UAV/UGV cooperation for surveying operations in humanitarian demining

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***Abstract*—Unmanned Ground Vehicles can be a useful tool to help operators in humanitarian demining. However in many difficult environments autonomous operations are impossible and moreover it can be really difficult to teleoperate the robot from an onboard camera. This work presents an architecture to allow cooperation between a ground robot and a quadrotor UAV. The UAV can autonomously follow the ground robot, 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.**

Keywords—UAV, UGV, GIS, Vision tracking, Robot cooperation.

I. INTRODUCTION

Clearing landmines in post-conflict areas is still one of the most important humanitarian problems to be solved. The regions worldwide still affected by landmines are wide and the time and resources needed to clear such areas by using only traditional and manual methods would be enormous.

The objective of the EU funded FP7 project TIRAMISU (http://www.fp7-tiramisu.eu/) is to provide the Mine Action community with a toolbox to assist in addressing the many issues related to Humanitarian Demining and thus promoting peace, national and regional security, conflict prevention, social and economic rehabilitation and post-conflict reconstruction. Among the tools to be developed in TIRAMISU there are *Remotely controlled Inspection Platforms* such as robots that can be of a great help during demining operations. Teleoperated or autonomous robots allow the human operators to stay at a safe distance from the risky areas. In many situations the environment is hard and autonomous systems are impossible to adopt so the UGV (Unmanned Ground Vehicle) has to be teleoperated.

However, in difficult environments, such as those that can be usually encountered in demining operations, it can be really hard also for a human operator to be aware of the situation and decide the best navigation strategy. One big problem encountered during the tele-control of an UGV is the limited field of view obtained by the on-board cameras and sensors, which make the situational awareness really difficult.

The use of an UAV (Unmanned Aerial Vehicle) that flying in cooperation above the UGV can oversee a wider area can represent a good solution to this problem [21]. However the control of the two systems at the same time would require two different operators. Our proposed solution is obtained augmenting the autonomous capabilities of the involved platforms, thus minimizing the intervention of the operators.

In this paper we present the recent results of a strategy that makes a quadcopter UAV able to follow a ground mobile robot autonomously, by means of a vision tracking algorithm [22]. In this way, the operator should control the ground vehicle only, while the UAV flies autonomously over the operation area. Moreover the images acquired by the UAV can be also adopted to survey the surrounding environment with the aim of gathering photogrammetry data and building traversability maps.

Several 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 and UAV trajectories; moreover the gathered data are integrated within the platform to improve the representation of the information.

In recent years many research groups have investigated the advantages obtained from the cooperation between flying vehicles and robotic ground platforms. The joint adoption of UAV and UGV is rapidly spreading as an innovative tool to be used for data gathering, search and rescue operations, civil protection and safety issues [1].

In several applications, complex tasks cannot be completed by just one type of unmanned robot. The work [2] 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. In [3], for example, a coordinate landing between a skid-steered UGV, used as mobile landing platform, and a quadrotor is developed.

In [18] a guidance law for an UAV tracking and landing on a moving target with the help of on-board vision sensor is presented. Similar ideas is presented also in [20] by using a projective geometry method. Another automatic take-off, tracking and landing system adopting as a main sensor a Wii remote infrared camera is presented in [19].

