

Land control and monitoring system for fire prevention

G. Buttazzo*, G. Chiandussi**, C. Demartini*, G. Iannizzotto*,
L. Lo Bello* and F. Quagliotti*

* Scuola Superiore S. Anna, Pisa, Italy

** Politecnico di Torino/Dipartimento di Meccanica, Torino, Italy

* Politecnico di Torino/Dipartimento di Automatica e Informatica, Torino, Italy

* Università di Messina/Dipartimento di Matematica, Messina, Italy

* Università di Catania/Dipartimento di Ingegneria Informatica e delle Telecomunicazioni, Catania, Italy

^ Politecnico di Torino/Dipartimento di Ingegneria Aeronautica e Spaziale, Torino, Italy

Abstract—This paper describes the project: “Study and development of a real-time land control and monitoring system for fire prevention” co-funded by the Italian Ministry for Instruction, University, and Research (MIUR) within the framework of the PRIN 2004.

This project has been devoted to study and develop a system for the territory control in order to prevent and manage natural disasters. The system can be thought as composed by two components: a mobile platform able to take on board a payload and a remote control station. The mobile platform is an Uninhabited Air Vehicle – UAV, while sensors, autopilot, and cameras are the payload. The paper presents the contributions of all research units that have designed and implemented both the platform and all the control systems used to allow autonomous and remote piloting of the UAV.

I. INTRODUCTION

UAVs (Uninhabited Aerial Vehicles) play an extremely important role as mobile platforms that can be employed for environmental monitoring. UAVs are aircrafts without crew and passengers that are remotely controlled by a control station. Their effectiveness is due to the possibility to reach hostile and inaccessible areas without exposing humans to hazards and dangerous situations. Moreover, the internal space can be fully designed in order to place sensors and the board systems. UAVs actually represent one of the most important technology in the aeronautic field due to their extreme flexibility, reconfigurability and, above all, due to the optimal ratio between mission costs and performances [1]. The employment of UAVs has involved before military tasks, but civilian applications are rapidly grown in the last years. Some examples are search and localization of missing people, fire prevention, aerial photography, traffic control, air quality monitoring in urban sites, monitoring of acoustic and sea pollution [2].

This kind of platform has to be able “to react” following commands and/or external-environmental events within temporal constraints. Too large response times (or highly variable) could degrade the system performance or involve stability problems. Real-time execution of processes of data acquiring and control, the effective resource management, the software control of

the consumed energy and the implementation of network real-time wireless protocols are still challenging tasks.

Another key point is the human-machine interface devoted to the control of the platform. Usual approaches to remote control of mobile platforms involve analog remote controls and direct visual feedback. A control station is provided with one or more cloches and the visual contact is the main source of feedback for the operator, who relies on his/her experience to visually drive the mobile device toward its target. Instrumental control (i.e., without any direct visual contact with the mobile device) has been exploited in unmanned vehicles, but when involved dynamics become very fast, a number of significant issues come up, several of them being related to human-computer interaction: since the control depends on human actions, a fast and reliable communication must be assured between the human operator and the computer, in order to build an efficient control chain. Thus data acquisition, merging and presentation becomes crucial as well as user action detection and interpretation.

A wide corpus of thorough research has been produced in the past years about flight remote control and unmanned platforms for remote sensing [3, 4] even supporting joint decision from both human and computer in controlling the mobile platform [5]; nevertheless, very few projects have been fully developed up to a working prototype as regards advanced, non-legacy human-computer interfaces [6, 7].

Six research units take part to this project. Table I summarizes affiliations, leaderships, and main goals of each unit. The six following Sections describe contributions and results obtained from each unit.

II GROUND CONTROL STATION AND FLIGHT SIMULATOR

One of the main goal of the proposed project has been to realize a high portable ground control station that could be carried by a single operator. For this reason, devices used to control the mobile platform have to necessarily be small and light (for instance, notebooks, tablet PCs and handheld devices).

TABLE I RESEARCH UNITS AND MAIN GOALS

Unit	Leader	Main goals
#1: Dipartimento di Automatica e Informatica - Politecnico di Torino	Prof. Claudio Demartini (Project Leader)	Ground control station and rendering engine for a flight simulator
#2: Dipartimento di Meccanica - Politecnico di Torino	Prof. Giorgio Chiandussi	Structure definition to obtain highest bending and torsional stiffness combined to the lowest weight
#3: Dipartimento di Ingegneria Aeronautica e Spaziale - Politecnico di Torino	Prof. Fulvia Quagliotti	Platform design, mathematical modelling, and control algorithms for the autopilot
#4: Dipartimento di Informatica e Sistemistica - Università di Pavia	Prof. Giorgio Buttazzo	Design and implementation of the autopilot
#5: Dipartimento di Matematica - Università di Messina	Prof. Giancarlo Iannizzotto	A wearable computer for a mobile control station
#6: Dipartimento di Ingegneria Informatica e delle Telecomunicazioni - Università di Catania	Prof. Lucia Lo Bello	A real-time and reliable communication link for UAV telemetry

These devices have to allow the remote management of the platform in the same way as traditional control stations.

