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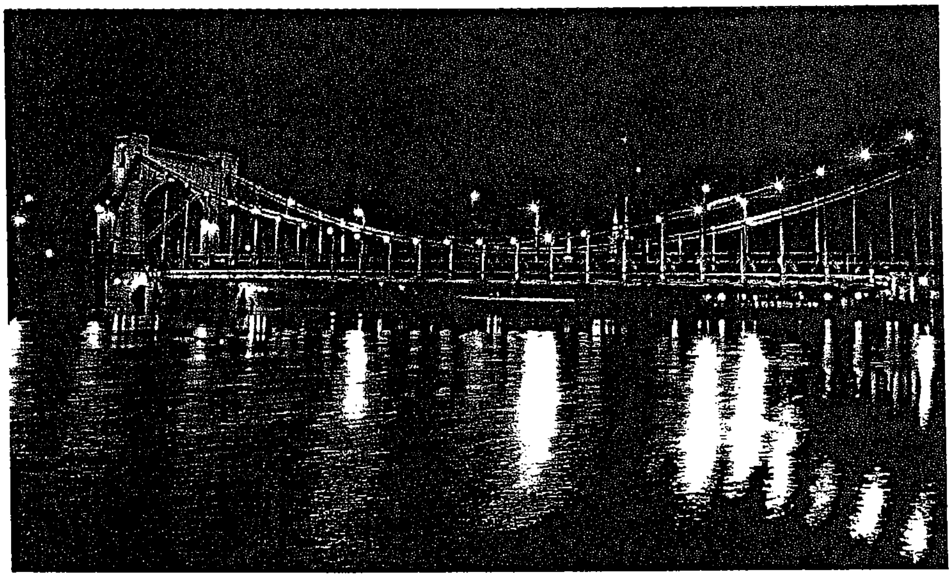
SYROCO'03

SEPTEMBER 1-3, 2003
WROCŁAW - POLAND



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CONTROL AND PERCEPTION TECHNIQUES FOR AERIAL ROBOTICS

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Abstract: This paper review methods and technologies that have been applied in Aerial Robotics. The paper presents several Unmanned Aerial Vehicle platforms. Then summarizes different control techniques including both control architectures and control methods. Furthermore, computer vision techniques for aerial robotics are shortly considerd. Finally the paper presents systems and projects involving multiple autonomous aerial and ground systems, including a short presentation of the COMETS European project devoted to the coordination of multiple unmanned aerial vehicles.

Keywords: Aerial vehicles, autonomous mobile robots, autonomous vehicles, helicopter control, computer vision, multi-robot systems.

1. INTRODUCTION

In the last decades many autonomous and teleoperated vehicles for Field Robotics applications have been developed, including wheeled, tracked and legged vehicles. However, in many cases, ground vehicles have significant inherent limitations to access to the desired locations due to the characteristics of the terrain and the presence of obstacles that cannot be avoided. In these cases aerial vehicles is the natural way to approach the objective to get information or even to perform some actions such as the deployment of instrumentation. Then, aerial robotics seems a useful approach to perform tasks such as data and image acquisition of targets and affected areas, localization of targets, tracking, map building and others.

Unmanned Aerial Vehicles (UAV) have been used for military applications but also are useful for many civilian applications such as terrain and utilities inspection, disaster monitoring, environmental surveillance, search and rescue, law enforcement, aerial mapping, traffic surveillance, and cinematography. In the last years UAVs improved their autonomy both in energy and information processing. However, the development of autonomous aerial robotic vehicles involves many problems related to limited payload, safety requirements, flight endurance and others.

This paper review some significant development in aerial robotics. In the next section different UAV platforms are reviewed. Then, the involved control techniques and the environment perception are considered. Finally multirobot systems are considered including a short presentation of the COMETS project on multiple heterogeneous aerial vehicles.

2. UAV PLATFORMS

Unmanned air vehicles (UAVs) are self propelled air vehicles that are either remotely controlled or are capable of conducting autonomous operations after being launched. UAV experimental research ranges from low level flight control algorithm design to high level multiple aircraft coordination.