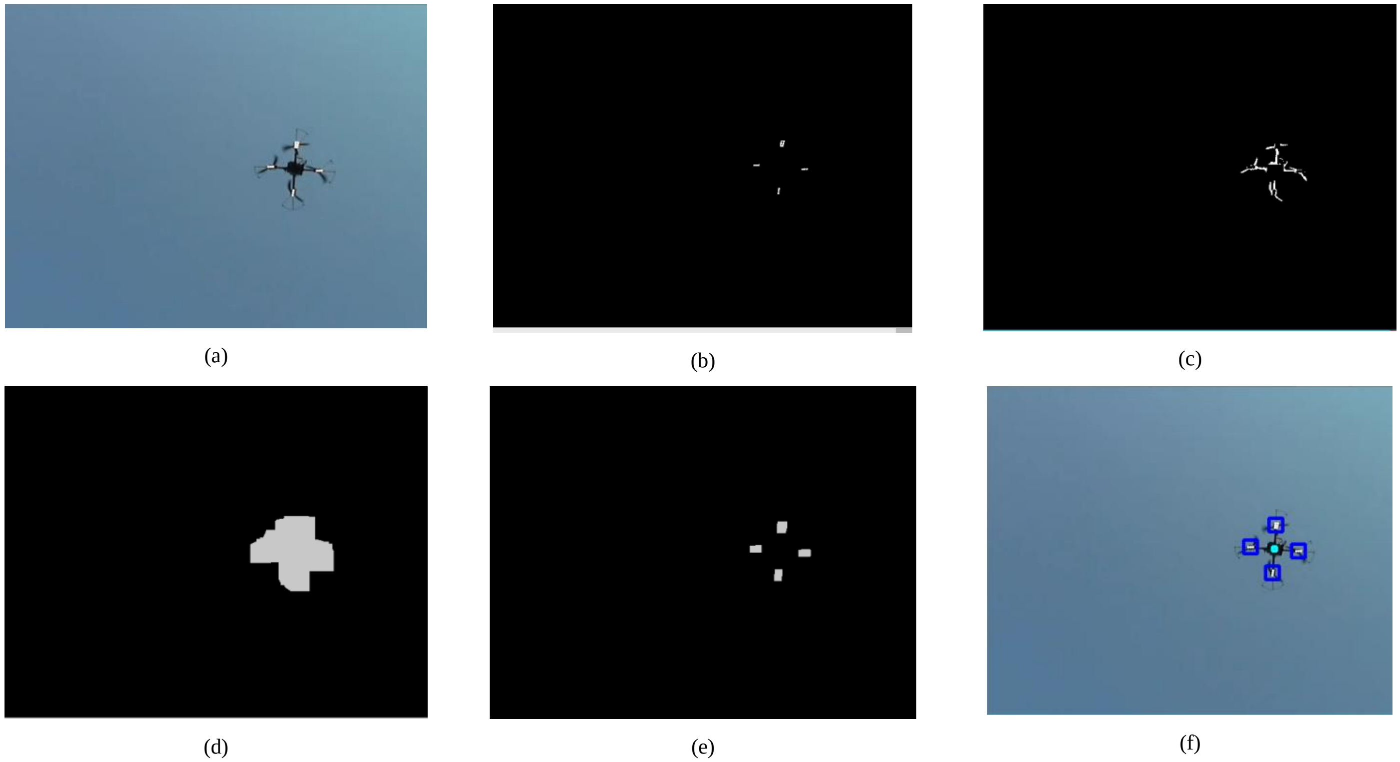

Fig. 1 The main steps needed to localize the quadrotor in the image.

The work [4] deals with a decentralized control, based on artificial vision, which takes place between a team of UGVs and a helicopter. The mission to be accomplished by the helicopter consists of tracking the centroid of the ground formation. In [5] the Polymorphic Control Systems (PCS) is exposed, providing emergency assistance and collaborative coordination between multiple systems to safely achieve the mission critical objectives. [6], [7] and [8] develop a coordinate control between UAVs and UGVs for the purpose of tracking a dynamic target. [9] 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 [10], terrain classification and path planning for the UGV [11], or supporting the UGV navigation as in case of GPS loss [12]. In the work reported in [13] a coordinate control based on probabilistic approach for UAV and UGV teams is employed in pursuit-evasion games. UAVs and UGVs are used for surveillance tasks in [14] and [15], for cooperative mapping in [16], and for detection and disposal of mines in [17].

II. THE COMPUTER VISION ALGORITHM

In order to allow the cooperation among the two robots, 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 pointed directly upward at the sky. Four strips of high-intensity LEDs have been placed at the edges of the quadrotor, under the chassis, to augment the contrast of the acquired images and to improve the recognition of the flying platforms. The algorithm is based on the following eight main steps:

a) Image acquisition and binarization by thresholding (Fig.1a).

b) White pixels extraction from the original image: this operation allows highlighting 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). Classical camera model is adopted to convert the estimated position from the pixels to the Euclidean space.

