Conference and Exhibition of the European Association of Virtual and Augmented Reality (2014)
G. Zachmann, J. Perret, and A. Amditis (Editors)

DroneAGE: an Advanced Graphic Environment for planning and control of Drone missions

E.Romano[1], M.G.Todeschini[1], G.P.Viganò[1] and M.Sacco[1]

[1] CNR-ITIA Istituto di Tecnologie Industriali ed Automazione,
via Bassini 15, 20133 Milano, Italy, tel: +39 02 2369 9602, fax: +39 02 2369 9616,
e-mail: enrica.romano, mauro.todeschini, giovannipaolo.vigano, marco.sacco@itia.cnr.it

Abstract

Unmanned Aircraft Systems (UASs, commonly known as "drones") have proven to be useful as a platform for remote sensing (RS), that is the acquisition of information about objects, areas or phenomena from a distance, without making physical contact. Benefits are the operational flexibility, the possibility to be used in challenging situations and the higher spatial and temporal resolution of acquired data if compared with alternatives (satellites, aircrafts, ground vehicles, etc.).
The paper presents DroneAGE, a software system that supports RS missions featuring UASs bearing different users, ranging from the mission planner to the pilot to the recipient of measured data.
The main component of the system is a virtual environment (VE) that shows the operational scenario and contextualizes relevant information about it; the goal is to provide unordinary features (i.e. usually unavailable within the tools bundled with the UASs) through an intuitive and natural interface that enhances the situation awareness of UASs operators. Independence from third party services, flexibility in terms of supported input/output devices, adaptability to other contexts and extensibility have been considered as priorities.
This work has been conducted in the frame of Progetto Space4Agri supported by AQ-Regione Lombardia-CNR.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [INFORMATION INTERFACES AND PRESENTATION (e.g., HCI)]: Multimedia Information Systems - Artificial, augmented, and virtual realities, I.3.7 [COMPUTER GRAPHICS]: Three-Dimensional Graphics and Realism - Virtual reality, D.2.2 [SOFTWARE ENGINEERING]: Design Tools and Techniques - User interfaces

1. Introduction

UASs can provide considerable advantages as a platform to support data acquisition if compared with more established tools (i.e. satellites, aircrafts, ground vehicles, etc.). Over the last years the adoption of such systems has been growing among different areas, earning an important role also in the civil sector, although the technology origin is mainly military. Some of these advantages are the relative low costs, the possibility to change the payload configuration and to re-plan a mission quickly, as well as the qualitative and quantitative improvements for RS results [Mir08].
UASs have found their way in operations that need to collect data from the ground. A wide range of passive sensor typologies can be installed on mobile platforms (e.g. aircrafts, satellites, ground vehicles, etc.) covering the visible, near infrared and thermal infrared spectrum among others, or active ones such as LiDAR (Light Detection and Ranging) and SAR (Synthetic Aperture Radar). Advances in miniaturization and energy efficiency have enabled RS to become one of the most exploited applications of UASs.
UASs are increasingly used as a platform for RS in agriculture: Precision Agriculture (PA) is considered one of the most important innovations of the last few decades. PA relies on acquisition of large quantities of data, which are processed on a spatial and time base to accurately determine the amount of seed, nutrients, water, pesticides and other substances that have to be supplied as well as the exact point of application. The goal is to increase agricultural production while reducing the use of substances in order to obtain environmental and economic benefits [Mul13].
Sometime UASs are mentioned as Remotely Piloted Aircraft Systems (RPASs): this expression emphasizes a UAS can hardly overlook the presence of a remote pilot. Even in

DOI: 10.2312/eurovr.20141338

situation where automatic flight is feasible and the most appropriate solution, a pilot can supervise the mission and react to unexpected situations by means of hardware/software interfaces and wireless links. The main concern and one of the main barriers to the spread of commercial UASs is safety. The risk of losing the control of the aircraft and of its fall down due to a lack of reliability of the system or a human mistake reduces applicability of these vehicles. The possibility of a fall down and therefore losing the vehicle and hosted systems dissuades the use of expensive payloads.

