most modern UAVs land like normal aircraft; earlier UAVs often use a parachute to land.

Ground-based part:

- Launcher – many UAVs are launched by a catapult-type launcher or with a rocket booster. UAVs with a wheeled undercarriage for take off like a normal aircraft, which is less stressing on the UAVs airframe, is becoming more common.

- Control system – used to fly the UAV; this includes a 'cockpit' from which the 'pilot' on the ground flies the UAVs (if remote-controlled). It is linked by two-way (radio) link to the UAV. The control system may include sub-control systems allowing other operators to take over flight.

- Data link – receiver for sensor data transmitted from the UAV. There may be several receivers of data, including some not part of the UAV system.

- Transport and maintenance – UAV systems are generally mobile.

After the initial study developed last year, we have continued with the development of the objectives of the project and to raise its milestones in the way that it can achieve a steady progression.

An important point has proved to be the reconciliation of teaching and research tasks in the case of the involved teaching staff and the classes and examinations for the trainees and students assigned to the project. Once defined the milestones and objectives to fulfil, the first step was done: real definition of system requirements, number of actuators, sensors, communications...

Since the means available initially were very limited, we decided to use existing systems already tested and adapted to our needs. It is not an exercise of taking advantage with the work of other teams, but an improvement in the design of one project and an attempt to reduce the economical cost of this project (not only in the price of the materials but in the hours of dedication of the members of the team, too, because these hours is time cost, that is, euros).

II. DEVELOPMENT (SEARCH FOR SOLUTIONS)

Broadly speaking, the project had two fronts: the electronic control unit both on land and in air and the own structure of the device.

After an exposition of available options, we decided to give priority to the electronics and communications fields and leave the static and dynamic development of the machine in the background.

Fig. 1. C130 RC model

In the search for a suitable hardware platform, commercial options were valued such as the PC 104 platform, platform based on FPGA Leon 3 certified for space projects, use of consumer electronics like VIA EPIA, AMD Geode or the recent Intel Atom, as well as use of microcontrollers as PIC or ARM. The latest one enabled advanced features thanks to the large number of applications available in the market and the easy incorporation of embedded operating systems for real time, as VxWorks, RTEM..., which would facilitate a deterministic scheduling of the system at low cost. For this reason we decided to use the microcontrollers as a solution for the first prototype.

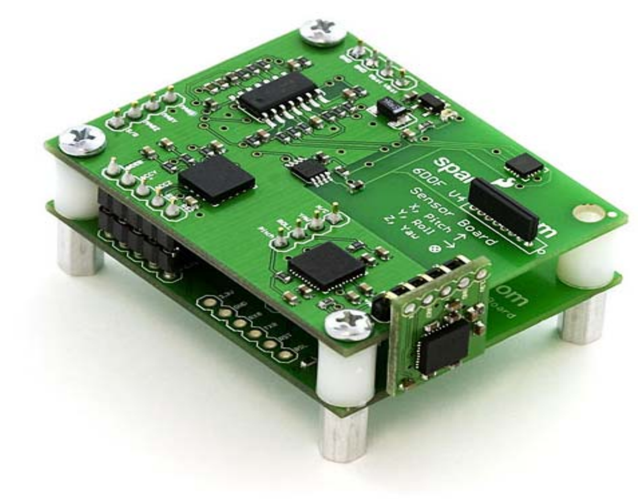

Fig. 2. Sensor pack

In order to search the ARM platform, we have chosen a development board of Sparkfun which has one LPC2138 ARM7, apart from sensors such as one Freescale MMA7260Q triple-axis accelerometer, 2 Invensense IDG300 500 degree/second dual-axis gyros, and one Honeywell HMC1052L and HMC1051Z magnetic sensors.

This board provides a boot system that simplifies the programming and debugging of the code writing a file with the code directly to the micro SD card avoiding these of Jtag connectors and such. All priced at 450$.

Regarding the sensors, we investigated in Internet to get products with enough characteristics to fulfil the needs at low cost.

Manufacturers such as Analog, Free Scale, ST and Honeywell sell accelerometers, gyroscopes, magnetic compasses, temperature and pressure sensors at a reasonable price.

The communications item was more complex than expected. On one side we wanted a complete telemetry, as well as a remote control and a video transmitter on board.

The solutions that we have found commercially are composed by a radio-modem for Telemetry, a R/C transmitter modified for its use with PC connection (USB) and then a circuit that suits to the RC control and transforms the standard emission of 35 MHz to another of 869 MHz of long-range (35 MHz to local tests and 869 for subsequent developments).

