Aerial and ground robots networked with the environment

I. Maza, A. Viguria and A. Ollero

Grupo de Robotica, Vision y Control (GRVC), Escuela Superior de Ingenieros, University of Seville, Camino de los Descubrimientos, s/n, 41092 Seville (SPAIN), fax number: +34 954 487340

Abstract

This paper presents a system for the cooperation of aerial and ground robots networked with other objects, including the nodes of wireless sensor networks, in outdoor environments. The system allows the centralized or distributed execution of missions. The robot team can provide transport, communication relay and localization services to other robots (or sensor nodes) during the mission. The distributed allocation of services and tasks to the robots has been implemented using a market based approach. The paper presents one experiment with a team of heterogeneous robots (aerial and ground) cooperating with objects in a mission of fire detection and extinguishing.

Key words: robot teams, aerial robots, cooperating objects, wireless communication, distributed task allocation

1 Introduction

This paper deals with robotic activities in scenarios involving wireless networking of cooperating objects with embedded capabilities. Particularly, both aerial and ground robots and their cooperation are considered in the framework of the *CROMAT Project* funded by the Spanish Research and Development Program. These objects could vary in size and capabilities, ranging from small sensors to autonomous vehicles, and including PDAs and other portable equipment for activities such as environment perception, planning and guidance. Thus, the robots are networked with these objects in the environment.

Email address: `imaza,antidio,aollero@cartuja.us.es` (I. Maza, A. Viguria and A. Ollero).

Different subnetworks can also exist in such environment. Particularly, wireless sensor networks can also be included. Robots and wireless sensor networks have been jointly considered by several authors in the last years. Thus, the robots can be considered as mobile nodes of the network interacting with static nodes. On the other hand, the static sensor nodes can be used by the robot for navigation [1–3]. Moreover, it is also possible to consider wireless sensors and actuators networks with the robots carrying devices to actuate in the environment. Wireless Sensor Networks and Cooperating Objects is the subject of the *Embedded Wisents* initiative, recently launched by the European Commission under the Embedded System priority of the IST Programme of the European Commission in which the authors are involved.

The paper is organized as follows. Section 2 introduces a forest fire scenario in which cooperating objects are valuable for the execution of missions. Section 3 presents the architecture of a system designed for distributed cooperation tested in some experiments during this year. In Section 4, the method used for the distributed allocation of tasks and services is presented. Section 5 presents experimental results obtained with a helicopter and two ground vehicles. The last sections are devoted to the Conclusions and References.

2 Cooperating objects forest fire scenario

In order to clarify the above concepts, a forest fire fighting scenario is considered in the paper. This scenario is illustrated in Fig. 1. The scenario involves different kind of cooperating objects of different size and characteristics. Thus, for example, Personnel Device Assistants (PDAs) can be used to have updated information from the environment and to guide the operational extinguishing personnel. Portable field computers and laptops are suitable for teleoperation and on-board vehicles for surveillance and fire fighting support. Satellite positioning systems, can also be integrated with PDAs, portable computers and laptops to know in real time the absolute position of people and vehicles.

Computer systems can be used at Monitoring and Control Centres in the forest or in the headquarters of the operational forces. These systems can support appropriated software for detection and fire fighting, including Geographic Information Systems, operation planning and human-machine interfaces.

Mobile Control Centres, such as the UNASIF shown in Fig. 1, are also used in Andalucia (Spain) in big fires. The Control Centres also have software to simulate the propagation of the fire by using terrain maps and vegetation information.

Visual and infrared cameras are required in this scenario to monitor the fire.

