THE AIVA FLY-BY-WIRELESS UAV PLATFORM

The AIVA project concerns to an UAV aimed to perform aerial surveillance, forest fire detection and also to monitor high voltage cables for stress or failures. The global project involves the design and development of the required aerial platform, as well as the electronics, communications hardware and software, flight control, artificial vision and systems integration, in order to provide an autonomous takeoff, flight mission and landing manoeuvres. Relevant goals, regarding the design and development of the AIVA platform, initiated in September 2004, have already been achieved, and they will be described over next topics.

The fly-by-wireless approach

Traditionally, UAVs present a processing system architecture consisting of one centralized and complex unit, with one or more CPUs to which the instrumentation devices are connected by wires. At the same time, they have bulky mechanical connections. One of the main innovative aspects of the AIVA platform concerns the flexible and distributed architecture of the onboard instrumentation and processing system. The used approach can be named as “fly-by-wireless”, meaning that the connections between the instrumentation and the processing units are made with Bluetooth wireless technology. At the same time, the traditional monolithic processing unit is, in this approach, replaced by several less complex units (nodes), spread out over the airplane. In that way, nodes are placed near the sensors and near the controlled surfaces, creating a network of nodes with the capacity of data acquisition, processing, actuation and communication over a wireless platform.

The main advantages of this approach are the following: a) Reduction of the weight, which is achieved by the suppression of several physical connections; b) Easy and quick installation procedures; c) High flexibility drills, allowed by the easier mixing of the aileron and the elevators commands; d) Less cables maintenance; e) Less electromagnetic interferences induced on wires; f) Small energy consumption; g) Good reliability; h) High modular development, allowed by the logical architecture of the nodes.

The aircraft design

The aerial platform is a relatively small, slow and steady flying 1.25m high aircraft, easy to transport and to operate, with a wing span of 4.80m, and a 2.90m fuselage. The aircraft is powered by two brushless 1,2 kW electric motors feeding on li-po batteries. It has a design total take-off weight of approximately 15 kg, 30% of which comprises the necessary cargo of onboard flight electronics and instrumentation for the navigation and control and for data transceiving on pre-assigned missions.

The design of this platform (fig. 1) depicts a relatively long fuselage of generous square-rounded cross section, a high mounting, trapezoidal, straight wing with a taper ratio λ=0.6, provided with winglets. The tail is a classical T arrangement, with the horizontal plane mounted on top of a high rudder. Electrical motors, driving 18 inches APC props, are located on the wing central panel, in a typical pusher configuration, for minimum prop wake interference.

The strong central part of the fuselage is designed to accommodate all the power sources need for the aircraft operation, engine batteries included, and to receive the main wheels of the fixed tricycle landing gear.

Global electronics architecture

The global architectural model of the computing and communication system, presented in fig. 2, is composed by a multitasking/multiprocessor based system connected by an asynchronous local bus that allows for speed adaptation of different tasks/processors.

The system supports one processing unit for the Bluetooth (BT) piconet master, one flight controller unit, one data logger and ground link, and one embedded vision system (EVS). In each of these nodes many critical processes are permanently running. Air-ground link communications are based on a classical producer/consumer model that manages message queues for uplink and downlink data traffic.

This architecture allows an easy way to introduce or remove processing units from the platform. For instance new sensors or new vision units can be included. In the first case a new module must be connected to the BT piconet, and in the second case the new module is connected to the local multi-access bus.

Onboard wireless network

The AIVA platform implements an onboard distributed data acquisition and control system based on Bluetooth wireless network technology and either on balanced or unbalanced scheduling policies. The BT technology presents some characteristics that suit the envisioned application. Firstly, it possesses smaller form-factor and drains less power than some alternative wireless network technologies like the IEEE 802.11 (WiFi). Secondly, it implements a medium access control protocol that provides support for real-time traffic. Thirdly, it provides an adaptive frequency hopping mechanism that allows the improvement of the performance of the communication link by avoiding interference.

All the Bluetooth modules on our platform are configured in a non discoverable mode. The node discovery process of Bluetooth is a slow process, in the order of seconds, however it is not a problem since the master stores the addresses of all slave nodes that should participate in the piconet, so this process is avoided. As the piconet formation is performed on the ground before the takeoff procedure, the associated delay does not constitute a problem as well.

Fig. 3 presents the architecture of the network nodes. Each node includes a low power microcontroller, a commercial-off-the shelf Bluetooth module and sensors and/or actuators. Fig. 4 shows distribution of the network nodes on the aircraft structure. The master module (MM) is placed at the fuselage body, and, as described earlier, acts as the network and flight controller, onboard data logger and communications controller for the link with the ground station. The other six nodes (Sensing & Actuation Modules - SAM) are slaves in the network. On each wing, there is a node for an electrical propulsion motor and for control surfaces like ailerons and flaps. Motor speed control, feedback loop, and operating temperature monitoring are responsibility of these wing nodes, as well as control surfaces actuation and position feedback. At the tail, there is another module for elevator and rudder control, and position feedback.