For the video, we opted for a low-cost solution used commercially for FPV flights. An OSD (On Screen Display) allows instant visual access to the basic parameters such as signal intensity, altitude, speed and autonomy of the machine.

Fig. 3. Communication devices

Fig. 4. OSD example

Fig. 5. FPV Kit example

Fig. 6. Electronic of our quadracopter

III. Commercial items found and synergies

In the search for the ideal platform for the development of the first prototype, we located a project developed in Europe of a quadracopter that is simply a device capable of levitate motionless in a position and move in any direction without delay. It consists of two microcontrollers PIC with three gyro, three accelerometers and compass integrated in a modular way within a small PCB with RS232 connection that enables the reception of PWM signals from a commercial R/C receiver. These signals are processed and led to the potentiometers responsible for the actions of each of the four electric motors that give power to the machine.

In itself the quadracopter is an excellent and affordable platform for implementing control structures, necessary for stability in flight.

As a development platform, it allows debugging and checking the entire software on board, as well as telemetry, video and the base station, all in a closed room firstly and in a controlled small area secondly. Being electric machine, the inherent danger in combustion engines (commonly in RC aircraft for long distances) is circumvented by providing greater security operation. So it would only get the design of

Fig. 7. Commercial grade quadracopter at www.microdrones.com

the flight unit responsible for monitoring the predefined route, to read data from the GPS and from sensors not presented in the electronics of the quadracopter (such as atmospheric pressure and temperature sensors), needed to know the altitude and speed relating to wind.

In addition, it constitutes in itself a new project. A levitation machine of low cost, of this kind, can have enormous applications, from the observation of burning buildings to the cleaning of high power towers, which is currently done with a helicopter and three human operators.

There are some commercial products of this kind in the market, like this German drone, priced at 25,000 Euros.

Other hardware that is being investigated for those projects is Qwerk, Enac´s Twog, Pandora, Beagleboard and the MRD6400L for the video.

A. Qwerk

The first hardware that we expose is Qwerk. We will see below an overview and characteristics of the hardware and the communications.

Overview

- Powerful robotics solution for university and high school educational and hobbyist markets
- High-performance CPU with an excellent I/O feature-set for robotics and mechatronics applications
- Low-cost

Hardware

- 200 MHz ARM9 RISC processor with MMU and hardware floating point unit
- 32 Mbytes SDRAM, 16 Mbytes flash memory
- Latest generation Xilinx Spartan 3E FPGA for custom I/O peripherals
- Linux 2.6 installed
- WiFi wireless networking support
- WebCam video input support
- 4 Amp switching power supply, 90% efficient, 7 to 30 Volt input range
- Rugged aluminum enclosure
- 5.1” x 5.8” x 1.3", 11.8 ozs

I/O

- 4 closed-loop 2.0 Amp motor controllers (supports both quadrature encoder and back-EMF “sensorless” feedback)
- 16 RC-servo controllers
- 16 programmable digital I/Os
- 8 12-bit analog inputs
- 2 RS-232 ports
- USB 2.0 host ports for connecting standard USB PC peripherals
- 10/100BT Ethernet port
- Built-in audio amp for playing MP3 and WAV files

B. Enac´s Twog

May be our “on fligth” autopilot.

Features:

Single LPC2148 MCU

- 8 x Analog input channels 0V - 3.3V (2 channels with optional on-board resistor bridge)

Fig. 8. Qwerk robotik platform

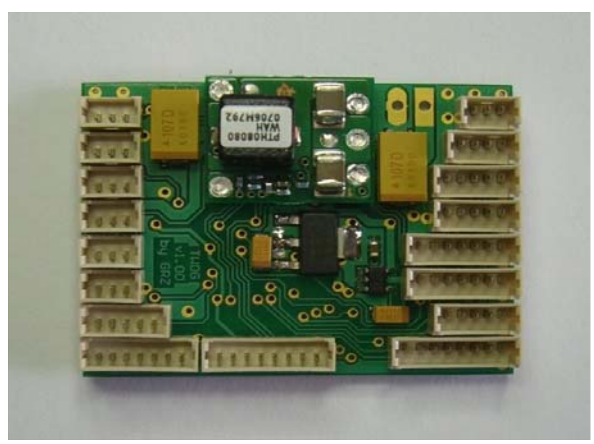

Fig. 9. Enac´s Twog.