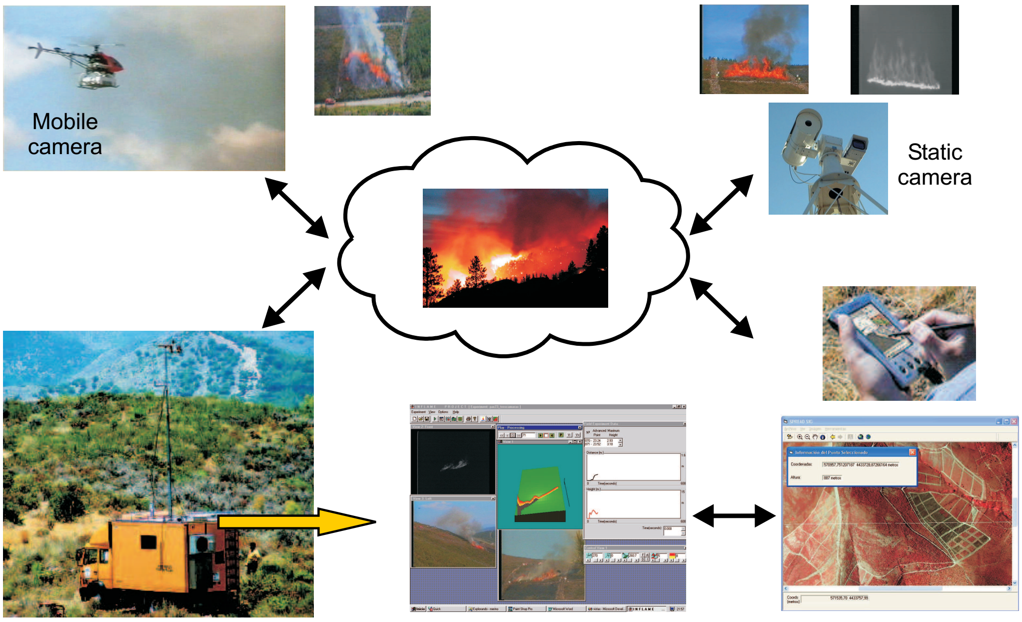

Fig. 1. Cooperating objects in a Forest Fire Scenario.

These cameras can be mounted on appropriated observatories, ground vehicles or aerial vehicles. Fig. 1 shows visual and infrared images provided from fixed cameras and also a visual image from a camera on-board a helicopter.

Different autonomous systems are valuable for surveillance, detection, localization and fire monitoring and measurement. These include computer vision systems, autonomous vehicles and robots to acquire information or even to actuate in the extinguishing operations.

Fig. 1 shows one screen of the forest fire monitoring tool developed at the University of Seville [5]. This tool integrates different computer vision functions for the processing of multiple sequences of infrared and visual cameras by applying cooperative perception.

Ground vehicles are currently used for fire observation and extinguishing. It is also possible to use autonomous ground vehicles. However, these ground vehicles have significant mobility constraints in the forest scenario. Then, it could be very difficult to access to the desired locations to acquire information. Then, the application of Unmanned Aerial Vehicles (UAVs) is also useful for the surveillance, detection and extinguishing activities. The *COMETS Project* of the European Commission (IST-2001-34304) on multiple heterogeneous unmanned aerial vehicles [6] also considers the application of multiple unmanned aerial vehicles for the forest fire detection and monitoring. Fig. 1 shows one of the autonomous helicopters developed at the University of Seville approaching the fire in a forest fire experiment.