The civil aviation institutions and authorities of many countries have been recently working to define proper rules and regulations to increase safety. The goal is to have a regulatory system that is as uniform as possible among countries and in line with the needs of the sector as well as the community. In the European Union the regulation concerning UAS weighing less than 150 Kg is entrusted to individual countries that have only recently put specific rules into practice or, in some cases, which are in the process of doing that.

In Italy the sector is regulated by the *Regolamento "Mezzi Aerei a Pilotaggio Remoto"* (RMAPR) issued by the *Ente Nazionale per l'Aviazione Civile* (ENAC, National Civil Aviation Authority of Italy) on December the 16th, 2013 [Ena13] and deferred until April the 30th, 2014; the regulatory situation in Italy is still not definitive as ENAC has issued a series of documents to clarify and complement the RMAPR, which are currently in draft status [Ena14].

2. High level goals

DroneAGE development has been conducted in the frame of Space4Agri project supported by the bilateral agreement between Regione Lombardia and Consiglio Nazionale delle Ricerche (CNR, National Research Council of Italy). Space4Agri main goal is to define and develop appropriate tools to enhance planning and management capabilities of agriculture in Lombardy and support its stakeholders. The purpose is to improve competitiveness while gaining sustainability; the need to develop an integrated knowledge base/information system has been underlined also by recent water stress events; in particular the anomalies registered in 2003 [CRV*05] and, more recently, by the unexpected and significant reduction in corn crop registered in 2012 in Lombardy with relevant consequences on agribusiness [BBC*13].

The approach followed in Space4Agri gives particular relevance to the correlation of data acquired through three complementary platforms: satellites, UASs and smart/mobile devices.

3. DroneAGE

DroneAGE focuses on aspects related to UASs mission planning and control with particular interest to RS thematic and its applications. DroneAGE puts particular emphasis on acquired data as the result of the mission, moving away from the mission planning and flight control details that are already adequately considered by ground station software (GSS) bundled with UASs. The reference actor of DroneAGE is the customer of data results, being it a researcher, a farmer, a food safety agent, a public safety responsible or a public authority official; the pilot is not the main reference figure of DroneAGE as it is in GSS.

Being oriented to users that are not necessarily specialists of flight and related problems, great attention has to be put on human-machine interface, both on the side of hardware devices and on the one of software presentation and interaction. An untrained operator is presumed to be more prone to source of distraction or to overlook particular circumstances, being slower in reactions to unforeseen events because of the lack of a specific training. DroneAGE interface must ultimately improve operator *situation awareness* by presenting relevant information in an intuitive fashion, by omitting distracting information or representations and by highlighting important circumstances or aspects. Virtual Reality has proven to be an effective tool to achieve these goals for its high flexibility in terms of scope and purposes [VGMS11], [VMG*04].

Pilots of Unmanned Aircraft Vehicles (UAVs) are not neglected by DroneAGE: even if commercial UASs are bundled with proprietary software which offer configuration of the aircraft, flight planning (e.g. through the definition of waypoints) and control of flight at least [TLDP13], a different approach may be more advisable considering the different users that DroneAGE is target to.

The preliminary requirements of DroneAGE were defined in collaboration with the Italian company Aermatica S.p.A. to complement, integrate and enhance the mission planning and flight control software of its ANTEOS RPAS system [Aer14].

One of the requirements is to visualize and lay down efficiently Flight Spaces (FS) and related information. The relevant concepts often adopted to delimit UAVs flight are:

- Flight Zones (FZ)/No Flight Zones (NFZ): i.e. areas where it is allowed/denied the flight of the UAV
- Landing Zones (LZ)/No Landing Zones (NLZ): i.e. areas where it is allowed/denied the landing of the UAV
- Flight Constraints (FC): as an example, it is possible to define a surface that the UAV can stick to, so that it can accomplish its tasks from a very precisely predefined position.

DroneAGE interface can be decomposed in two main components: the VE and the 2D Graphical User Interface (2DGUI).