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.

The led strip in the front part of the UAV has eight LEDs, while the other strips are constituted by four LEDs. This allows to detect the front part, thanks to the higher intensity of the light, and to estimate the heading angle of the vehicle.

The camera adopted in the experimental trials was a Logitech HD Webcam C310, with a resolution of 640x480 pixels, a vertical field of view of 33°. The algorithm was capable of processing the images acquired at 25fps.

The localization 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.

III. GIS FOR TRAJECTORY PLANNING AND MONITORING

GIS provide different functionalities, including the storage, processing and representation of all possible information from media geo-maps, satellite positioning systems, innovative systems for remote sensing, modelling and environment mapping. Therefore GIS technologies as support for the navigation of mobile robots, allow to plan and define optimal paths depending on the actual characteristics of the robot and on the external environment where it operates.
The software platforms that use the functionalities typical of the GIS are divided in Desktop GIS and WebGIS, allowing the distribution on the web of all data and tools of the GIS.
The data managed and used within the GIS architecture are enriched by spatial characteristics successively georeferenced in the territory. These data can be divided into two main categories, called raster and vector.

Raster data represent the cartographic support used in the GIS environment, including satellite images, orthophotos, etc. as it is show in Fig. 2.
Vector data comprises geometric primitives, to computerize, interconnect and represent each element of the territory, e.g. towns, road infrastructures, and network services. To this aim, a support database is used for the storage and management of spatial data. In Fig. 3 a screenshot of vector data managed in the Desktop GIS is represented.

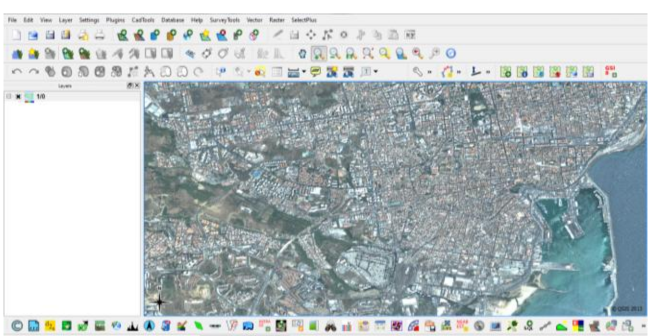

Fig. 2: Raster data managed in the Desktop GIS: Satellite image, 2006-2007 WGS84 Quickbird.

Fig. 3. Vector data managed in the Desktop GIS.

In order to assign the path for the UGV and the UAV in this work only free and open source GIS technologies have been adopted. The developed GIS architecture 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 architecture, different kinds 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 Qgis (http://www.qgis.org/) and GRASS (http://grass.osgeo.org/) were adopted, while the webGIS platform has been developed customizing Mapserver (http://mapserver.org/) and OpenLayers libraries (http://openlayers.org/). For the spatial database PostGreSQL with the spatial extension PostGIS was used.
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. As cartographic support, 2007-2008 orthophotos managed in the GIS desktop environment as WMS (Web Map Service) raster layer were used. The possible routes were digitized in overlap as linear vector themes, while the possible starting and ending points as punctual vector themes. Successively these themes have been exported in the spatial database and stored in a relational data structure. Finally the spatial table containing the possible paths was converted into text files for the robot and the UAV. Thanks to the connection between the webGIS and the spatial database, this information is also available on line.
Using the Network analysis tool in GRASS, we determined the optimal path to be assigned to the robot or UAV, in terms of short distance or depending on the characteristics of the territory (e.g. the slope).
The webGIS platform, shown in Fig. 4, was developed with the free JavaScript library OpenLayers (http://openlayers.org/).

It has been customized to manage the possible paths for the robot thanks to the real-time tracking of the robot position in the GIS environment using the information collected through the GPS installed on board.