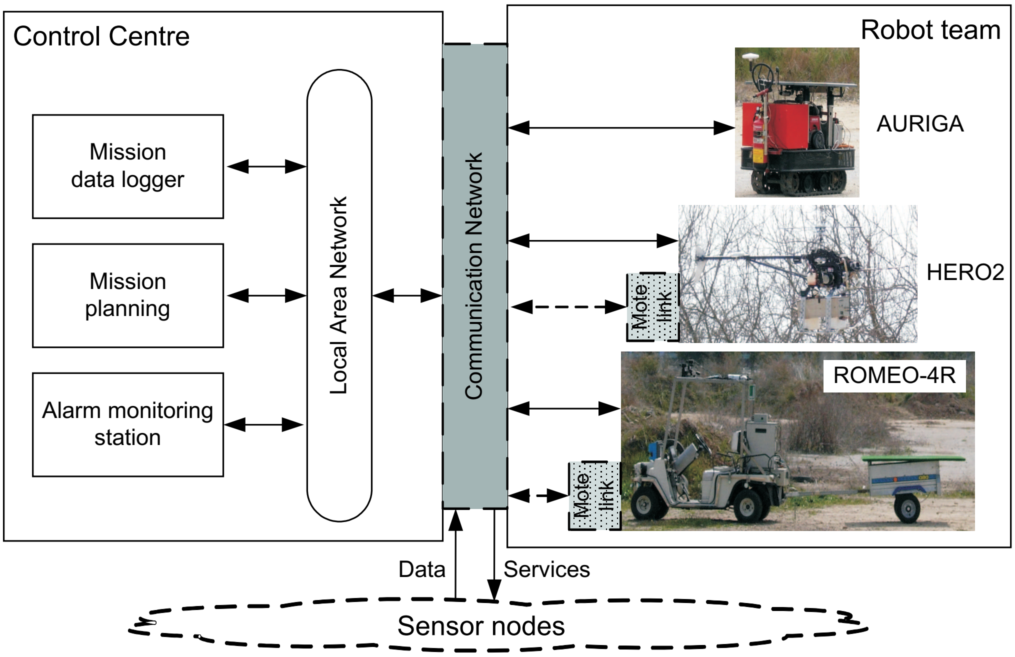

Fig. 2. Global architecture illustrated with the vehicles used in the experiment described in Section 5: Romeo-4R with trailer (take-off and landing platform) and HERO2 from the University of Seville, and AURIGA from the University of Malaga.

This paper is related with the cooperation of aerial and ground robots in the above described scenario. However, the cooperation with other objects in the environment is also addressed.

3 System architecture

3.1 Global architecture

The global architecture of the system is depicted in Fig. 2. Four main blocks are involved: the control centre, the communication network, the robot team and a sensor network.

The Control Centre provides means to send missions, prepare plans in a centralized way (when expected), and monitor the tasks execution by the robots. It also encompasses the Alarm Monitoring Station, which is in charge of performing cooperative perceptions processing, and specialized images processing activities such as fire detection. Finally, there is a database to save all the information related to each mission execution.

The Communication Network is the support for every communications between the different components of the system. It deals with tasks requests/status transmissions, as well as data sending, such as images or robots telemetry. Up to the network layer, all the components in the system are using homogeneous communications (wireless 802.11b), but higher levels are heterogeneous due to different communications programming in the software of each robot/object (BBCS, sockets, etc).

Regarding the BBCS (BlackBoard Communication System), it should be noted that some robots in the architecture (HERO2 and Romeo-4R) are using this system recently developed by the Technical University of Berlin [7]. It is a robust communication system implemented via a distributed shared memory, the blackboard (BB), in which each network node has a local copy of the BB portion it is accessing.

The robot team gathers the different robots themselves and the distributed decisional features. When autonomous decisional capabilities are delegated to the robot team, the CNP layer is enabled and the robots dynamically allocate their tasks based on the *Contract Net protocol* (CNP) (see [8]) while they are building their plans.

In order to support interactions with a sensor network, every robot can be equipped with a mote connected by a serial port to the hardware on-board. This mote is the communications interface with other motes deployed in the environment.

3.2 Robot team architecture

The architecture of the robot team (see Fig. 3) supports two different levels of autonomy:

- Low autonomy mode: a supervisor module manages individual elementary tasks and sequences of elementary tasks, as they are requested from the Control Centre. This module also manages the tasks and robot status returned during the mission execution.
- High autonomy mode: a CNP module allows to autonomously negotiate tasks allocation in a distributed way by using a variant of the Contract Net protocol during the plan building. Regarding this module, tasks allocation can be re-negotiated dynamically trying to converge toward an optimal tasks distribution over robots, regarding their individual capabilities, requirements, and constraints. In this mode, the Control Centre should only provide a list of elementary tasks to be executed by the robot team.

In both modes it is assumed that each robot is able to manage ordered sequences of elementary tasks, and to return execution status of the tasks.