The ground control station has to allow to visualize, in real-time, all information needed for the mission control. Techniques to focalise human perception are necessary to allow the user an immediate identification of “critical and interesting situations”. Moreover, the traditional paradigm keyboard-mouse has been replaced by a set of vocal commands; in this way, the whole interface of the ground control station can be controlled without using the hands.

The mobile platform can be equipped by expensive sensors; for this reasons the piloting has to be performed, for security reasons but not only, by a trained staff. The training can be partially planned using a simulated environment able to reproduce realistic situations. The same devices used during a real mission have to be used also for the implementation of the simulator and the behaviour of the mobile platform has to be simulated as realistically as possible.

A. Ground Control Station

At the ground control station a high gain antenna is connected to a receiver able to manage up to eight channels. Channels are switched every three seconds, and the communication range is about three miles in line of sight. The receiver is directly connected to a PCMCIA card able to capture and display video streams coming from the platform. Four windows are presented: the video stream, a georeferenced map (showing the position

of the UAV over the territory), a 3D representation of the model (very useful to understand flight attitudes and for the remote piloting), and a set of navigation parameters (telemetry).

The user can interact with the ground control station by means of vocal commands. A speech recognition system, based on SAPI 5.1 [8], has been developed. This vocal interface allows the user to: perform the “classical operations” on a window, select an active application, move the mouse, simulate left/right/double click, simulate some keyboard functions.

B. Rendering Engine and Virtual Scenarios

A set of input devices (keyboard, joystick, data glove, and remote radio control) allows the user to pilot the UAV. The simulator can be considered as a system composed of two modules: the dynamic model of the aircraft and the rendering of a virtual scenario.

A set of input files is loaded at the beginning of a simulation session; these files describe both the geometry of the scenario and the aircraft configuration.

The rendering engine is entirely based on OpenGL [9], Glut [10], and PLIB [11] libraries and it is therefore platform independent. The scenario is implemented by altitude maps (real DEMs – Digital Elevation Maps – of Italy) organized in tiles. Tiles are dynamically loaded and rendered according the position and orientation of the aircraft. Buildings, trees, fires, and other 3D objects are inserted to allow the user to do more realistic and effective training sessions. PLIB and Glut allow to manage input devices, sounds, rendering levels of details, and more in general all the human-machine interface.

During the simulation session the user can choose among three different views: internal, external and from the ground control station. The internal view is aimed to represent the video stream the user should view on the ground control station monitor coming from an on-board camera. This “point of view” is necessary whenever the user has to pilot the aircraft not in line of sight or the UAV’s attitudes cannot be clearly visible. The external view is not directly related to a real piloting mode, but represents an important opportunity provided to the operator in order to train its skills in piloting the aerial platform and to experience its maneuver response; in this case the user can rotate around the aircraft in order to better understand the attitude variation.

A simple HUD (Head-Up Display) is also available. The HUD shows a set of information very useful to pilot the UAV (for instance, altitude, speed, climbing angle, and so on); in the event of a real mission it can be reconstructed in real time using the information received by the UAV. The third view reproduces the observation point from the ground control station. It is representative of the line-of-sight control mode and it allows to set the constraints of this mode of operation in terms of platform’s visibility, not to mention datalink range.

III STRUCTURE DEFINITION

Several airworthiness requirements have to be considered in the UAV design:

- an adequate endurance;
- a large mission range;
- an adequate maximum speed;
- an adequate service ceiling;
- a minimum payload.

A minimum payload is required in order to carry out several equipments like a camera in the visible field, an infrared camera and wind direction and intensity detection sensors. The structural weight of the UAV strongly influences the possibility to comply with the above cited requirements. A reduction of the structural weight of the vehicle leads to thinner and lighter structures, lower applied loads and larger payloads. It implies the requirement of less powerful propellers and leads, as a consequence, to a lower fuel consumption and a larger mission range. As a consequence, weight reduction represents a priority task in air vehicle design and, particularly, in Uninhabited Air Vehicle design.

Three design solutions have been analysed: 1) a truss-like structure (longerons and ribs) covered by a thermo-retractable elastomeric layer, 2) a composite closed thin-walled structure (fiberglass or carbon epoxy composite material) with internal ribs and a possible fulfilment of the wings and the fuselage with low density structural foams, 3) a low density polystyrene structure with several different solutions for the fuselage (fulfilled polystyrene fuselage, composite material fuselage).

