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Integration of aerial robots and wireless sensor and actuator networks. The AWARE project

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***Abstract*—This paper and video are devoted to the last experiments and demonstration of the AWARE project (European Commission, FP6) carried out in Utrera, near Seville (Spain) May, 2009. The project has developed and validated in field experiments a platform providing the functionalities required for the cooperation of aerial robots with ground sensor-actuator wireless networks, including static and mobile nodes carried by people and vehicles. The project demonstrated the self-deployment, self-configuration and self-repairing of the network by using autonomous helicopters that transported and deployed sensor nodes and loads. These features are highly relevant in natural and urban environments without pre-existing infrastructure or where the infrastructure has been damaged or destroyed. Two validation scenarios have been considered: Disaster Management/Civil Security and Filming.**

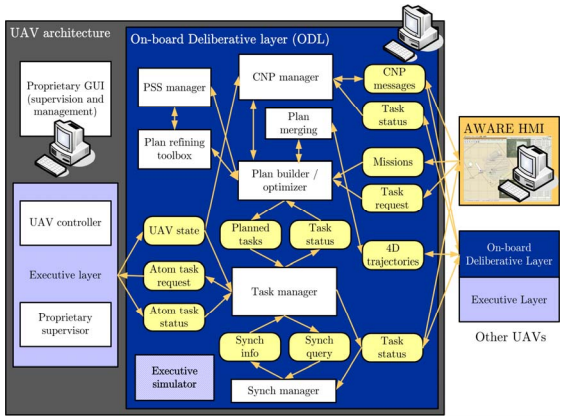

Figure 1: Multi-UAV on-board deliberative layer detailed architecture

AWARE has developed new aerial robots, architectures and methods for cooperative perception and actuation. Thus, the project developed new fully autonomous helicopters such as H3 for R&D in aerial robotics and the electrical helicopter SARAH, which is the first 30 minutes flight VTOL electrical Unmanned Aerial Vehicle (UAV) in the world capable with more than 5 Kg payload. The robust mechanical design and control algorithms developed in the project allow the usage of these systems under strong weather conditions.

AWARE also developed a distributed autonomous decision framework (See Figure 1) that build/optimize plans and allocates tasks automatically to aerial robots to execute cooperatively surveillance and tracking missions, generating way points to the autonomous helicopters by means of the algorithms SET [9] and S+T [10] that implement market based approaches [4]. When an area should be surveyed, it is optimally divided between the UAVs taking into account their capabilities and sensors on-board [5] and zig-zag patterns are generated for each UAV also taking into account the models of the cameras on board and the model of the terrain. The trajectories to be executed are processed by a Plan Merging module that implements new collision detection and avoidance methods. All these modules have been demonstrated in the Utrera 2009 validation scenario.

AWARE also developed very innovative load transportation systems. Multi-robot load transportation had been previously demonstrated with ground robots [8], and simulations of multiple helicopters transporting the same load have been also carried out since the nineties (i.e. the twin-lift [7]) motivated by the exponential increasing of the cost with the payload of the helicopters, but never was demonstrated before the project. In AWARE the single UAV slung load transportation was demonstrated by transporting a 1.1 Kg jerry can, connected to H3 by a 5 m long rope by cancelling the oscillations (maximum amplitude of 0,5 m) even with wind gusts of 30 km/h. Later AWARE demonstrated, for the world-wide first time, in December 2007, the transportation of a load by using multiple coupled autonomous helicopters. Three H3 helicopters cooperated in the transportation of a load that a single helicopter cannot transport due to payload constraints. Several modeling, identification and control methods have been designed and implemented to solve this challenging problem involving the cooperative control of the three helicopters by cancelling the effects of external perturbations. Note that when the three helicopters are connected to the load, in addition of the well known effect of the orientation control on the translation control, the translation also influences the orientation complicating the problem and requiring, to control each helicopter, full models of all the helicopters and the motion of the load. However, the usage of a rope force sensor in the controller design, simplifies the orientation controller in such a way that the consideration of the whole system is not required,

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and the orientation controller of each helicopter becomes independent of the number of helicopters [1]. The last demonstration in Utrera 2009 [6] consisted of the load (WiFi webcam mounted on a suitcase) deployment on the top of a building structure with 12 m. height. This demonstration was carried out with wind gust of more than 35 Km/h. The accuracy of the load placement was 0.5 m.

The AWARE platform also includes a publish/subscribe middleware with support for mobility and a gateway application to enable the cooperation between the high bandwidth network of the autonomous systems and the low bandwidth Wireless Sensor Network (WSN). The project has developed and demonstrated in Utrera 2009 a scalable, energy-efficient and self-organizing WSN. Furthermore, a WSN with camera nodes for localization and tracking of mobile objects has been developed and validated.

AWARE generalizes existing results on autonomous helicopter WSN deployment [3], by means of multiple helicopters that deploy sensors where measurements are needed in particular locations or to repair the connectivity of the network [6]. Sensor deployment devices and enclosures have been developed for this application that has been also demonstrated in the experiments shown in the video. The AWARE project also developed fully distributed cooperative perception functionalities. Each autonomous system (autonomous helicopter, WSN with static and mobile nodes, ground camera nodes) has software able to decompose complex tasks into simple ones and to automatically allocate the tasks according to the aerial robot capabilities. The perception information was locally processed in the autonomous entity and shared with the rest of the PS software involved. The results of the fully distributed cooperative perception compare well with the ideal centralized estimation not affected by communications delays, information double counting, or partial information.

In addition of the above mentioned load transportation, AWARE has been demonstrated in Utrera 2009 in fire experiments, surveillance and firemen tracking. The fire demonstration consisted of the detection, in the room of a structure simulating a building, by means of the ground sensor network, the confirmation and precise localization (error lower than 1 m) by means of ground camera nodes and an autonomous helicopter with on-board infrared and visual cameras, and the transmission of the fire coordinates to a fire truck that pointed automatically the extinguisher to the fire and activated the water jet to extinguish it. The autonomous helicopter with the infrared camera confirmed the extinguishing of the fire by image processing.

The surveillance mission were performed by two helicopters that applied the modules in the architecture shown in Figure 1 to collect potentially dangerous objects (barrels) that could be affected by the fire, the computation of their positions from the on-board perception system and the cancellation of alarms.

Furthermore, a demonstration of the co-operative tracking of two firemen by using two autonomous helicopters was also carried out. Each of the firemen carried a node of the wireless sensor network. The radio signal strength of the nodes and its identification was fused with the visual tracking from the cameras on-board the helicopters and on the ground to improve the accuracy of the position obtaining a maximum error of 1 m. The sensor data fusion algorithms for tracking are described in [2].

AWARE also developed techniques for autonomous helicopter visual aerial navigation in GPS denied environments and for the position estimation of WSN nodes by using only the radio signal strength. Other results of the project have been: tools for the identification and development of UAVs embedded control systems, and a WSN for firefighter protection with nodes equipped with sensors (toxic and inflammable gases concentrations), information processing and communication capabilities integrated in the fire fighters costumes.

The technologies developed in the project can be applied to disaster management and civil security, including surveillance of critical infrastructures, monitoring of disaster evolution avoiding the presence of humans in dangerous zones, search and rescue, protection of fire fighters and others. The AWARE technologies are also useful in the filming of dynamic events as for example for documentary in risky scenarios and in the filming of sport events.

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