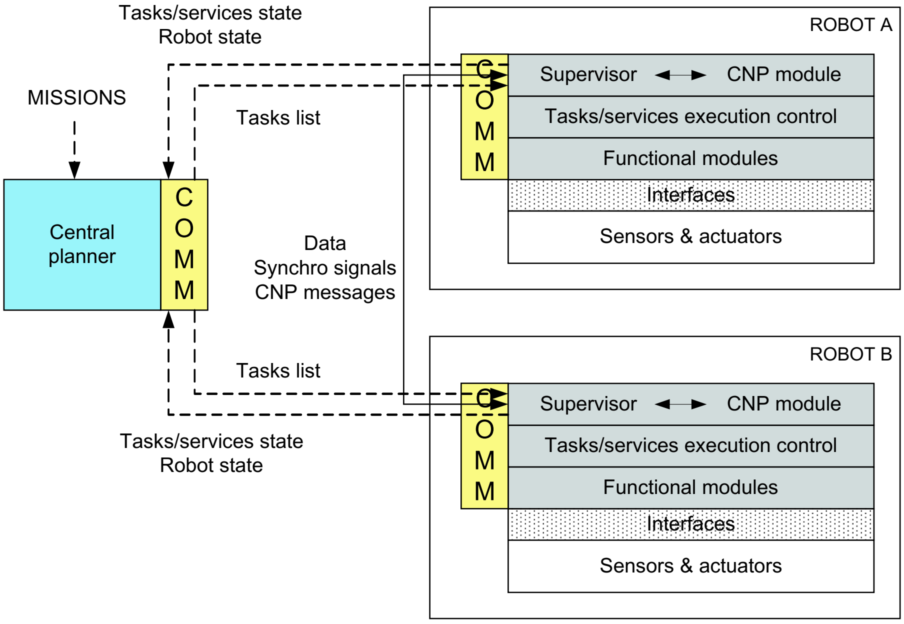

Fig. 3. Robot team detailed architecture (dashed lines correspond to the low autonomy mode)

4 Distributed tasks/services allocation

In this section, the allocation process of tasks and services used in the high autonomy mode is presented.

4.1 Tasks and services

From the full set of tasks, the following subset has been selected for the experiment presented in Section 5:

- `Go-to(P)` tasks: To visit a point `P` given by its GPS coordinates.
- `Survey-area(A)` tasks: To cover an area `A` given by a convex polygon searching for objects of interest (fire in the experiment described in Section 5). The local planner of the robot computes a sequence of waypoints to cover the area of interest easily and efficiently by back and forth motion along rows perpendicular to the sweep direction [4] sending images to the Alarm Monitoring Station.

Under certain conditions, some tasks could require a service from a different robot. Services considered include:

- `Transport(P)` services: Some robots (for example Romeo-4R in the experiment described in Section 5) are equipped with platforms allowing aerial robots to be transported from an initial location to a point `P`.

- `Communication-relay(CRP)` services: During the execution of a `survey-area` task, the Alarm Monitoring Station should be receiving images from the area, so if the communication range does not allow this link, another robot (or a chain of robots) should provide the `communication-relay` service moving to a certain point `CRP`.
- `Localization` services: during the execution of `survey-area` tasks, the robot broadcasts its GPS positions through the "Mote interface" mentioned in Section 3.1. As it has been shown in [3], it allows the node localization outdoors and without inter-node communication.

4.2 Market based approach

In the classic market-approach, the distributed allocation of tasks and services can be viewed as an incremental process. Each task is offered to the robots, and each robot can bid on it using the cost of inserting that task in its plan. Then, the task provider allocates it in order to minimize the global cost for the whole system (this robot could also make a proposal for the task it provides). The whole process is repeated offering all the tasks until none of them is bought by any robot. In our system, the Control Centre is the entry point for the tasks, which are defined by the human operator in the Mission Planning computer.

The implemented incremental task allocation algorithm is based on the Contract Net protocol [8], but several changes have been introduced due to the relations between tasks and services. Those relations lead to a hierarchical structure of tasks and services with dependencies between them that should also be coded in the CNP messages interchanged during the negotiation process. These dependencies can be temporal (requiring synchronization between robots) or related with a change in the cost of execution of a task. Furthermore, the level of fulfillment of a constraint due to dependencies is included in the cost of the proposals to allow a proper allocation of services.