Fig. 4. WebGIS platform developed with the free JavaScript library OpenLayers. On the left side, a large map area, latitude/longitude of the possible paths digitalized, and a mask control for the GPS receiver, are available. On the right side, a retractable layer tree is displayed together with different tools at the top bar.

Using the standard libraries, simple geometric primitives can be digitized on the cartographic support as simple drawings, not georeferenced. To overcome this limitation, a JavaScript and PHP application was implemented to digitize geometric primitives (points, lines and polylines) on the raster supports available in the webGIS platform that can be managed as vector layers. In this way they are characterized by spatial information, e.g. the latitude and longitude of each vertex, which can be saved as waypoints in text file used by the navigation system of the robot. With this procedure, the webGIS platform can be used to assign the path to the robot.

IV. RESULTS

In order to validate the proposed approach several trials have been performed in static and dynamic tracking. As regard dynamic tracking testing of the architecture has been carried out by using a tracked vehicle made by ETNAMATICA S.r.l (www.etnamatica.com) and a Hummingbird quadcopter by Ascending Technology. The tracked UGV, shown in Fig. 5 with the quadcopter on-board, has two independent DC motors driven by two CAN bus based drivers.

Fig. 5. The adopted UGV platform with the quadcopter on-board ready to take-off.

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.

A typical mission consists of the following steps:

i. A preliminary trajectory for the UGV is planned on the WebGIS or on the Desktop GIS platform;

ii. The UGV is moved autonomously with the supervision of the operator, looking at the onboard camera and on the actual position of the vehicle on the map;

iii. When, from the images or from the map, the supervising operator recognizes a difficult situation, he can command the quadcopter to take-off from the UGV;

iv. Once a given height is reached, the vision-based tracking algorithm is activated and the UAV begins following autonomously the UGV trajectory;

v. In the meantime the aerial images are transmitted to the base station and allow the operator to eventually reschedule the UGV trajectories or manually control the robot;

vi. When the problematic environment is passed, the quadcopter lands on the UGV and the mission continues.

As soon as the quadcopter is on the UGV it could also recharge its batteries, thus increasing its autonomy. The landing operations on the UGV are not autonomous on the actual version. Fig. 6 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.

The tracking algorithm is robust to external disturbances as the terrain irregularities found from the UGV and the wind; moreover, it allows the UAV to follow the UGV moving at its maximum speed of 1m/s.

Fig. 6. The vision tracking system computing the position of the quadrotor.

With the actual approach, weather and light conditions can influence the proposed algorithm. Further work is in progress to overcome these difficulties by putting the camera on-board the UAV and the visual target on the UGV.

As an example of tracking, in Fig. 7 the relative trajectory executed during a windy day with wind gust above 6m/s is shown. The red arrows represent the control action on each point. Fig. 8 reports the distance from the target position, while in Fig. 9 and Fig.10 the altitude and the heading estimated by the vision algorithm for the same trial are shown. The peaks in the altitude and in the heading are due to unfiltered noise in the images. As it can be seen the mean error is 0.633m with a standard deviation σ=0.22m and a maximum error of 1.2m for a relative altitude with respect to the target of about 5m.

In Fig. 11 an aerial view of the UGV from the camera on-board the quadcopter, is shown.

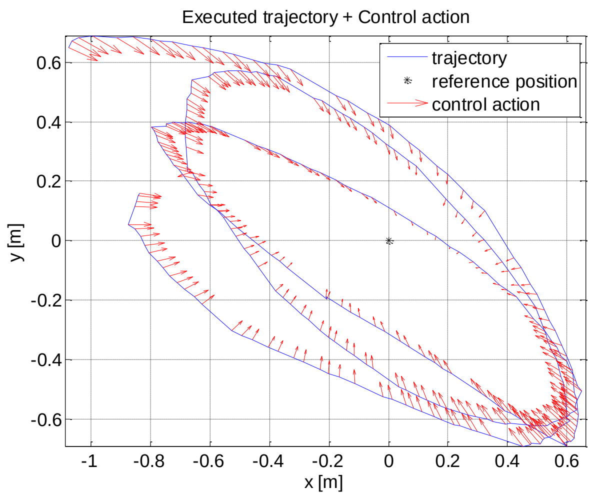

Fig. 7. An example of tracking during a windy trial.