The first structural solution is characterised by a very low weight but also by some difficulties in housing the scientific instrumentation on board and by the difficulty of the assembly process. This structural solution has not been taken into account for the present project.

The second structural solution is usually characterised by a very low ratio between structural weight and bending/torsional stiffness. The vehicle manufacturing requires the presence of a mould for the composite material layout. Due to the presence of a mould, a set of vehicles of the same shape can be easily manufactured. The structure can be reinforced internally with ribs or fulfilled with low density structural foams. Low density structural foams contribute to increase the local stiffness of the structure and to reduce the negative effects of a possible crush of the vehicle on the scientific instrumentation. Fiberglass and carbon-epoxy composite materials have been taken into account in order to manufacture the vehicle. Even if the maximum stresses are very small and the smallest thickness composite fiberglass layers available in the market have been taken into consideration, the total weight of the structure showed to be too large if compared to the requirements in terms of minimum admissible payload. A quasi acceptable weight could be obtained if carbon-epoxy laminates are taken into consideration. Due to these

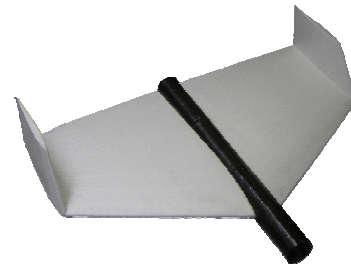


FIGURE 1 UAV with the carbon-epoxy fuselage and the low density polystyrene wings.

results, also the closed thin-walled structural solution has been neglected.

The third structural solution is based on the utilization of a low density polystyrene for the full vehicle manufacturing (solution A) or for the wing manufacturing only (solution B). The low density polystyrene (10 g/l – 45 g/l) is a material that can be easily found on the market and can be easily modelled. The manufacturing difficulties are intermediate with respect to previously considered design solutions. A sequence of vehicles with exactly the same shape can not be easily carried out. The lowest structural weight can be achieved with a vehicle fully made of polystyrene (solution A), about 400 g. Solution A represents an optimal solution from the weight minimization point of view but several difficulties arise when the housing of the functional and the scientific instrumentation is considered. These difficulties led to the analysis of a hybrid solution (solution B) characterised by a carbon-epoxy fuselage and low density polystyrene wings (figure 1). The total weight of the vehicle is slightly larger than obtained with solution A but the void fuselage allows for a quite easy housing of all functional and scientific instrumentation. The total weight of the vehicle is about 500 g. In order to guarantee a large bending/torsional stiffness of the vehicle and in order to minimize the structural weight of the joints between the fuselage and the wings, the fuselage has been manufactured with two external symmetric fins that slip into two corresponding inserts in the wings. The load transmission between the wings and the fuselage is guaranteed by the fins and the maximum stresses in the wings can be minimised. The analysis of the described design solutions has been performed by taking advantage of FEM codes starting from the CAD model. The design solutions have been evaluated by taking into consideration the static requirements (maximum stresses and required torsional/bending stiffness) and a few dynamic requirements (modal analysis).

IV DESIGN, MODELING AND CONTROL

The contribution of the Aerospace Department of Politecnico di Torino to the project can be identified in the following areas of interest: platform design, flight testing, mathematical modelling, flight simulation, control algorithms and control laws architecture.

A scaled version of the MicroHawk configuration named MH1000, characterized by 1m maximum dimension and a total weight of approximately 1.5 kg, has been developed to carry on-board sensors and cameras in order to provide the user real time information about the territory under monitoring. The platform's configuration, a tailless integrated wing-body, has been affected by the mission profile through mission range, operating altitude, environmental topology and atmospheric conditions. The flight envelope of the aerial platform ranges from 40 km/h to 72 km/h and it is characterized by an operating altitude from 5 m to 100 m. An average flight speed of about 55 km/h allows to achieve a flight endurance not less than 40 min.

The platform has been designed and tested in order to perform both remotely piloted flight and autonomous flight. Off-line simulation of the mission profile has been carried out to evaluate optimal trajectories, platform dynamic response and to define the controller architecture.