- 1 x 3.3V TTL UART (5V tolerant)
- 8 x PWM outputs
- 1 x R/C receiver PPM frame input

- 1 x SPI bus
- 1 x I2C bus
- 1 x USB (client)
- 5v / 2.25A switching power supply (input voltage range 6.1v → 18v)
- 3.3v / 1A linear regulator
- 3 x status LEDs with attached test point
- 8 grams (0.28 oz)
- 40.2 x 30.5mm (1.6" x 1.2")

C. Pandora

Designed for videogames, it can be a good and cheap portable groundstation.

Features:

- ARM® Cortex™-A8 600Mhz+ CPU running Linux
- 430-MHz TMS320C64x+™ DSP Core
- PowerVR SGX OpenGL 2.0 ES compliant 3D hardware
- 800x480 4.3" 16.7 million colours touchscreen LCD
- Wifi 802.11b/g, Bluetooth & High Speed USB 2.0 Host
- Dual SDHC card slots & SVideo TV output
- Dual Analogue and Digital gaming controls
- 43 button QWERTY and numeric keypad
- Around 10+ Hours battery life

D. BeagleBoard

For a fixed groundStation we can use this board, It is a low-cost, fan-less single-board computer based on Texas Instruments OMAP35x processors featuring the ARM Cortex-A8 core with all of the expandability of today's desktop machines, but without the bulk, expense, or noise. Instead of using a fixed, embedded LCD, Gerald used the digital and analogical LCD ports to add monitor/TV connections, so that any DVI-D enabled monitor or S-Video enabled TV could be used. The USB port (eventually, ports) can be used to add a high-speed hub for adding a keyboard, mouse, and Wi-Fi connection and the MMC/SD connector can be used to add multiple gigabytes of storage.

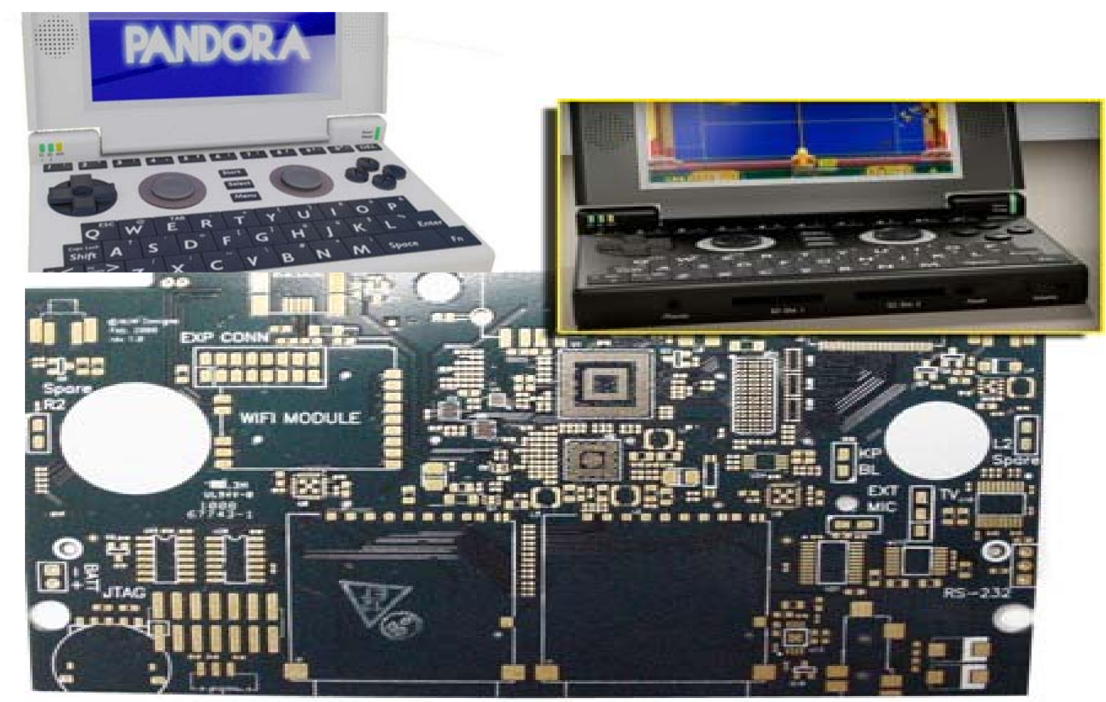

Fig. 10. Pandora´s platform.