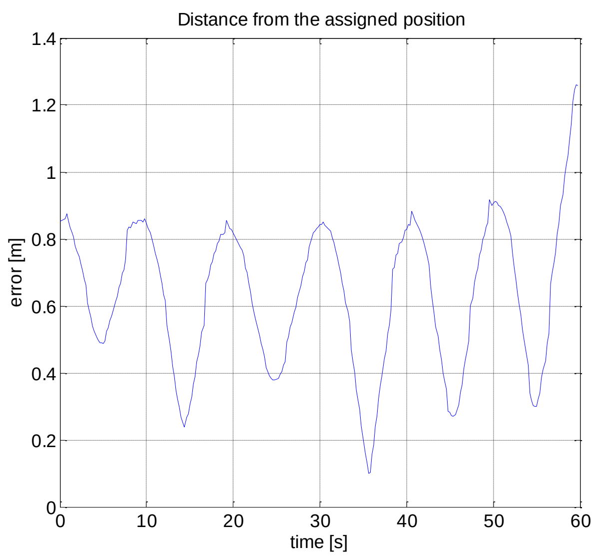

Fig. 8. Distance from the target position.

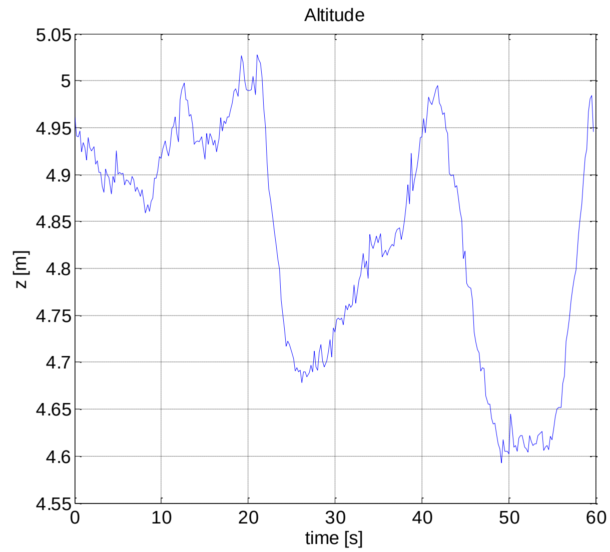

Fig. 9. Altitude estimation by means of the vision algorithm.

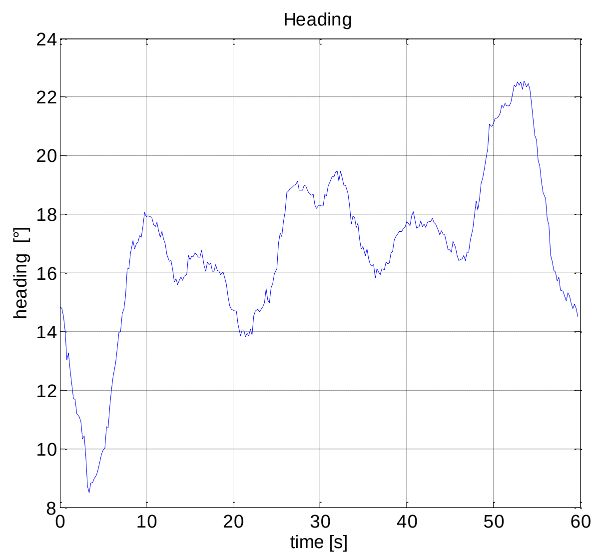

Fig. 10.Heading estimation by means of the vision algorithm.

Fig. 11. An aerial view of the UGV as seen from the quadcopter.

V. CONCLUSIONS

In this work a strategy to improve the capabilities of an Unmanned Ground Vehicles by using the images taken from a 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.

The system will be adopted to help remote teleoperations of ground robots in humanitarian demining operations within the TIRAMISU project.

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