In the fuselage body, we have another two additional SAM type nodes, one for GPS and the other for electronic gyroscopes, which assure some basic information assessment for navigational purposes. At the front node is the nose probe, which consists of a proprietary design based on six independent pressure sensors that give valuable digital information for flight control. Also in this node the information from an ultrasonic probe provides support for the automatic take-off and landing system.

In terms of communications, a wireless multidrop access scheme is adopted, where all slaves are able to listen to the frame sent by the master, in a point-to-multipoint strategy.

In order to cope with typical problems that arise in these embedded systems, namely asynchronous events, the technical design approach used to model the system was a set of state machines. These also solve other major issues like resolving simultaneous events. The state machines are organized in a two layered architecture: the lower transport layer, which is common to every application, deals with network packets; the upper application layer implements the application specific functionalities. Both have independent design.

This strategy was designed to be application independent, and this fact was tested and validated by successfully applying this networking platform to other areas, such as for control of agricultural greenhouses. It was also recently presented (May 2006) at the Hannover industry fair in a biomedical body monitoring system application.

Performance tests

The experimental setup used to produce the results consisted of one piconet with a configurable number of slaves (from one to six). Data packets composed by 15 octets were sent periodically from the slaves to the master (and vice-versa), with sampling rates varying from 10 Hz to 2 kHz. Performance metrics evaluated in the tests include the network throughput, the delay from the source node to the destination node and the packet loss rate.

The observed results showed that the network throughput increases linearly with the offered load (derived from the sampling rate) until the point it reaches saturation, after which the throughput stabilizes. With a piconet configuration containing six active slaves transmitting to the master, the network can support sampling rates up to 200 Hz before reaching saturation. This linear behaviour is a desirable property of the system, derived from the contention-free medium access control (MAC) protocol implemented by Bluetooth, which is not affected by collisions, unlike the protocols used by other popular wireless networks, such as the WiFi networks.

For the same conditions as above, it was observed that the packet loss rate was limited to less than 0.5 % in the region where the network is not saturated, increasing rapidly after the saturation point, as expected.

Relatively to packets travelling from the slaves to the master, it was observed that the delay was not adversely affected by a rise in the offered load, as long as the network operates below the saturation point. For sampling rates ranging from 10 Hz to 200 Hz, the mean delay was around 27 ms and the overall delay was below 90 ms for 99 % of the packets.

These results show that the system is able to reach a sampling rate of 200 Hz for each of the 6 slaves simultaneously (which represent a total of 1200 samples each second) without performance degradation in terms of throughput, loss or delay, which denotes a satisfactory performance for the AIVA onboard communication purposes.

Regarding the master to slave communications, the tests with piconet topologies composed by one to four slaves showed similar results.

Air-ground link

The communications link between the mobile platform and the ground station is based on a commercial-off-the-shelf spread spectrum radios. It's composed by two physical links: one unidirectional – the video link and the other a multiplexed bidirectional – the data link.

The video link (Live VDO) guarantees live video images at the ground station and at this stage only allow two video channels. The data link implements two logical links, one for system console data and operator control and the other for flight info. These links are multiplexed on the physical link by means of a logical entity that accepts data from two input queues (one for each logical channel) and performs traffic scheduling in order to maintain efficiency without compromising significantly the global throughput of each of the channels.

Ground station

In order to have flexible operation, ground station functionality is spread among several networked computers, which communicate using TCP/IP protocol.

The system is composed by a meteorological station, a geo-referenced station (layout in fig. 5a), a simulator station to examine aircraft dynamic behaviour in a visually fashion, a live video station with real-time imagery captured onboard and an operator console (layout in fig. 5b). Due to the adopted architecture, there can be redundant stations on different places, so there can be different teams examining particular aspects of flight in different places at the same time. A reception computer implements the ground side of the flight monitoring logical channel described above, as well as the system console and operator control logical channel.

Flight control

Flight control, a working phase at the present moment, is concerned with the modelling and simulation of the lateral and longitudinal control of the aerial platform, focusing on the development of an autopilot specifically designed for this application (i.e. surveillance and reconnaissance missions for civilian purposes) and guidance and navigation procedures.

Some of the tasks (and subtasks) as well as the final objective of this "flight control phase" will address modelling and dynamic analysis, stability evaluation, multivariable control theory and computer-aided design techniques. In the literature, there is a rich set of mathematical tools and realistic aircraft algorithms for performing flight simulation and flight control design. However, it is required a clear idea of their applicability and the rationale and design goals for automatic flight control systems. The control system is specified depending on the type of aircraft or the desired flight. Specifically, control systems will be developed to implement roll, pitch and yaw damper; roll and pitch rate; pitch attitude, altitude and speed hold; automatic landing; roll-angle hold; heading hold and turn coordination.

