Autonomous Cooperation Between UAV and UGV to Improve Navigation and Environmental Monitoring in Rough Environments

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Abstract: An architecture to allow cooperation between an UGV and an UAV is proposed. The UAV can autonomously follow the UGV, by using an image processing algorithm. In this way aerial images are provided that can help trajectory planning in rough environments, via a developed webGIS platform.

1. INTRODUCTION

One of the main problems encountered during the tele-control of an UGV (Unmanned Ground Vehicle) is the limited field of view obtained by the on-board cameras and sensors. In difficult environments, such as those that can be encountered in demining operations, it can be really hard for the operator to be aware of the situation and decide the best navigation strategy.

A possible solution can be the adoption of an UAV (Unmanned Aerial Vehicle) that flying above the UGV can oversee a wider area. However in this case two operators are needed to control the two systems at the same time. A possible solution is obtained augmenting the autonomous capabilities of the involved platforms, thus minimizing the intervention of the operators.

In this paper we present the result of a strategy that makes a quadcopter UAV able to autonomously follow a ground mobile robot by means of a vision tracking algorithm. In such a way, the operator should take care of the ground vehicle only, while the quadcopter flies over the operation area. The images acquired by the UAV can be also adopted to survey the surrounding environment with the aim of building traversability maps and gather photogrammetry data.

Experimental trials have been performed at different flying heights by using a tracked UGV developed by Etnamatica srl and an Asctec Hummingbird quadrotor.

A GIS platform has been adopted to plan and monitor the UGV trajectories; moreover the gathered data are integrated within the platform to improve the representation of the information.

The cooperation between flying vehicles and robotic ground platforms is a is rapidly spreading as performing tools to be used for data gathering, search and rescue operations, civil protection and safety issues [Muscato, 2012].

In some cases, complex tasks cannot be completed by just one type of unmanned robot. [Habib, 2011] deals with different types of unmanned robots (UGV, UAV), which are employed in search, rescue, and risky intervention tasks. In particular, cooperation between UAV and UGV is a topic held in high consideration in the scientific community. [Daly, 2011], for example, develops a coordinate landing between a skid-steered UGV, used as mobile landing platform, and a quadrotor. [Brandao, 2010] deals with a decentralized control, based on artificial vision, which takes place between a helicopter and a team of UGVs. The mission to be accomplished by the helicopter consists of tracking the centroid of the ground formation. [Ippolito, 2008] exposes the Polymorphic Control Systems (PCS), providing emergency assistance and collaborative coordination between multiple systems to safely achieve the mission critical objectives. [Tanner, 2007], [Cheunga, 2008] and [Owen, 2010] develop a coordinate control between UAVs and UGVs for the purpose of tracking a dynamic target. [Grocholsky, 2006a] is another application of decentralized control, which is used in teams of UAVs and UGVs.

In some cases, an UAV is used to improve the navigation performance of an UGV. For example, tracking and state estimation of a UGV [MacArthur, 2007], [Heppner, 2013], terrain classification and path planning for the UGV [Hudjakov, 2010], or supporting the UGV navigation as in case of GPS loss [Frietsch, 2008]. [Kim, 2001] uses a coordinate control based on probabilistic approach for UAV and UGV teams employed in pursuit-evasion games. UAVs and UGVs are used for surveillance tasks in [Grocholsky, 2006b] and [Saska, 2012], for cooperative mapping in [Chaimowicz, 2005], and for detection and disposal of mines in [Zawodny, 2005].

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2. THE DEVELOPED ARCHITECTURE AND ALGORITHMS

A computer vision based method has been adopted to recognize and localize the position of the quadrotor by processing images coming from a camera on-board the UGV. To augment the contrast of the acquired images and to improve the recognition of the flying platforms, four strips of high-intensity LEDs have been placed at the edges of the quadrotor, under the chassis. The algorithm is based on the following steps:

a) Image acquisition and binarization by thresholding (Fig.1a).
b) White pixels extraction from the original image: this operation allows to highlight the high-density LEDs (Fig. 1b).
c) Black pixels extraction from the original image, in order to identify the chassis of the quadrotor (Fig. 1c).
d) Erode and dilate operations to remove noise (Fig. 1d).
e) Logical AND between the obtained white image and the black one: this allows detecting the white LEDs in the four corners of the chassis of the quadrotor (Fig. 1e).
f) Geometric validation of the detected points: the pattern of the LEDs should be a square (Fig. 1f).
g) Estimation of the pose on the basis of the obtained pattern, of the quadrotor inertial data and of the UGV pose (Fig. 4).
h) Kalman techniques to filter the reconstructed pose: this allows to reduce noises caused by the surrounding environment and to improve the localization when the quadrotor is not recognized by the computer vision algorithm.