These techniques have been tested in real experiments involving a robot team. The next section describe one of these experiments.

5 Experimental results

The experiments were done in the "Alamillo" park in the city of Seville, in cooperation with the team of the University of Malaga also participating in the CROMAT Project. These experiments involved three different robots: the autonomous ground vehicle ROMEO-4R developed by the GRVC at the University of Seville, provided with a trailer for helicopter take-off and landing, the helicopter HERO2 also developed by GRVC, and a mobile fire extinguisher unit. This unit was the all terrain tracked vehicle AURIGA developed by the University of Malaga which was teleoperated in this experiment from a laptop. AURIGA was provided with a conventional fire extinguisher. These robots are shown in Fig. 2.

The goal of the mission is to detect a fire and to extinguish it with the collaboration among the robots and other cooperating objects in the environment.

The mission execution was as follows (see Fig. 4):

(1) At the beginning the two ground vehicles were in their initial positions (marked as `H` in Fig. 4) and HERO2 (blue line) was on the take-off/landing platform on the ROMEO-4R (red line) trailer.
(2) After the distributed negotiation process (see Section 4), HERO2 won the `survey-area(A)` and `go-to(WP1)` tasks, and ROMEO-4R won the `transport(WP1)` service (associated with the `go-to(WP1)` task) and the `communication-relay(CR)` service (associated with the `survey-area(A)` task).
(3) `Go-to(WP1)` was the first task to be executed, so ROMEO-4R moved to the `WP1` coordinates (see Fig. 4) with HERO2 on the take off/landing platform. After reaching `WP1`, the first task and its associated service were completed. HERO2 started the `survey-area(A)` task, which implied to take off and fly towards the `A` zone. ROMEO-4R executed the service associated to this task and moved to the `CR` point (Fig. 4) to act as a communication relay between HERO2 and the Control Centre.
(4) HERO2 started to survey `A` following a list of waypoints generated by its local planner (marked as `WP2`, `WP3`, `WP4` and `WP5` in Fig. 4).
(5) When HERO2 detected the fire, it sent the GPS coordinates of the fire to the AURIGA (Fire Extinguisher Unit) teleoperation laptop and to the Alarm Monitoring Station. Then, AURIGA was commanded to go close to the fire and activated the extinguisher. HERO2 checked the extinguishing and declared the fire extinguished (mission completed).

After this, another fire extinguish mission could be launched (several fire focuses). However, in this particular experiment, HERO2 and the ground vehicles returned to their initial positions and HERO2 landed on the ROMEO-4R platform.

Notice that the fire extinguisher role can be also played by other cooperating objects in this scenario such as conventional fire fighting units. These units could be guided to the fire by using the information obtained by the robot and the sensor network.