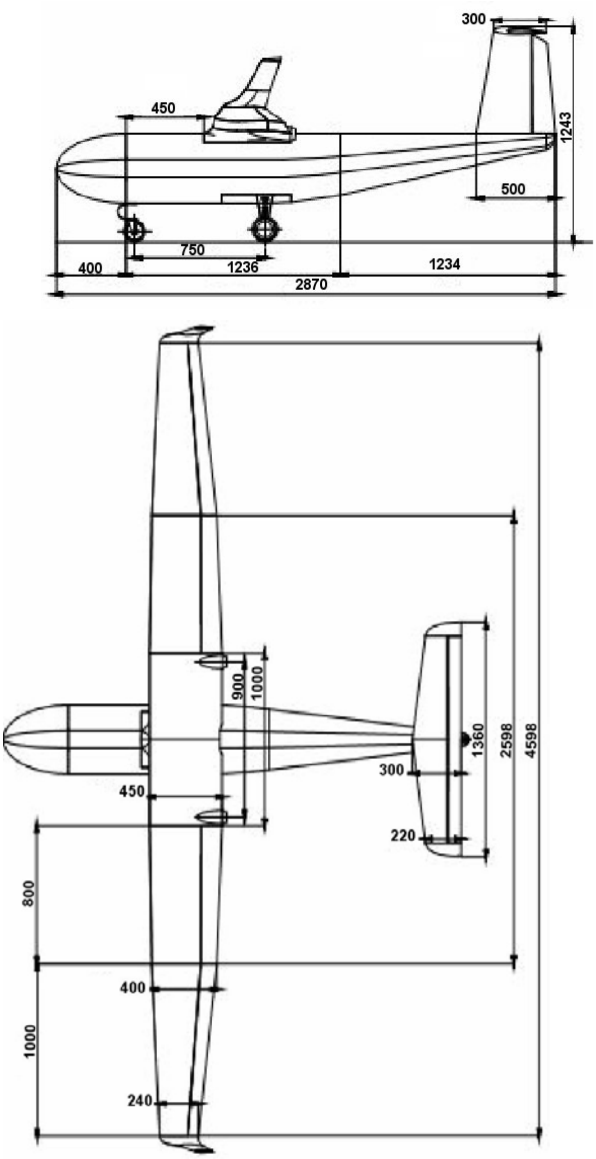
Vision system

The development of vision system is an ongoing part of the project and some especially designed software applications have already been developed for the detection of relevant targets, such as fire and moving vehicles. This stage deals with the analysis of the thermal and hyperspectral image and involves the development of image calibration and segmentation tools. The nest task will be addressed to the developments necessary for obstacles detection, using stereo vision techniques.

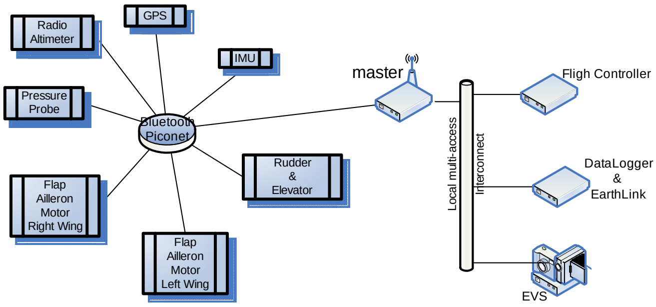
The algorithms will be running in the onboard embedded vision system, at the same time the images are sent to the ground station in real time.

Conclusions

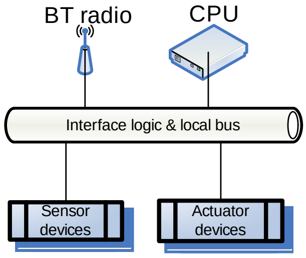
Although this article focused all the major areas in which the team is working, the flexible and distributed onboard communication architecture is the work-phase that more advances has been achieved. It uses a wireless distributed data acquisition and control system, which is based on Bluetooth wireless technology and on a multiprocessor architecture. This approach leads to a more flexible platform when compared with the conventional ones. This flexibility is reflected mainly in UAV design and construction and in the introduction of new sensors, actuator or other complex units to the platform. On the other hand, the fly-by-wireless approach is also a major advantage because by suppressing cables a more flexible design is possible. Bluetooth technology also provides mechanisms to increases the reliability of the wireless communications when subject to interference.



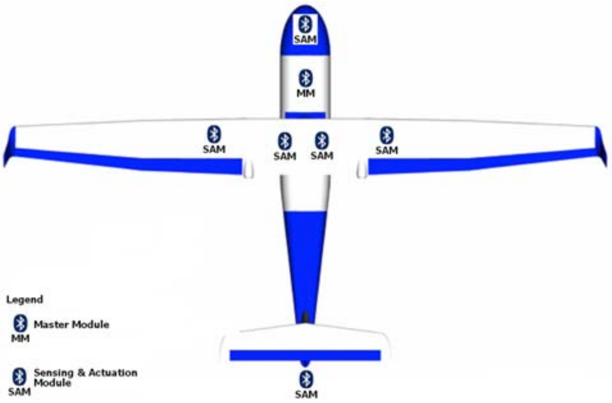
1. General views of the AIVA aerial platform.



2. Global electronics architecture of the AIVA platform.



3. Architecture of a Bluetooth node.



4. Node distribution adopted for the aircraft structure.

a) b)

5. Ground Station: a) Layout of the geo-reference station. b) Layout of the operator console station.