During the last decades significant efforts have been devoted to increase the flight endurance and payload of UAVs. Thus, there are High Altitude Long Endurance (HALE) UAVs, as for example the Northrop Grumman Ryan's Global Hawks (65000 ft altitude, 35 hours flight and 1900 lbs. payload) and Medium Altitude Long Endurance (MALE) UAVs, as for example the General Atomics' Predator (see Figure 1, with 27000 ft altitude, 30/40 hours flight and 450 lbs payload), and the Tactical UAVs such as the Pioneer with 15000 ft altitude, 5-6 hours flight and 25 Kg. payload. In the last years man portable or hand launched UAVs, called "Organics UAV", such as Pointer (AeroVironment), Javelin (BAI) or Black Pack mini (Mission's Technologies) have been presented.

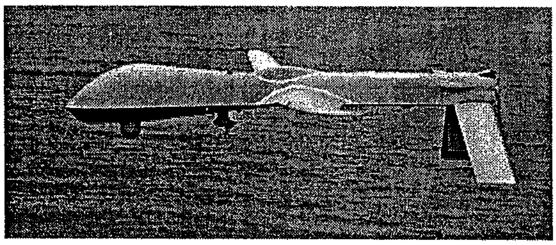

Fig. 1. The Predator from General Atomics.

Furthermore, many different Vertical Take-Off and Landing UAVs including helicopters and several new designs such as the Guardian from Bombardier, and the Sikorksy's Cypher or Dragon Warrior (see Fig. 2).

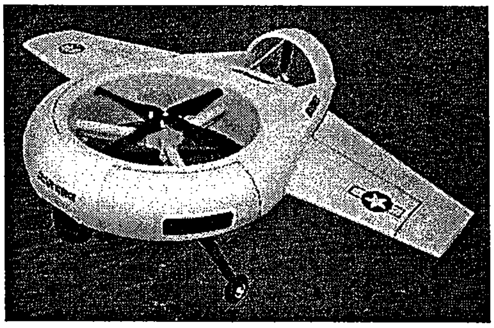

Fig. 2. The Sikorsky's Dragon Warrior (Cypher2).

On the other hand, in the last years, Micro Air Vehicles, with dimensions lower than 15 cm, have gained a lot of attention. These include the Black Widow manufactured by AeroVironment (see Fig. 3), the MicroStar from BAE and many new designs and concepts presented in several Universities such as Entomopter (Georgia Institute of Technology), Micro Bat (California Institute of Technology), MFI (Berkeley University), as well as other designs in European Research Centres.
In the Unmanned Aerial Vehicles Roadmap (2001) a survey of platforms and UAV technologies mainly for military applications is presented.

In many aerial robotic projects, adaptation of conventional remote controlled model aircrafts with modest flight endurance, altitude and payload are used. Some of these platforms are the same than used for entertainment and applications such as aerial photography, cinematography, chemical spraying, inspection and other tasks in which the vehicles are maintained in the line of sight of the human pilot. In some cases the evolution of the conventional platforms leaded to new vehicles with increased flight endurance and payload such as the Yamaha R50 and Rmax. Thus, the Rmax is able to fly for one hour carrying a 24-kilogram payload

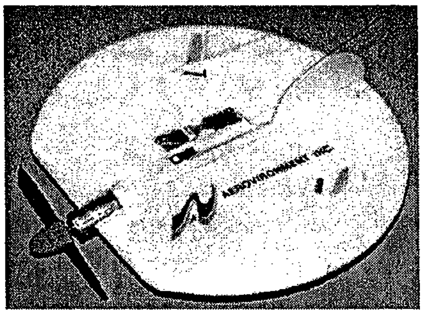

Fig. 3. Black widow (AeroVironment).

Aerial robotics has mainly involved helicopters and other VTOL designs, airships and fixed wing small UAVs. The main advantage of helicopters and other VTOL platforms is the manoeuvrability, which is needed for many robotic applications. The ability to maintain the aerial vehicle in hovering is very important in many tasks. However, they are difficult to control and require experienced safety pilots for their development and application. Moreover, fully autonomous control of helicopters is a difficult task that requires the application of reliable control laws.