A mathematical model of the overall system has been developed at the Aerospace Engineering Department of Politecnico di Torino and it has been implemented for several design issues. The mathematical formulation of the platform dynamics represents the core of the flight simulation tool for the virtual ground control station and the control algorithms definition. The aerial platform is described by a full six degrees-of-freedom nonlinear mathematical model, consisting of twelve, coupled, nonlinear, ordinary differential equations. As the main aim of the flight simulation application are trajectory analysis and the overall flight performance evaluation, structural flexibility is neglected so that the rigid body assumption is made. This assumption makes further sense because we are dealing with a Mini-UAV characterized by small dimensions and weight. The flat and non-rotating Earth assumption is also used since it does not affect model accuracy of low speed flight over a small region of the Earth. Finally, the aerodynamic loads acting on the aerial platform are obtained utilizing an aerodynamic model, based on experimental wind tunnel testing and numerical computations. The mathematical formulation includes the modelling of the propulsive system, consisting of a DC motor - propeller group, the actuator system. A simple model of the atmospheric turbulence, considering both stochastic gusts and steady winds, is included. The equations governing the aircraft dynamics and the propulsive system are implemented within the flight simulation tool providing the virtual ground control station. Model fidelity and running time have been the main guidelines in outlining the architecture of the mathematical representation of the aerial platform. The atmospheric turbulence, including gusts and/or steady winds, has been modelled in order to enhance flight simulation fidelity allowing to evaluate the vehicle performance and maneuver response dynamics also when ideally calm air conditions are not verified.

The main control commands are represented by the stick input and the throttle input. The former one is directly related to the control surfaces deflection, that, according to the present aerial platform, are the aileron and elevator for longitudinal and lateral-directional control, respectively. The control commands, quite apart from the ground operator interface (RC transmitter, joystick, data glove), are provided to the mathematical model as angular deflection of control surfaces and percentage of maximum regime of rotation of the propulsive system. A second order actuator dynamics is taken into account within the model.

Differently from conventional piloted aircraft, MiniUAVs are affected by highly nonlinear system behavior and unconventional dynamics. Due to the unconventional dynamics and due to its sensitivity to geometric, inertial and aerodynamic characteristics, control system design for MiniUAVs represents a challenging task whenever stability and performance requirements related to aircraft flying qualities have to be fulfilled. The robustness characteristics of the designed controller play a key role in granting adequate level of tolerance to plant uncertainties, environmental changes and flight condition variations within the planned mission profile. A gain synthesis methodology based on randomized algorithms has been applied to the design of the flight control system. The developed methodology is based on a three-step approach, including gain synthesis, stability robustness and performance robustness analysis. These steps of the methodology are strongly dependent by each other and strictly related to the operating flight conditions and to the flying qualities standards. The autopilot system includes guidance, navigation and loop stabilization. The results of the control algorithms methodology are implemented to perform feedback loops concerning trajectory tracking and platform stabilization issues. Guidance laws and stabilization loops are defined both for longitudinal and lateral-directional plane dynamics assessment. Different configurations of the feedback loops can be set as active, depending on the operating flight condition and the current mission profile.

The overall system performances have been evaluated and optimised by an extensive flight testing activity, concerning both the bare aerial platform and the integrated system. Several tests have been aimed to the flight performance assessment and to the analysis of compliance to the project requirements concerning mission profile. The first set of flight tests allowed to define the on-board systems configuration and to evaluate the relationships between flight performance (flight duration, mission range) and configuration setup (maximum take-off weight). To this aim several prototypes of the MH1000 configuration, characterized by different structural weight and on-board systems allocation, have been tested. The second set of on-the-field activities has been carried out in order to test the integrated system, consisting of the aerial platform, the

communication system, the flight control system and the on-board payload. Extensive flight testing has been carried out to assess the autopilot system and to grant autonomous flight capabilities.

V THE AUTOPILOT

The autopilot has been developed at the Robotic Laboratory of the University of Pavia using a custom embedded platform. The design has been carried out taking several constraints into account, coming from the application characteristics, such as light weight, small size, low energy consumption, small memory usage, and sufficient computational power for performing navigation and sensory processing in real-time. Such constraints were satisfied using a Microchip dsPIC 30F6014 microcontroller, which is small enough to be mounted on a 10x12 cm board and powerful enough to handle complex real-time control activities.

The onboard processing unit is a 16-bit microprocessor where most of the 24-bit wide instructions are executed in 1 cycle up to 30 MIPS and it seamlessly integrates the control attributes of a microcontroller (MCU) with the computation and throughput capabilities of a Digital Signal Processor (DSP). The model selected for prototyping includes a program memory space of 144 Kbytes, a data memory space of 8 Kbytes, and a non-volatile data EEPROM of 4 Kbytes. In terms of peripherals the chip supplies Capture/compare/PWM functionality, 12-bits Analog-to-Digital Converters (A/D) with 100 Kbps conversion rate and up to 16 input channels. Connectivity is provided through a full range of channels: I2C, SPI, CANbus, USART and Data Converter Interface (DCI), which supports common audio Codec protocols as I2S and AC'97.

A. Application

The microcontroller performs the following main tasks: sensors analysis in order to determinate the status of the aircraft (position, altitude, velocity, etc.), sensory acquisition for mission-related purposes, computation of the control algorithm, communication with the base station, and data logging for off-line analysis of the system behaviour. To obtain the status of the system the following sensors are acquired by the MCU: accelerometers, gyroscopes, GPS, inclinometers, and pressure sensors. These sensors have different sampling rates. Accelerometers and gyroscopes are acquired with a frequency of 80Hz and integrated to obtain velocity, position and altitude. Since these sensors presents problems related with noises and drifts, GPS and inclinometers are used, together with a Kalman filter, to bound the errors. Pressure sensors are used to compute the altitude and the velocity along the motion direction.