The VE is in charge of the visualization of a Virtual Globe (VG) as an abstraction to contextualize other relevant information. The visual appearance of the VG derives from different data-sources: Digital Elevation Models (DEM) for the terrain morphing and various kinds of image maps that are projected onto them. In addition to these features the VE can display suitable information as colored 3D shapes:

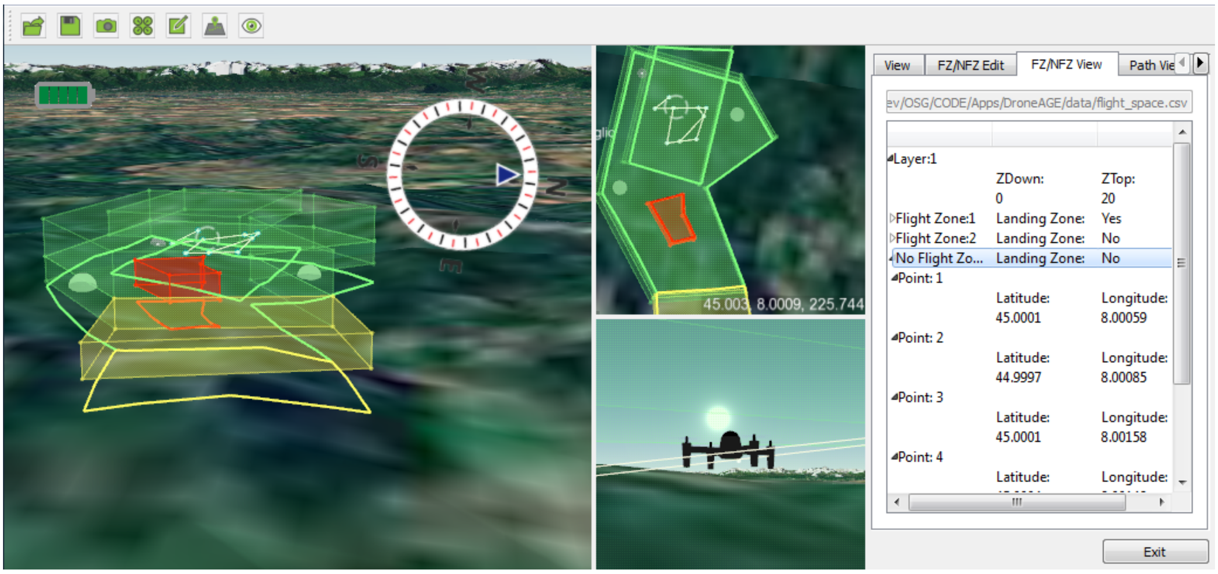

Figure 1: *DroneAGE main window*

The use of a 2D representation of the FZs (sometimes adopted by UASs software tools) decreases the capability to detect altitude boundaries and may lead to critical situations. The VE of DroneAGE can be freely explored to observe the FZs, FP and the UAV position in relation to the VG.
The 2DGUI displays numerical and structured data, their logical relations and allows the access to relevant features of the software tool. These features include:

- defining the FS as a composition of FZs and NFZs, accurately specifying the numerical and geometrical properties of each of them
- showing/hiding of georeferenced visual information (e.g. FSs, FPs) in the context of the VG
- configuring multiple views of the VG
- modifying the VG lighting conditions based on the realistic effects of sun and stars positions
- accessing the FSs, FZs and NFZs import features.

The 2DGUI allows the specification of accurate numerical values (e.g. the geographical coordinates of points) whereas the VE shows them in a more natural and intuitive way. Their complementarity may be exemplified by the alternative representations of a FP, which is a sequence of segments in the VE and a list of waypoints in the 2DGUI.

An event system (ES) has been designed to mediate data communication among DroneAGE components providing maximum decoupling and flexibility. The ES implements the publish/subscribe pattern where an event, conceivable as a data blob, is notified and made accessible to a set of interested components.
The ES core can manage multiple different event typologies transparently: it doesn't handle semantics of events while performing notification and transport.