Several Universities in the USA have developed autonomous helicopters. Thus, the Robotics Institute at Carnegie Mellon University (CMU) conducted since the early nineties an autonomous helicopter project. They have developed different prototypes from small electrical radio controlled vehicles to autonomous helicopters using the Yamaha R50 platform. The autonomous CMU helicopter won the AUVSI aerial robotic competition in 1997.

The University of Southern California (USC) conducted, since 1991, an autonomous helicopter project developing several prototypes, such as the AVATAR (Autonomous Vehicle Aerial Tracking and Retrieval/ Reconnaissance) prototypes presented in 1994 and 1997. The AVATAR helicopter won the AUVSI Aerial Robotics competition in 1994.

The University of Berkeley also developed autonomous helicopters in the Berkeley AeRobot project, BEAR, in which the autonomous aerial robot is a testbed for an integrated approach to intelligent systems.

The Georgia Institute of Technlogy (GIT) has the Unmanned Aerial Vehicle Research facility and developed several platforms and aerial autonomous systems during the last decade. GIT also won the AUVSI aerial robotics competition.

In Europe the University of Linköping is conducting the WITAS project which is a long term basic research project involving cooperation with different

Departments, other Universities and private companies (Doherty, 2000). The Yamaha Rmax helicopter is currently being used in the project (see Fig. 4). Moreover, several Universities such as the Technical University of Berlin, ETH Zurich (Eck and others, 2001), Universidad Politécnica de Madrid (Del Cerro and others, 2002) and the Universidad de Sevilla are using the adaptation of conventional radio controlled helicopters with different autonomous capabilities.

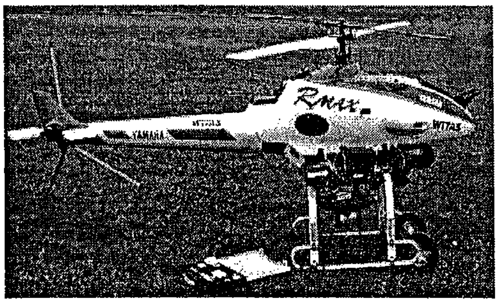

Fig. 4: Yamaha Rmax platform used in the WITAS project.

Fig. 5 shows MARVIN developed by the Technical University of Berlin (Remuss and others, 2002), which won the AUVSI Aerial Robotics Competition in 2000, and Fig. 6 the helicopter being developed jointly by the University of Seville and Helivision.

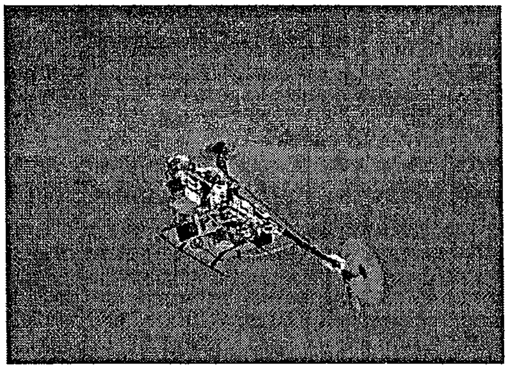

Fig. 5. The Marvin autonomous helicopter flying in experiments of the COMETS project (May 2003).

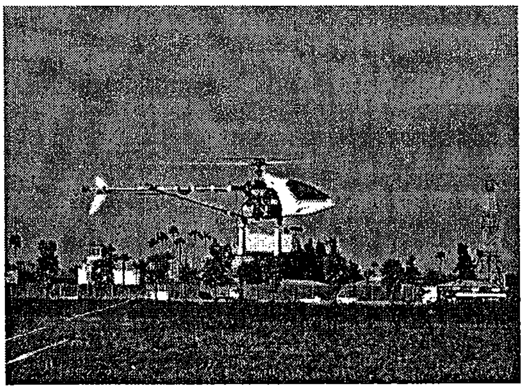

Fig. 6. University of Seville-Helivision helicopter flying in experiments of the COMETS project (May 2003).