B. Real Time Kernel

To predictably manage concurrent activities with periodic and aperiodic activations and explicit timing constraints, the application is implemented on the Erika real-time kernel [17]. Erika is an advanced real-time operating system available on the market that has been specifically designed for minimal embedded systems with limited onboard resources. It is fully configurable both in terms of services and kernel objects (tasks, resources, and events) from a minimal memory footprint of 2 Kbytes, up to more complete configurations. It is available for a wide variety of 8, 16, and 32 bit CPUs and supports advanced scheduling mechanisms, such as Rate Monotonic, Earliest Deadline First [18], aperiodic servers, and resource reservations [19].

C. Data Logging

An important feature to have in an autopilot used for research purposes is a data logging capability, since it allows performing off-line analysis on the system behaviour. To better obtain this goal, our data logger is configurable by the user through a set of parameters, used to decide, for example, the frequency of the saved data or the subset of sensory information to be logged. To simplify the log analysis, all data are saved on a MMC card, which can be quickly replaced between two consecutive missions. Data related to each fly are saved in a different file in order to maintain all the logging of a single session within the same memory card.

D. Power management

An interesting feature of the used microcontroller is that it can operate at different supply voltages and clock rates (from 512Hz to 40MHz), each one characterized by a given power consumption. A method is also provided to disable a peripheral module by stopping all clock sources supplied to that module. When a peripheral is disabled with this method, it is in the minimum power consumption state. This feature allows us to apply dynamic voltage scaling techniques [20] and energy-aware strategies [21, 22, 23] to balance performance vs. power consumption.

The approach used to minimizing energy consumption while guaranteeing real-time constraints has been considered on a realistic CPU model, which takes in account discrete processor speed, overhead during voltage switching, task execution time not linear with frequency, and tasks with different power consumption. To guarantee timing constraints, the algorithm performs the analysis assuming that each task executes for its worst case execution times (WCET). This is usually a strong conservative hypothesis which may cause a waste of computational resources. To exploit the additional slack coming from early completions we mix an off-line approach based on WCETs with an on-line method, which is in charge of reclaiming the unused computation time for a further reduction of the CPU frequency [24].

Effective power management also requires a proper support from the operating system, which must allow the application to dynamically configure the onboard resources to save energy consumption while guaranteeing the required real-time and performance constraints. Our algorithm proposes a system-wide approach to energy management applied to all the architecture levels and integrated with the scheduling algorithm to guarantee real-time constraints [23].

Reducing energy consumption at the system level is possible because most peripheral devices support various operating modes and the MCU has the capability of putting each device in a sleep state. A problem is that some peripherals trash the current job when switched in low-consumption states. For example the A/D converter loses the ongoing acquisition and the UART does not listen to incoming data. To reduce the power consumption without affecting the behaviour of tasks, the system-level coordination is obtained with a kernel structure that coordinates all requests from user and system. The resulting interface is easy to use because it includes a small number of primitives and provides the same abstraction for each device.

VI A WEARABLE COMPUTER

Modern wearable computer designs package workstation level performance in systems small enough to be worn as clothing. These machines enable technology to be brought where it is needed: everyday mobile environments. A wearable computer [25] is a small portable computer that is designed to be worn on the body during use. It should be worn like a piece of clothing, as unobtrusive as possible and an user should interact with the computer based upon context. Wearable computers are especially useful for applications that require computational support while the user's hands, voice, eyes or attention are actively engaged with the physical environment [26]. Such applications include presentation of information to mechanics [27], military [28] or paramilitary personnel [29], pathfinding for the blind [30], real-time translation from one spoken language to another, and continuous medical monitoring. Because of this focus on minimal impact, the largest differences between wearable and other mobile computing platforms are the human-computer interface [31]. Depending on the application, the primary input to a wearable might be a chording keyboard, gesture, speech recognition or even just passive sensors (context awareness). Output might be presented via speech, audio tones, a head-mounted display or haptic output. Output can also be combined with the physical world through a visual or audio augmented reality interface. Most wearable computers today derive their interfaces from concepts in desktop computing such as keyboards, pointing devices and graphical user interfaces. If wearable computers are expected to become as natural as clothing, we must re-examine the interface with different

standards of usability. In our work we consider the role of audio and video in the interface of wearable computers. Our system employs a mixture of audio and video to "display" information. Audio and video are used as primary communication media of the interface. The wearable ground control station is composed of two main components:

- Pocket PC iPAQ hx4700: the computational unit that we use to manage the physical user-interface (microphone, earphone, HMD, etc.);
- Acme Systems Fox board: a "ready-to-run" Embedded Linux System that we use as acquisition system of the signals transmitted by the platform (vehicle). The signals received by the Fox board are:
 - two video signals (transmitted by colour and infrared cameras);
 - position, orientation, linear and angular velocity (of the vehicle);
 - static and dynamic pressures;
 - linear acceleration;
 - power supply level and temperature.