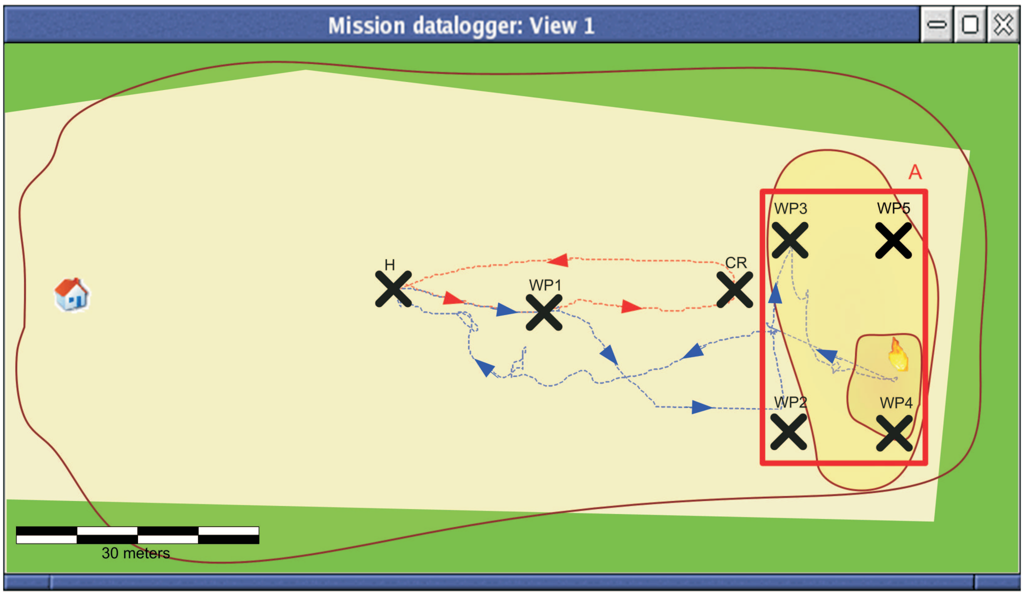

Fig. 4. Experimental results.

6 Conclusions and future developments

The paper presents a system that allows the cooperation among robots and other objects in their environment. It involves multiple heterogeneous robots (aerial and ground) networked with objects such as actuators and sensors. The system is mainly based on a negotiation protocol for distributed allocation of services and tasks to the robots. This protocol has been implemented using a market based approach. Some experiments to test the feasibility of the system to execute missions in a distributed way have been performed. One experiment with the HERO2 helicopter and the ROMEO-4R ground robot cooperating with objects in a successful mission of fire detection and extinguishing has been presented.

Future work will include the implementation and experimentation of a wireless sensor network including static nodes and mobile nodes on-board the robots.

Acknowledgements

This work was partially funded by the *CROMAT Project* of the Spanish Research and Development Program (DPI2002-04401-C03-03) and the *Embedded Wisents Coordination Action* of the European Commission (IST-004400).

The authors would like to thank TUB (Technical University of Berlin) for the software used to implement the BBCS in our system and the University of

Malaga for their participation in the experiments contributing with their all terrain tracked vehicle AURIGA. The first author would also like to thank LAAS-CNRS (Laboratory for Analysis and Architecture of Systems - France) for the helpful ideas and information provided during his stay there in 2004.

References

[1] M. Batalin, G.S. Sukhatme, and M. Hattig, Mobile robot navigation using a sensor network, in: *Proc. of the 2004 International Conference on Robotics and Automation* (New Orleans, USA, 2004) 636–641.

[2] P. Corke, R. Peterson, and D. Rus, Networked robots: Flying robot navigation with a sensor net, in: *Proc. of the 2003 International Symposium on Robotics Research* (Siena, Italy, 2003).

[3] P. Corke, R. Peterson, and D. Rus, Coordinating aerial robots and sensor networks for localization and navigation, in: *7th International Symposium on Distributed Autonomous Robotic Systems* (Toulouse, France, 2004) 281–290.

[4] I. Maza, and A. Ollero, Multiple UAV cooperative searching operation using polygon area decomposition and efficient coverage algorithms, in: *7th International Symposium on Distributed Autonomous Robotic Systems* (Toulouse, France, 2004) 211–220.

[5] A. Ollero, J.R. Martinez-de Dios, B.C. Arrue, L. Merino, and F. Gomez, A Perception System for Forest Fire Monitoring and Measurement, in: A. Halme, R. Chatila and E. Prassler, eds., *Proc. of the 3rd International Conference on Field and Service Robotics* (Helsinki, Finland, 2001) 135–140.

[6] A. Ollero, G. Hommel, J. Gancet, L. Gutierrez, D.X. Viegas, P. Forssen and M.A. Gonzalez, COMETS: A multiple heterogeneous UAV system, in: *Proc. of the IEEE International Workshop on Safety, Security and Rescue Robotics* (Bonn, Germany, 2004).

[7] V. Remuss, M. Musial, and U.W. Brandenburg, BBCS Robust Communication system for distributed system, in: *Proc. of IEEE International Workshop on Safety, Security, and Rescue Robotics* (Bonn, 2004).

[8] R. G. Smith, The contract net protocol: High-level communication and control in a distributed problem solver, in: *IEEE Transaction on Computers*, ser. C-29, no. 12 (1980) 1104–1113.