Airships are stable platforms to take images and in case of failure present a graceful degradation which is not the case of other platforms such as helicopters. Furthermore, the control is easier than helicopters and can be piloted without important training. However, they have significant manoeuvrability constraints, they are larger and the deployment is more difficult. Moreover, they can only flight when the wind velocity is low. Airship platforms are also used in aerial robotics projects, such as Karma (see Fig. 7) at LAAS (CNRS, France), AURORA (Autonomous Unmanned Remote Monitoring Robotic Airship) at CENPRA (Brazil) (Bueno and others, 2002), and the airship of the University of Stuttgart (Wimmer and others, 2002).

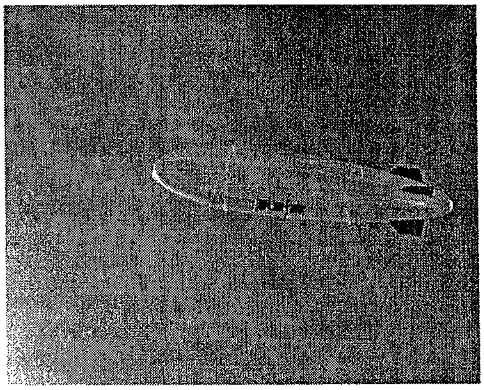

Fig. 7. Karma, developed at LAAS-CNRS, flying in experiments of the COMETS project (May 2003).

Conventional fixed wing airplanes also have manoeuvrability constraints. The lack of hovering capabilities imposes significant limitations for their application in aerial robotics. However, the reach and flight endurance can be larger than helicopters and other VTOL designs. Furthermore, both manual control and autonomous control are simpler. Then, many autonomous airplanes have been designed, mainly for reconnaissance, surveillance, environment monitoring and others. Some of these platforms are also used in aerial robotics projects involving localisation and mapping functions such as the delta wing unmanned aerial vehicle Brumby at the University of Sydney, which has been designed to fly in excess of 100 knots and currently has an endurance of 1/2 to 1 hour flight time. The aircraft has the capacity to carry up to six kilograms payload when remotely piloted, or four kilograms when operated autonomously.

3. UAV CONTROL

Control architectures.

On board control architectures for UAV have to integrate a variety of sensor information (GPS, 3-axis rate gyro, 3-axis accelerometer, aircraft attitude reference sensor, compass, altitude sensors among others), and low level motion servo-controllers, to control the vehicle typically in different control modes. Eventually, environment perception, object tracking, and local reactive (obstacle avoidance) and planning capabilities are considered. However, in existing aerial robotic prototypes these capabilities are modest when comparing to ground robots. In fact, the on-board hardware is seriously constrained by the load and energy consumption. On-board UAV control hardware is an ideal application for new embedded control systems involving DSPs and new powerful microcontrollers. However, other hardware platforms such as the PC-104 computer system with real-time OS are also applied to simplify the development.

The on-board control hardware is linked to an operator ground controller which is used to send commands and GPS corrections to the on-board controller and to visualize information transmitted from the UAV. In many projects these controllers are now implemented by means of laptops.

Several commercial autopilots for remotely piloted airplanes that are able to follow way points are in the market. Typically GPS techniques are applied for position estimation and the reliability and accuracy depend on the GPS technology applied.

However, the autonomous control of helicopters and other VTOL platforms with different control modes is more complex and motivated the research activities of several Universities.

In the following this section concentrates in autonomous helicopter control. The position and orientation of an helicopter is usually controlled by means of 4 control inputs: the main rotor thrust (collective input) which has a direct effect on the helicopter height (altitude control), the tail rotor which controls the heading of the helicopter (yaw motion) and compensates the anti-torque generated by the main rotor, the longitudinal cyclic which modifies the helicopter pitch angle and the longitudinal translation, and the lateral cyclic, which affects the helicopter roll angle and the lateral translation (lateral cyclic). Then, it is multivariable non-linear underactuated system with strong coupling in some control loops.