An independent BSS (ad hoc) wifi communication is used to transfer video and the other signals from Fox board to iPAQ. The signals received are visualized by the iPAQ in a customized way. To present the information to the user we have used customized widgets and three windows: colour video window, IR video window and others variables window. The user can interact with the system by vocal commands and receives warning messages about the sensors data received through a speech-based interface. If the primary input to the wearable is the speech, the primary output (video) is presented via a head-mounted display. We use the HMD Icuiti M920 CF, one of the smallest and lightest head-worn displays in the world. The vocal signal is recognized by a basic speech recognition system that allows a user to interact with the system by using spoken commands. The recognized command is passed to the main application which, after processing the query, produces the appropriate response. This response is delivered to the user through a speech synthesizer and/or the visual interface. Volume and speed of movement of the audio streams will signify the content type, level of urgency and associative characteristics of the information presented.

VII COMMUNICATION ARCHITECTURE

The activity of the Unit at the University of Catania focused on the communication architecture (including the UAV-antenna project). This is a critical task, as providing a reliable real-time communications link between the UAV and the ground station is crucial for the success of the system. As it was mentioned in the Introduction, the mobile platform has to feature the ability to react to commands and/or external events from the environment within given time constraints. Unpredictable response times could in fact degrade the

performance or cause stability problems, thus severely impairing the proper operation of the whole system. For this reason, the temporal performance achievable over the wireless communication link used to connect the UAV to the ground station was investigated. A timing analysis which assesses the components of a message response time has been performed and then mapped on the particular case of the wireless technology adopted in the project. While choosing the communication technology to be adopted, a number of aspects, depending on the environment in which the UAV has to operate, were taken into account. For example, flying at a certain height above the ground may be an advantage as regards propagation of the wireless signal (as a UAV can fly over obstacles and thus be reached by the radio signal) [32]. However, the high speed of the UAV can interfere with the communication and may cause it to suddenly leave the area covered by the transmitters used for the connection, and thus isolate it from the ground station [33]. In addition, operating in non-built-up areas may make it impossible to use communication systems based on fixed infrastructures (such as GPRS or GSM). To find a proper communication system to connect the UAV and the ground station, it was therefore necessary to conduct a thorough investigation and evaluate the impact of the various possible approaches and their feasibility in the context being considered [6]. It was also investigated the integration of more than one communication system, with different characteristics, to be used to provide a communication back-up. The choice of the wireless protocol was also strictly related to other research issues in the project, such as the requirements imposed by the execution of real-time processes performing data acquiring and control, and the autopilot used by the UAV as a back-up solution when remote control from the ground station is not possible. After examining the pros and cons of the different eligible solutions, it was decided to adopt a communication link provided by radio modems [6] to connect the UAV to the ground station. One communication link consists of two radio units, one mounted on the UAV and the other on the ground station. There is also include a 802.11 link between the ground station and a coordination station, which is the final collector of the acquired and processed data. To address the need for real-time support in the communication link between the coordination station and the ground station, a wireless traffic smoother, which extends the work in [34], was also developed, which proved to be able to provide real-time traffic with the required level of QoS.

A. Antenna requirements

To determine the optimal UAV antenna characteristics for an optimal coverage., we assumed a fixed base-station radio-modem sensitivity (i.e the receiver minimum input requirements for the required BER) and a “matched” antenna- receiver pair.

With the above assumptions the minimum required available power is fixed and we are able to address the antenna link in terms of available power. Given a transmitting UAV antenna-1 and a receiving base station antenna-2, the available power at the antenna-2 terminals is given by:

$$P_{d2} = t G_1 G_2 \left(\frac{I}{4\pi r} \right)^2 P_{r1} \quad (1)$$

where t is a polarization matching factor (for power), G_1 and G_2 are the gain of the transmitting and receiving antennas, respectively, λ is the wavelength, r is the distance and P_{r1} is the antenna-1 radiated power.

In order to choose the optimal antenna to maximize available power we had to consider the single terms of equation (1).