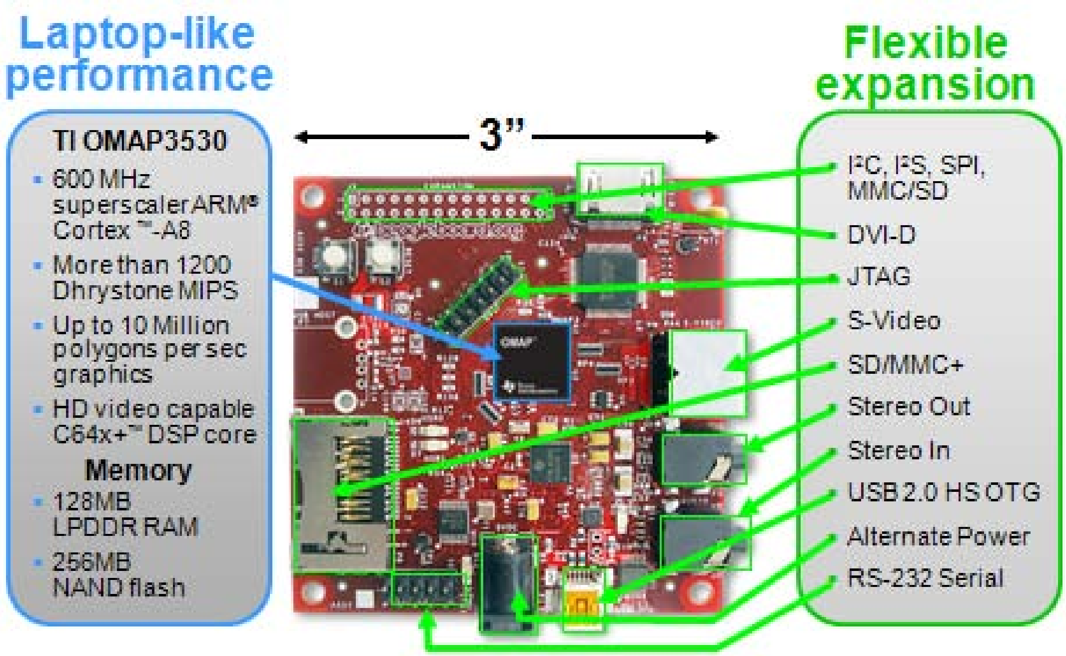

Fig. 11. BeagleBoard ´s platform

E. The MRD6400L

Due to his dual video coding-decoding capabilities, it may be our on board video platform.

It is a Linux-based ARM processor module designed for easy systems development and cost-effective solutions. The design utilizes Samsung ARM11 series CPUs which are specially designed for mobile and multimedia applications. A wide variety of peripherals are centred around the core to build a seamless multimedia communication device.

Features

- CPU : Samsung AP S3C6400
- Linux Kernel v 2.6.21
- Basic UI support
- Multimedia Function for MP3, e-Album and Movie with various movie formats
- Wireless Connectivity with WLAN11g

Hardware Features

- CPU: Samsung mobile AP S3C6400 (633MHz)
- Display : 7” TFT Touch Screen (800 * 480)
- Flash : 64MB NAND
- mDDR : 128MB
- IDE for HDD
- Audio Out
- USB OTG
- WiFi (WLAN 11g)
- AC97 Audio CODEC
- SD Card Slot
- 5V DC Adaptor

Fig. 12. MRD6400L board.

IV. Present Tasks

Both the Qwerk as MRD6400L are found to be interesting development tools, since both are based on free software

Fig. 13. Paparazzi Ground System

(Linux), although some specific driver is owner. This is approximately our design: a central unit and a module to control every existing parameter.

The MRD6400L is a powerful development platform thanks to its 600 MHz of processing capability, and his ability to handle concurrently two independent sources of video, apart from wireless communications such as Wi-Fi.

The next step will be to develop the software, and with this aim we can also start from existing commercial examples or from free software such as The Paparazzi mini UAV Project.

Paparazzi is a free and open-source hardware and software project intended to create an exceptionally powerful and versatile autopilot system, The project includes not only the airborne hardware and software, from voltage regulators and GPS receivers to Kalman filtering code, but also a powerful and ever-expanding array of ground hardware and software including modems, antennas, and a highly evolved user-friendly ground control software interface.

V. Conclusion

The consumer society in which we live provides us with commercial elements to facilitate the work of searching existing elements usable for our purposes, saving time and development costs. While it is not usually get too much quality materials, they are enough to nascent stages of development as well as educational tools for students of first and second grade. Once the development platform fulfil the purposes for which it was thought, acquired knowledge will be incorporated on the fire-prevention plane, programming real maneuvers employed in the existing aircrafts such as Bombardier Canadair, Air Tractor AT-802F or the ancient Canso PBY - 5A Flying Boat.

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