The University of Southern California (USC) developed a behaviour-based architecture for the control of the AVATAR helicopter (Fagg and others, 1993). The low-level behaviors correspond to the generation of the four input commands of the helicopter (collective throttle, tail rotor, longitudinal and lateral cyclic). The second level implements short-term goal behaviors: transition to altitude and lateral velocity. The highest-level behavior, navigation control, is responsible for long-term goals such as moving to a particular position and heading.

Intelligent control architectures for unmanned air vehicles (helicopters) are also researched at Berkeley. The hierarchical architecture segments the control tasks into different layer of abstraction in which planning, interaction with the environment and control activities, including switching between control modes, are involved. Thus, both continuous and discrete event systems are considered. In order to model these control systems hybrid system theory has been proposed (see for example Koo and others, 1998a).

GTI also developed autonomous helicopter control systems and research in flight controls, avionics and software systems.

Learning and pilot knowledge-based control methods.

As far as the research in control methods is concerned different approaches can be used. Thus, fuzzy logic has been applied to control the Yamaha's helicopter at the Tokyo Institute of Technology, which demonstrated autonomous capabilities and also person-machine interfaces including voice command (Sugeno and others, 1993).

Fuzzy logic with rules generated by the observation of a human pilot and consultation with helicopter experts is the approach used in Calvacante and others (1995).

In Montgomery and others (1995) the behaviours of the control architecture proposed in the USC architecture are implemented as PD control loops with gains tuned by trial and error. In Montgomery and Bekey (1998), the "teaching by showing" approach is presented. In this work the controller is generated by using training data gathered while a human teacher controls a system until the synthesized controller can also control the system to meet predefined performance criteria.

The analysis of the pilot's execution of aggressive manoeuvres from flight test data is the base of the method presented in Gavrilets and others (2001) to develop a full-non-linear dynamic model of an helicopter. This model will be used in the design of new control systems for automomos helicopters.

In Buskey and others (2001) learning is based on the direct mapping of sensor inputs to actuator control via an artificial neural network. Then, the neural network controller was used for the helicopter hovering.

Model Based control methods.

On the other hand, several methods have been applied for model based control of UAVs. Modelling the UAV dynamics is a main issue. The full model of a helicopter involving the flexibility of the rotors and fuselage and the dynamics of the actuators and the combustion engine is very complex. Then, in most cases, the helicopter is considered as a rigid body with inputs forces and torques applied to the center of mass and outputs the position and linear velocities of the center of mass, as well as the rotation angles and angular velocities. Furthermore, the relations between the control inputs of the helicopter and the above mentioned forces and torques should be considered in the model. In general, these relations involves the consideration of the aerodynamics of the fuselage and the effect of stabilizers. However, at low speeds these effects can be ignored (Koo and Sastry, 1998b).

In Kim and Tilbury (2003) a mathematical model and experimental identification of a model helicopter is presented. The model of the interactions between the stabilizer flybar and the main rotor blade is also included showing its effects in the stability of the model helicopter. The identification of the parameters is performed on a SISO basis using a specially-built stands to restrict the motion of the helicopter to one degree of freedom. It should be noted that the identification from input-output data collected when a human pilot is controlling the vehicle, is difficult because it is not possible to study the individual effect of each control input (the pilot has to apply more than one input to maintain the stability).

It has been shown that the multivariable nonlinear helicopter model cannot be converted into a controllable linear system via exact state space linearization. In addition, for certain output functions, exact input-output linearization results in unstable zero dynamics. However, if only the position and heading are chosen as outputs, by neglecting the coupling between moment and forces, the approximated system with dynamic decoupling is full state linearizable and output tracking can be applied (Koo and Sastry, 1998b).

