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Decentralized Control Architecture for UAV-UGV Cooperation

El Houssein Chouaib Harik¹, François Guérin², Frédéric Guinand¹,
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Abstract— We present a decentralized control architecture for an heterogeneous group of mobile robots made of one Unmanned Aerial Vehicles (UAV) and several Unmanned Ground Vehicles (UGVs) performing collaborative tasks (area inspection, object transportation, etc...). The UAV is used to help a human operator to supervise and guide a group of UGVs by providing an aerial coverage view of the navigation area. Our control scheme is based on minimalistic computation and communication requirements, as well as an architecture complexity kept at a simple level regardless of the deployed number of grounds robots. Simulation and experimentations are performed and show the efficiency of our proposed control architecture.

I. INTRODUCTION

The present research is partially funded by Le Havre town council (CODAH), CNRS and the Normandy Region and takes place in two projects conducted by several research laboratories of both University of Le Havre and University of Rouen. The main goal of the work is the design and implementation of a platform made up of ground and air mobile robots to carry out, in a coordinated way, a set of different tasks in an industrial area.

Unmanned Aerial and Ground Vehicles (UAVs, UGVs) cooperation attracts increasingly the attention of researchers, essentially for the complementary skills provided by each type to overcome the specific limitations of the others (payload, computing power, movement velocities, local vision, etc...), thus, deploying UAVs and UGVs in a single mission allows to envisage a wide range of applications.

In [?] the authors used a group of UAVs to coordinate a group of UGVs in urban environment.

An agricultural application of UGV-UAV coordination is presented in [?], where aerial images taken by a quadrotor are processed by a ground mobile robot to extract and to navigate towards a waypoint in order to perform a specific task (eg: apply pesticides/herbicides).

The authors in [?] proposed a reactive supervisory control strategy for a team of UAVs and UGVs used in search and rescue missions. Another application for UAV-UGV cooperation is target tracking, the authors in [?] used a Parrot drone to track an omnidirectional Mecanum Wheel UGV.

In [?] the authors fused information gathered from ground and aerial robots in order to track a moving target in an open environment.

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For some applications the human must be part of the processing cycle. This observation motivates our work. For instance, the inspection of industrial sites cannot be done, legally, without a human for piloting and/or supervising the task. Thus, to fulfill the industrial expectations in this matter, we propose an adequate scheme: a pilot for operating the UAV, an expert for taking some decision about the supervision of the surveillance process and mobile robots (UAVs and/or UGVs). We made the choice of using an UAV for vision purpose only and one or several UGVs for both vision and action.

This paper is organized as follows: In section II we introduce the problem statement, define the objectives of our work and present the hardware configuration and the overall architecture. We discuss in section III the simulation and experimental results, and we conclude in section IV the present work and discuss future perspectives.

II. PROBLEM STATEMENT AND ARCHITECTURE DESIGN

For numerous and unavoidable reasons, monitoring, surveillance and inspection of industrial sites belonging to Seveso category (ranking highly critical sites) cannot be performed without a constant and careful attention of human experts. However, nothing forbids the use of additional elements for helping supervisors in their critical tasks, provided that the crucial decisions are still taken by men.

With these constraints in mind, we have proposed a global architecture including Unmanned Ground Vehicles (UGVs), Unmanned Aerial Vehicles (UAVs) and men. Figure 1 presents the global architecture.

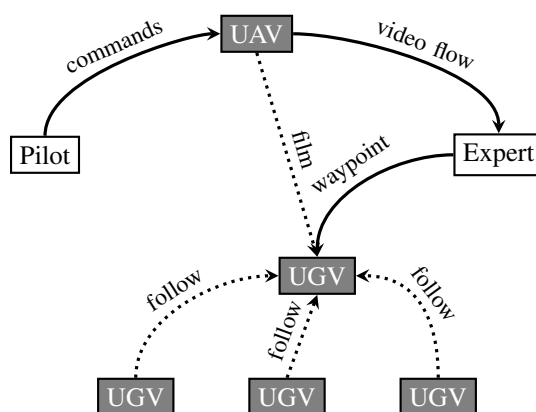


Fig. 1. Global architecture including UAV, a team of UGVs, an expert for moving decisions and a pilot.