- One option was acting on the transmitted power P_{r1} , but this aspect does not directly regards the antenna.
- Another possibility was choosing “long” wavelength to reduce the so-called “free space path loss”, at the expenses of a bigger antenna. In our case several consideration including the final antenna size, the “free space path loss”, as well as bandwidth and unlicensed band approved in Europe made us to choose the 868 MHz ISM band corresponding to a free space wavelength of ~ 345 mm.
- We could not use high gain antennas since an antenna with greater gain simply focuses the energy of the signal in certain direction and a high directivity would, therefore, require an accurate antenna alignment (and this is not possible for the UAV antenna).
- The last term to be examined was the polarization matching factor t , $0 = t = 1$. Polarization matching requires aligned antennas (this is again not possible with non-fixed antenna). unless circular polarization is used for both transmitting and receiving antennas (in this case $t = 1$ regardless the antenna orientation).

From the above considerations we concluded that in order to avoid the need of antenna alignment (for both directivity and polarization matching) a nearly omni directional circularly polarized antenna was to be used.

The UAV can easily accommodate relatively large antenna on the wings therefore two crossed $\lambda/2$ dipole have been proposed to achieve circular polarization. This antenna configuration has a radiation pattern nearly omnidirectional with maxima orthogonal to the plane of the crossed dipoles the polarization is perfectly circular only in directions of the maxima and is linear in the plane of the dipoles. Dipoles were used instead of monopole since no natural ground planes were available on the UAV. The dipole is printed on FR4 substrate. The use of circularly polarized antennas avoids the large loss that would occur if the transmitting and receiving antennas were cross-polarized.

VIII CONCLUSION

The proposed project present a flying platform

equipped by an autopilot, two cameras (a micro colour camera and an thermal IR camera), and other sensors. Two kinds of ground control station have been proposed: the first one uses a notebook and by means of a set of vocal commands allows the operator of managing the whole interface, the second one adopts a wearable computer in order to allow the operator a full mobility over the territory. The platform is able to perform autonomous missions as well as tasks where remote piloting is needed. A reliable communication link is used to send the ground control station both navigation and telemetry data.

ACKNOWLEDGMENT

This project is supported by the Italian Ministry for Instruction, University, and Research (MIUR) within the frame of the project PRIN 2004 (Project Number. 2004095094). The aerial platform is based on the MicroHawk configuration, developed at the Aerospace Engineering Dept. of Politecnico di Torino (national patent no. TO2003A000702, holder Politecnico di Torino, international request PCT/IB2004/002940).

Moreover, project team wish to thank The Ufficio Provinciale di Protezione Civile and l'Assessorato Agricoltura e Foreste della provincia di Enna that have supported the project as end users.