It should be noted that in hovering, the nonlinear system can be linearized and then multivariable linear control techniques such as LQR and Hinfinite can be applied. In Shim and others (2002) multiloop linear PID techniques also obtained good results when applied to the Yamaha R-50. However, if large perturbations should be compensated, or significant tracking abilities are required, this strategy could be not enough. In this case further improvements can be obtained by adding nonlinear control terms that compensate significant deviations with respect to the hovering conditions.

In Kadmiri and others (2001) a fuzzy gain-scheduling approach, based on the linearization of the original nonlinear helicopter model, is proposed and tested in simulation.

Johnson and Kanan (2002) combine the helicopter attitude inner control loop and the outer trajectory control loop and apply adaptive techniques to cancel model errors by preventing unwanted adaptation to actuator limits and dynamics in the inner loop.

In Shim and others (1998) linear robust multivariable control, fuzzy logic control and nonlinear tracking control are compared in the simulation of two scenarios: vertical climb and simultaneous longitudinal and lateral motion. It is noted that nonlinear control techniques by applying feedback linearization are more general and cover wider ranges of flight envelopes but requires accurate knowledge about the system and are sensitive to model disparities, such as changes in the payload, or to the aerodynamic thrust-torque model.

In general no guarantee of robustness against model uncertainties or disturbances and no adaptive capabilities is provided by many feedback linearization techniques. However, in some cases, nonlinear controller robustness properties are increased using sliding mode and Lyapunov based control (Maharaj, 1994). Typically, these techniques trade the controller performance against uncertainty, but require a priori estimates of parameter bounds, which may be difficult to obtain.

However, research efforts to design new robust non linear control low are pursued. Then in Isidori and others (2001) the vertical motion of a nonlinear model of a helicopter to a reference signal, while stabilizing the lateral and longitudinal position and maintaining a constant attitude, is studied. The problem is motivated by the synchronization of the vertical motion of the helicopter with a sea carrier subject to wave-induced oscillations, and then the reference signals are sum of sinusoidal signals (assumed not to be available to the controller). A nonlinear adaptive output regulation and robust stabilization of systems in feed-forward form by means of saturated control is applied in simulation. The simulation results show robustness against uncertainties on the model and on the exogenous reference signal. The method also requires the a priori computation of robustness bounds.

In Shim and others (2002), nonlinear model predictive control is proposed to improve the autonomous helicopter tracking performance at the expenses of heavy computing load.

In Fantoni and Lozano (2002) the control of underactuated systems including helicopters and Planar VTOL (PVTOL) is studied. Several control techniques are presented including backstepping, energy based controllers and Lypunov-based controllers.

At CMU a non linear helicopter model is identified using MOSCA (MOdelling for Flight Simulation and Control Analysis). Then, a high –order linear model of the R-50 Yamaha helicopter is used to control the helicopter. This controller consists of 1 multivariable (MIMO) inner loop for stabilization and 4 separate (SISO) guidance loops for velocity and position control. Several maneuver test have been conducted with the helicopter (square, forward turn, backward turn and nose-out circle). The controller is designed for hovering but its robustness leads the helicopter to perform the maneuvers efficiently even if the trajectories are not optimal (La Civita and others, 2003).

4. ENVIRONMENT PERCEPTION TECHNIQUES

These techniques are used for autonomous UAV control as well as for some applications such as detection, monitoring or terrain mapping.

Environment perception technologies includes cameras and range sensors. For some particular operations such as autonomous landing, range sensors (laser and ultrasonics) are widely used. However, computer vision plays the most important role.

Computer vision is used for several applications in Aerial robotics. Thus, the concept of visual odometer (Amidi and others, 1998) was implemented in the CMU autonomous helicopter. Using this concept the helicopter can visually lock-on to ground objects and sense relative helicopter position in real time. The methods relies on the application of tracking templates in images. Coupled with angular rate sensing, the system is used to stabilise small helicopters over reasonable speeds. The same visual tracking techniques have been applied to autonomously take off, follow a prescribed trajectory, and landing.

The CMU autonomous helicopter also demonstrated autonomous tracking capabilities of moving objects by using only on-board hardware.