For the chosen scenario UGVs are organized as a team

with a leader and followers (as illustrated in Figure 2. A UAV takes, thanks to a camera mounted on it, and continuously sends images of the monitored area where UGVs (mobile robots) are present. These images are sent to a ground station. A human expert gets these images and take some decision about the next direction of the UGV team. This decision is expressed through the choice of a waypoint (a simple clic in the window for the visualization of the video). These waypoints may also be chosen prior to the start of the mission as a path through the industrial site. In such a case the video taken by the UAV is a way of verifying the good progress of the mission with the possibility at any moment to change the direction of the team by a simple clic in the window displaying the video provided by the UAV.

The UGV team is made of a leader, that receives the waypoints from the expert, and of other UGVs called followers. As the leader navigates to each next waypoint, these followers take the leader as a target and follow it keeping a certain separation distance [?] in order to form a specific configuration that can be defined prior, or during the mission. In our study, we used two followers, but this number can be extended depending on the mission goals. On the top of the UGV leader two colored markers have been fixed. The orientation of the leader can be deduced from these markers.

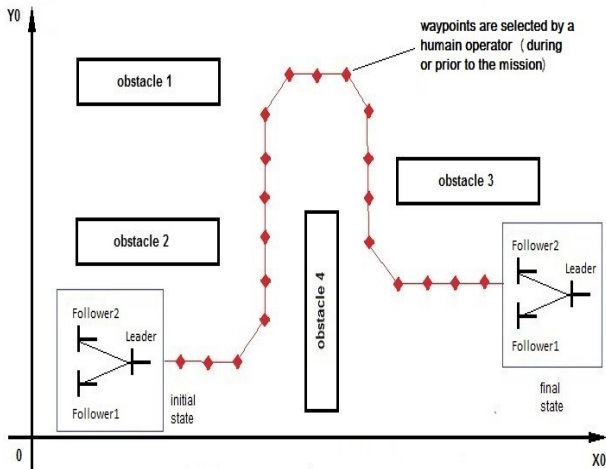


Fig. 2. The leader and the followers moving among obstacles thanks to waypoints defined, before or during the mission, by experts.

We have considered in this work three similar non-holonomic, unicycle-like, Wheeled Mobile Robots (WMR) and a quadcopter drone equipped with a color camera. The video flow is sent continuously to the ground station where it is processed to extract the position and the orientation of the leader relative to the next waypoint. These information are then sent to the leader in order for it to correct its trajectory in real time using a non-linear kinematic controller [?].

At a functional level our architecture (Figure 3) can be divided in two layers: Drone-Leader layer, and Leader-Followers layer. We will explain in the next section the functionality of each layer.

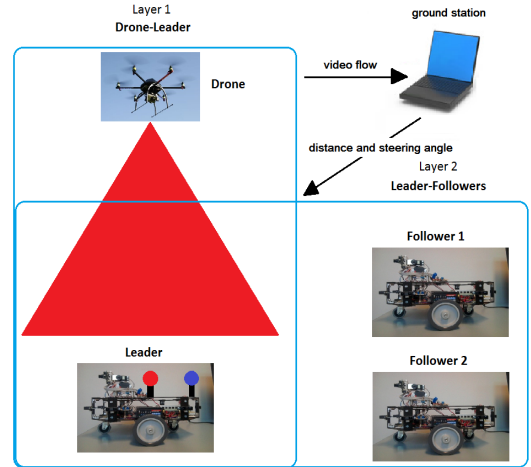


Fig. 3. A tow-layer architecture.

The ground station processes the video flow sent continuously via a wireless communication from the color camera mounted on the drone, to extract the position and the orientation of the leader to a waypoint selected by a human operator (the expert). The ground station sends this information (distance and steering angle) to the leader via another wireless communication device.

The human operator can give waypoints w to the leader by selecting them in the image using the developed software.

III. RESULTS

We will present in this section simulations and experimental results. In both cases, we consider that the center of the image is the center of the drone. The altitude of the drone can be estimated using the distance between the colored markers on the leader, or using the drone's altimeter.

A. Simulation results

To check the efficiency of our architecture and controllers, we simulated a real-like scheme to navigate in an industrial area avoiding obstacles.

For each WMR (leader and followers), we have used the dynamic model of [?] and [?].