REFERENCES

- [1] J.R. Wilson, "UAVs and the Human Factor," Aerospace America, 2002
- [2] P.Von Blyenburg, "UAVs—Current Situation and Considerations for the Way Forward," RTO-AVT Course on Development and Operation of UAVs for Military and Civil Applications, 1999
- [3] H.L. Jones, E.W. Frew, B.R. Woodley, S.M., "Rock: Human-Robot Interaction for Field Operation of an Autonomous Helicopter," Mobile Robots XIII and Intelligent Transportation Systems, 1998
- [4] T. Fong, C. Thorpe, and C. Baur, "Robot as Partner: Vehicle Teleoperation with Collaborative Control," Workshop on Multi-Robot Systems, Naval Research Laboratory, 2002
- [5] D.J. Bruemmer, Julie L. Marble, Donald D. Dudenhoefter, M.O. Anderson, M.D. McKay, "Mixed-Initiative Control for Remote Characterization of Hazardous Environments," HICSS 2003.
- [6] T. Fong, and C. Thorpe, "Vehicle Teleoperation Interfaces," Autonomous Robots, vol. 11(1), Kluwer, 2001
- [7] K.S. Tso, G.K. Tharp, A.T. Tai, M. H. Draper, G. L. Calhoun, and H.A. Ruff, "A human factors testbed for command and control of unmanned air vehicles," in Proceedings of the 22nd Digital Avionics Systems Conference, 2003
- [8] SAPI web site: www.microsoft.com/speech/default.msp
- [9] OpenGL Architecture Review Board, D. Shreiner, M. Woo, J. Neider, T. Davis, "OpenGL Programming Guide: The Official Guide to Learning OpenGL," Version 1.4, Fourth Edition, Addison Wesley, 2003.
- [10] Glut: the OpenGL Utility Toolkit, web site <http://www.opengl.org/resources/libraries/glut.html>
- [11] PLIB: a portable game library, web site: <http://plib.sourceforge.net/>
- [12] B. L. Stevens, F. L. Lewis, "Aircraft Control and Simulation," Second Edition, John Wiley & Sons, 2003.
- [13] A. Sanna, B. Pralio, "An Innovative Tool for Simulating and Controlling Mini Air Vehicles," WSEAS Transaction on Information Science and Applications, Vol. 2, No. 10, pp. 1659-1666, 2005, ISSN: 1790-0832.
- [14] B. Pralio, L. Loreface, "A Random Search Algorithm for Robust Control Design of MiniUAVs," WSEAS Transactions on Systems, Vol. 5, No. 1, pp. 256-263, 2006, ISSN: 1109-2777.
- [15] R. Tempo, G. Calafiore and F. Dabbene, "Randomized Algorithms for Analysis and Control of Uncertain Systems", Springer-Verlag, London, 2005.
- [16] Q. Wang and R.F. Stengel, "Robust Nonlinear Flight Control of a High Performance Aircraft", IEEE Transactions on Control Systems Technology, Vol. 13, pp. 15-26, 2005.
- [17] Erica web site: <http://www.evidence.eu.com/Erika.asp>
- [18] C.L. Liu and J.W. Layland, "Scheduling Algorithms for Multiprogramming in a Hard real-Time Environment," Journal of the ACM, 20(1), pp. 40-61, 1973.
- [19] G. Buttazzo, "Hard Real-Time Computing Systems: Predictable Scheduling Algorithms and Applications," Second Edition, Springer, 2005.
- [20] P. Pillai and K. Shin, "Real-Time Dynamic Voltage Scaling for Low-Power Embedded Operating Systems," Proc. of the 18th ACM Symposium on Operating System Principles, October 21-24, 2001, Alberta, Canada. Operating System Review, 35(5), ACM, 2001.
- [21] H. Aydin, R. Melhem, D. Mossé, and P. Mejia-Alvarez, "Power-Aware Scheduling for Periodic Real-Time Tasks," IEEE Transactions on Computers, 53(5), pp. 584-600, 2004.
- [22] E. Bini, G. Buttazzo, and G. Lipari, "Speed Modulation in Energy-Aware Real-Time Systems", IEEE Proc. of the Euromicro Conference on Real-Time Systems, Palma de Mallorca, Spain, July 2005.
- [23] M. Marinoni, G. Buttazzo, T. Facchinetti, and G. Franchino, "Kernel Support for Energy Management in Wireless Mobile Ad-Hoc Networks," Proc. of the Workshop on Operating Systems Platforms for Embedded Real-Time applications (OSPERT 2005), Palma de Mallorca, Spain, July 5, 2005.
- [24] M. Marinoni and G. Buttazzo, "Adaptive DVS Management through Elastic Scheduling," Proc. of the 10th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2005), Catania, Italy, September 2005.
- [25] E. O. Thorp, "The invention of the first wearable computer," The Second International Symposium on Wearable Computers: Digest of Papers, IEEE Computer Society, pp. 4-8, 1998.
- [26] M. Miyamae, T. Terada, M. Tsukamoto, K. Hiraoka, T. Fukuda, S. Nishio, "An Event-driven Wearable System for Supporting Motorbike Races," Eighth IEEE International Symposium on Wearable Computers, Arlington, VA, 2004.
- [27] G. Kaefer, G. Prochart, R. Weiss, "Wearable Alertness Monitoring for Industrial Applications," 7th IEEE International Symposium on Wearable Computers, White Plains, NY (US), 2003.
- [28] M.J. Zieniewicz, D.C. Johnson, C. Wong, J.D. Flatt, "The evolution of Army wearable computers," Pervasive Computing, IEEE Volume 1, Issue 4, pp:30 - 40, 2002.
- [29] D.J. Haniff, C. Baber, "Wearable computers for the fire service and police force: technological and human factors," The Third International Symposium on Wearable Computers, 1999.
- [30] C. Costanzo, G. Iannizzotto, P. Lanzafame, F. La Rosa, "Badge3D for Visually Impaired," 1st IEEE Workshop on Computer Vision Applications for the Visually Impaired (CVPR05). San Diego, CA, 2005.
- [31] Herman, Jeffery Allen, "NewsTalk: A Speech Interface to a Personalized Information Agent," M.S. Thesis, MIT Media Lab, 1995.
- [32] M. J. Feuerstein, K. L. Blackard, T. S. Rappaport, S. Y. Seidel, and H. H. Xia. Path loss, delay spread, and outage models as functions of antenna height for microcellular system design. IEEE Trans. On Vehicular Technology, 43(3):487-498, Aug 1994.
- [33] C. Hoene, A. Gunther, and A. Wolisz. Measuring the impact of slow user motion on packet loss and delay over IEEE 802.11b wireless links. In Proc. of the 28th Annual IEEE International Conference on Local Computer Networks (LCN'03), pp. 652-662, Oct 2003.
- [34] L. Lo Bello, G. Kaczynski, O. Mirabella, "Improving the Real-Time Behaviour of Ethernet Networks Using Traffic Smoothing", IEEE Trans. on Industrial Informatics, vol.1(3), pp. 151-161, 2005