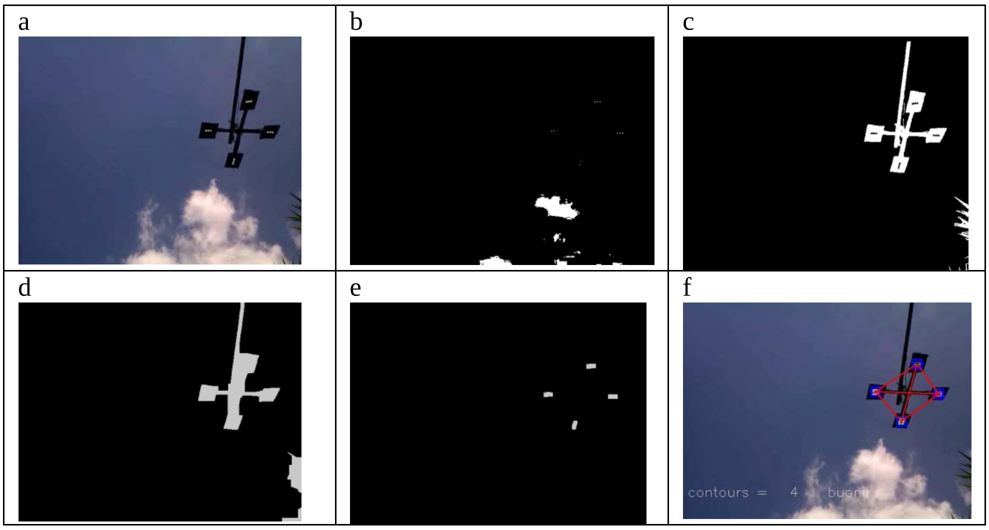

Fig. 1. Sequence of the main steps needed to localise the quadrotor in the image.

The localisation solution is adopted to compute the error signals for the control algorithm that works to maintain the flying vehicle over the UGV. Three simple PID control loops computes the commands (roll, pitch and yaw command) to be sent to the quadrotor via a wireless link.

In order to assign the path for the UGV and the UAV only free and open source GIS technologies have been adopted. In particular, the GIS platform architecture proposed is based on a spatial database, which communicates with both the GIS (Desktop and Web) and the robot. This architecture was born from the need to guarantee a unique software tool for the management of the spatial data, allowing to exploit all instruments provided by the spatial database and the characteristics available within the DMBS. With such an architecture, different kind of access policies can be integrated. For example, the administrator can access and modify the whole data, while the uses of the Desktop or WebGIS can only visualize and perform basic operations on data. Another advantage provided by the architecture designed regards the database, which is located in an “ad hoc” remote server so that the exclusive management of the hardware and software resources is guaranteed.

As desktop GIS software, we used Qgis (http://www.qgis.org/) and GRASS (http://grass.osgeo.org/), while the webGIS platform has been developed customizing Mapserver (http://mapserver.org/) and OpenLayers libraries (http://openlayers.org/). For the spatial database, we used PostGreSQL with the spatial extension PostGIS.

The architecture designed allows to digitize the paths for the robot or UAV in a GIS environment as thematic vectors on the cartographic support and to save them in the spatial database. In Fig.2 an example of the interface with some assigned waypoints is shown.

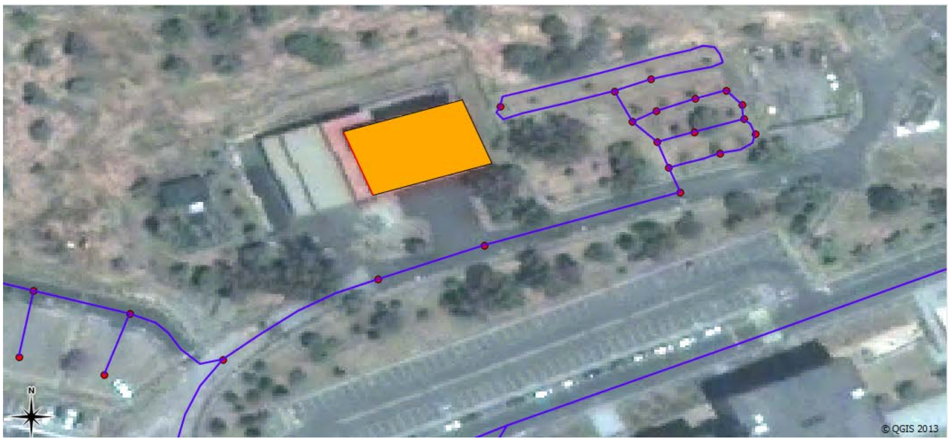

Fig. 2. Example of waypoints assigned into a map by using the webGIS platform.

3. Results and Conclusions

Testing of the architecture has been carried out by using a tracked vehicle made by ETNAMATICA S.r.l and a Hummingbird quadcopter by Ascending Technology. The tracked UGV, shown in fig. 3 with the quadcopter on-board, has two independent DC motors driven by two CAN bus based drivers. The payload of the system is about 300kg. The robot has an Xsens Mti IMU, a Leica RTK-DGPS, a SICK Laser scanner and a wireless link for telemetry and remote control. The low level control is based on a FPGA NI board and the navigation and localization algorithms are implemented by using the LabView language.

During the trials the UGV was programmed to move autonomously following a given path planned on the GIS interface. Once a difficult situation is encountered the quadcopter take-off from the UGV, the tracking algorithm is started and it begins following autonomously the UGV trajectory. In the meanwhile the aerial images are transmitted to the base station and allow replanning the UGV trajectories. Then the quadcopter lands on the UGV and the mission continues. In the actual version landing operations on the UGV are not autonomous. Fig. 4a shows the image of the quadcopter from the UGV camera with the results of the localization algorithm and the control actions superimposed as white vectors. In Fig. 4b the aerial view of the UGV from the camera on-board the quadcopter, is shown.

The system is capable to successfully track the quadcopter in a wide range of environmental conditions and lights. The altitude of the flight can be changed without compromising the tracking performance. Further work is needed to allow autonomous landing on the vehicle and to track the UGV in very low altitudes.

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Fig. 3. The adopted UGV platform with the quadcopter on-board ready to take-off.

(a) (b)

Fig. 4. The vision tracking system computing the position of the quadrotor (left) and the aerial view of the UGV (right).

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