The chosen scenario consists in giving waypoints to navigate in a specific area. Figure 4 shows the trajectories of each WMR:

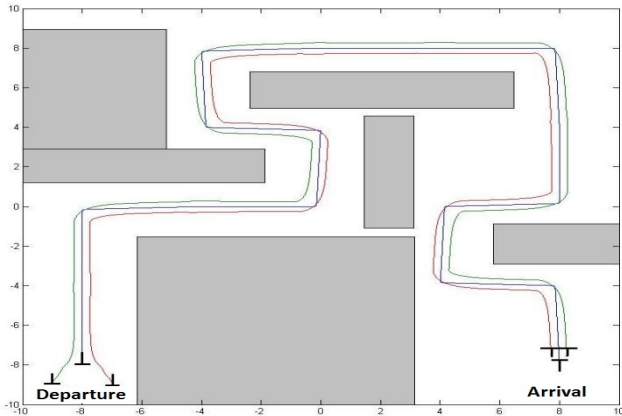


Fig. 4. Waypoints tracking simulation

The simulation gave promising results, it showed the efficiency of the developed architecture and the proposed controllers (not described in this paper but that can be found in [?]). The leader is able to follow the given waypoints and the followers are able to navigate considering the leader as a target while keeping a predefined separation distance (range) and angle (bearing).

B. Experimental results

For brevity, we only present the experimental results of the drone-leader layer. The leader-follower experiments (vision target tracking) were carried out successfully in [?]. Our unicycle-like WMR (Figure 3) has been designed in the GREAH laboratory of the University of Le Havre (France). We used as a UAV a quadcopter (Phantom 2 Vision) developed by DJI [?], with a sufficient payload to carry our open platform device (android phone) that is used to take a video flow and send it continuously via Wifi (IEEE 802.11) to the ground station in order to localize and correct the position of the leader regarding its next waypoint. During our experiments, the UAV was manually piloted, but the work remains valid for autonomous flights.

We created a user interface (Figure 5) using the development environment Processing [?] running on the ground station, where we can supervise in real time our WMR through a video flow received continuously from the smartphone mounted beneath the drone. We can select waypoints in the image by a simple click, or define them prior to the mission. The program extracts and send the distance between the leader and the target and the orientation of the leader w.r.t. the target. The communication is performed via ZigBee module (IEEE 802.15.4) at a frequency of 50Hz (real time interrupt). With the leader in their vision field initially, the followers will have to track the leader keeping a predefined separation distance and bearing angle in order to form a specific configuration (triangle is our case).

The experiments were carried out with the smartphone mounted under the quadcopter instead of the built-in camera that has a limited tilt angle (the camera has to face the ground). The drone was piloted by a professional (for safety

and legal reasons), but autonomous flights can be envisaged, since the quadcopter we used can fulfill this task.

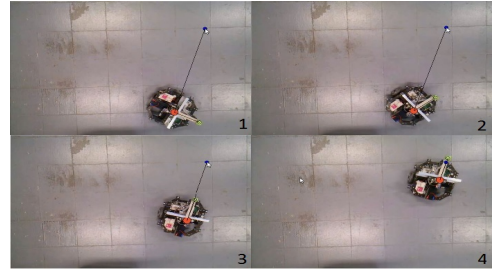


Fig. 5. Waypoint tracking experimentation. The four images represent the progression of the UGV toward the target. The robot changes its orientation and moves towards the target simultaneously

Figure 5 shows what happen when the expert clicks on a new waypoint within the window displaying the video received from the UAV. The robot uses the steering angle and the distance, both received from the ground station, to move successfully to that point.



Fig. 6. Experiments: The pilot (1) manipulates the drone (2) that takes a video of the navigation area and sends it to the ground station (3). The operator (4) selects new waypoints to guide the ground robot (5)

IV. PERSPECTIVES AND CONCLUSION

We introduced in this paper a hierarchical architecture for air-ground coordination. We presented our testbed and explained the features of the whole system. The efficiency of our architecture has been proved by both simulations and experimental results, where a UGV (leader) followed by two other UGVs (followers) in a certain configuration (triangle), were able to navigate through waypoints extracted from an image taken from a drone. The architecture is fully functional and we now envision new developments, in three main directions.

- At first we would like to design a new control algorithm for allowing our UGV team to collectively carry a given cumbersome load in an environment with obstacles.
- In a second step we are planning to subject the UAV movement to the leader movement, based on image processing and using a specific communication protocol.

- Finally, as a mid-term goal, we plan to dramatically improve the autonomy of the UGV team allowing robots to behave as a swarm according to their environment.

V. ACKNOWLEDGMENTS

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