Computer vision is also used for safe landing in the AVATAR project. Thus, in Garcia-Pardo and others, (2001) a strategy and an algorithm relying on image processing techniques to search the ground for a safe place to land is presented. In Saripally and Sukhatme (2003) a system for landing the AVATAR helicopter in a slow moving target is presented. The system applies target detection using computer vision and a Kalman filter for target tracking.

In the BEAR project, vision based pose-estimation of unmanned helicopters relative to a landing target and vision-based landing of an aerial vehicle on a moving deck are researched (Shakernia and others 2002; Vidal and others, 2002).

Computer vision activities in the WITAS project at the Linköping University play a key role and include: fast filtering techniques for detection of lines/edges and estimation of their orientation, and for detection of corners and other local symmetries in aerial images; motion estimation by using multi-scale schemes for ground vehicle detection; visual odometers to compute 3D displacement and change in orientation of the camera (camera egomotion); fast tracking of ground vehicles; and learning methods based on associative perception action structure (Nordberg and others, 2002).

Saripally and Sukhatme (2003) present a technique for helicopter position estimation using a single CMOS pointing downward camera with a large field of view and a laser pointer to project a signature onto the surface below in such a way that can be easily distinguished from other features on the ground.

UAV simultaneous localisation and map building using a delta fixed wind platform is presented in Kim and Sukkarieh (2003). In this work images of known landmarks and inertial data are used.

The perception system being designed for Karma (Lacroix and others, 2001 and 2002) applies stereo vision, interest point matching and Kalman filtering techniques for motion and position estimation in the framework of the COMETS project.

Motion estimation, object identification and geolocation by means of computer vision is also done in Merino and Ollero (2002a, 2002b) in the framework of the COMETS project. The perception system designed in this project also implements image stabilization by using visual tracking techniques.

Object identification of ground targets by using previously known appearance or colour has been also implemented by several authors. In Merino and others (2003) the identification of other aerial vehicles from on-board cameras by using a phase-only matched filter is presented.

Another application of UAV computer vision techniques is terrain mapping. Scanner laser sensors have been used in the CMU helicopters to build terrain maps. This helicopter built accurate aerial maps of the experimental site of the VSAM project and portions of the Haughton crater in Devon Island for NASA geologist.

At the LAAS (Lacroix and others, 2001) terrain mapping techniques have been developed and will be also used in the COMETS project.

An important aspect on the application of computer vision techniques in aerial robots is the hardware implementation. The CMU helicopter uses custom vision hardware to perform on-board all the computer vision and control activities. On-board computer vision is needed for helicopter control (visual odometer) and for efficient robotic tracking of moving objects. The application of computer vision techniques on ground computer is seriously constrained by the communication bandwidth and then only slow motions can be controlled.

5. MULTI-ROBOT SYSTEMS

In the last years research on the coordination and cooperation of multiple UAVs and of multiple aerial and ground autonomous system has been conducted.

Several efforts are related to the coordination of homogeneous teams of aeroplanes (McLain, 2000). The problems are related to the control of multiple UAVs (aeroplanes) in close-formation flight, as for example in the Air Force Research Laboratory (Schumacher and Singh, 2000); or in the Air Force Institute of Technology (Hall and Patcher, 1999). The Phoenix Project at Princeton University also considers the coordinated flight of a fleet of homogeneous UAVs (aeroplanes) and the design scenario is autonomous aerobatic manoeuvring. The problem of autonomous formation flight control is also consired in Giulietti and others (2000) where a standad linear quadratic control structure is synthesized for each vehicle and for the formation. The definition of a formation management structure capable of dealing with a variety of transmission and communications failures between aircraft is also presented.

Formation flights have been proposed as a way to deploy multiple sensors on the terrain. This strategy can be considered as biologically inspired (animals that have the ability to form formations such as flocks of birds).

Multiple flying helicopters and groups of helicopters and ground vehicles are considered in BEAR. The research includes hierarchical multiagents system architectures for coordinated team efforts, vision-based pose estimation of multiple UAVs and ground vehicles, and pursuit-evasion games in which a team of UAVs and ground vehicles pursue a second team of evaders while concurrently building a map in an unknown environment (Vidal and others, 2002).

The cooperation between aerial and ground robots is also researched at USC. In Sukhatme and others (2001) different cooperation cases are studied such as the use of an aerial robot in a marsupial-style deployment of a small wheeled robot and the localisation of an aerial robot by visually locating and communicating with a ground robot. "Micro" air vehicles (MAV) are also researched (Vaughan and others, 2000) in this framework. Furthermore, the Raptor project (Saripally and others, 2002) considers the use of small electric-powered radio-controlled (R/C) model helicopters (electric powered) with micro-controllers and Micro Electro-Mechanical based Sensors (MEMS). Relative localization of each robot will be accomplished using only local sensing (CMOS camera), in contrast to global localization techniques (GPS), and then it could be applied in environments where GPS is not available (i.e. indoors or between skyscrapers). Each robot will only have knowledge of its relative location with respect to one or more of its neighbors.

The main objective of the COMETS project (Merino and Ollero, 2002) is to design and implement a distributed control system for cooperative detection and monitoring using heterogeneous Unmanned Aerial Vehicles (UAVs). Particularly, both helicopters and airships are considered.

In order to achieve this general objective, a control architecture has been designed, new control techniques are being developed, and the integration of distributed sensing techniques and real-time image processing capabilities is being considered. Figure 8 shows a general picture of the COMETS system.

The COMETS project exploit the complementarities of different UAVs in missions where the only way to guarantee the success is the cooperation of several autonomous vehicles due to the requirements on the required coverage and the different characteristics of the vehicles. Furthermore, this approach leads to redundant solutions offering greater fault tolerance and flexibility when comparing with the use of a single UAV with long endurance flight and important on-board capabilities. The project also involves the cooperation between robotic aerial vehicles and remotely piloted vehicles. This approach will take benefit from the expertise of human operators in missions where the full autonomy is very difficult to achieve, but pose additional coordination and control problems due to the variability of the human operator.

In order to test and validate these concepts and systems, experiments and demonstrations will be carried out in forest fire alarm confirmation, localisation and monitoring. The first experiments with two helicopter and one airship have been carried out in May 2003.

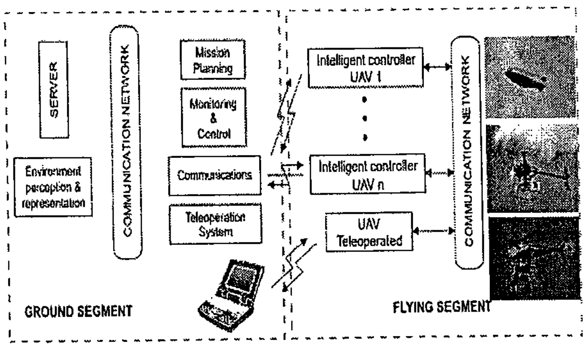

Fig. 8. The COMETS system.

6. CONCLUSIONS

In the last ten years a significant progress toward autonomous aerial vehicles with on-board intelligent capabilities has been experienced. This progress is fuelling the development of Aerial Robots with significant autonomous capabilities. These systems open new applications in Field Robotics including surveillance, disaster (environmental, industrial, urban) remediation, search and rescue, environment monitoring and many others.

Many different techniques have been applied for UAV control and particularly for autonomous helicopter control. These include techniques to cope with the expertise of human pilots by means of predefined rules or by autonomous learning from the pilots, and model-based control methods. Both linear and non-linear control techniques have been applied for model-based control. Some of these methods are shortly reviewed in the paper.

Computer vision is the most relevant perception technology applied in Aerial Robotics Perception. It is applied for motion and position estimation, object detection and tracking, autonomous take-off and landing, as well as for applications such as detection, monitoring and terrain mapping.

Finally, the paper has presented a summary of the recent research on multiple aerial robots and coordination of aerial and ground robots, and has shortly presented the COMETS project on the real-time coordination and control of multiple unmanned aerial vehicles.

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