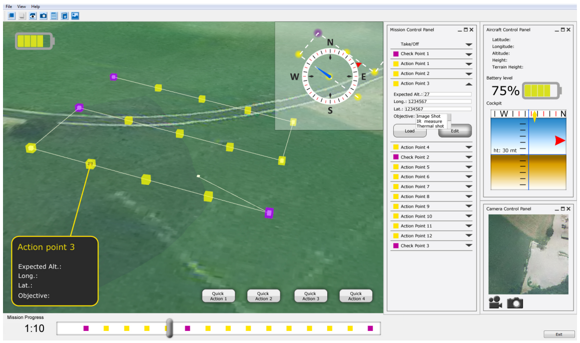

Figure 2: *DroneAGE interface layout (preliminary concept)*

The semantics of an event must be known and shared only among producer (publisher) and consumers (subscribers) of the event.
The architecture is flexible:

- an event may be notified to one or multiple subscribers
- the subscribers interested in an event typology may vary at execution time in number and behaviour
- it is acceptable if there is no subscriber interested in an event at a specific time: in that circumstance the event would be discarded
- it is acceptable if a subscriber of an event typology is not even implemented in the system
- it is possible to define and implement the subscriber of an event before the publisher
- a single event may be notified to multiple subscribers

- multiple events (possibly of different typologies) may be notified to a single component.

The decoupling is achieved through the ES core (EventsCore in Figure 3): the only component which publishers and subscribers interact with. Since publishers and subscribers interested in a specific event may concern different subsystems of DroneAGE, events have to be highly general in data types and semantics. General events and the ES core as the only mediator, on the other hand, make it easier to substitute or backup a component with another one.
Sources of events that must be considered are: user input (VE, 2DGUI), UAS telemetry, data sources (maps, DEM, 3D models availability, etc.), RS subsystem, etc.

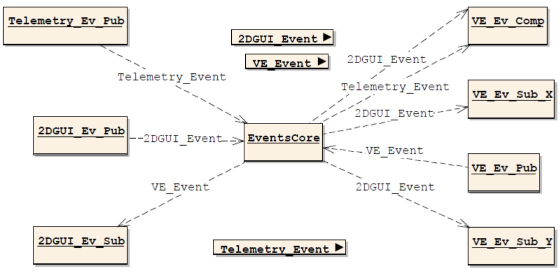

Figure 3: *DroneAGE ES*

In Figure 3 three different events are notified by publisher components and transferred to subscriber components for proper reaction. The same event may be notified to different components and there are single components that are interested in different event typologies.
The current overall DroneAGE architecture is depicted in Figure 4; while some components have already been introduced (VE, 2DGUI, ES Core) others take part or have been planned:

- **Data(Core)** constitutes a single point of access to data that is relevant to different components; this way data is not duplicated, all components view the same data and there is no need of replication/synchronization mechanisms.
- **Input/Output** functionalities transform data (e.g. FSs, FZs, NFZs, FPs, etc.) for use in DroneAGE and vice versa.
- **3rd Party HW/SW Interfaces** take care of interaction with devices (e.g. UAS, ground control station, communication system, etc.) and data repositories.

The architecture in Figure 4 represent the status of DroneAGE nowadays or in the near future, but it is expected to enrich of new components as long as new features are implemented or new goals are pursued.

DroneAGE has been developed in C++ for the Windows OS, mainly adopting cross-platform toolkits and libraries

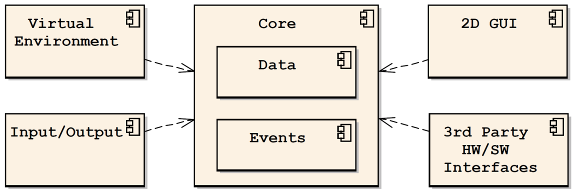

Figure 4: *DroneAGE overall architecture*

selected for their features and after assessments of the restrictions of their licenses. In particular OpenSceneGraph [Osf14], osgEarth [Pel14] and Qt [Dig14] have been extensively employed.

4. Working with DroneAGE

The services provided by DroneAGE can be associated to two main phases: mission planning and flight control.
Mission planning is supported by the access to online maps and DEMs sources or the availability of such data in the local file system. While highly detailed or complete information is not a strict requirement, it allows the user to plan the mission according to local constraints (terrain height, buildings, roads, facilities, etc.).

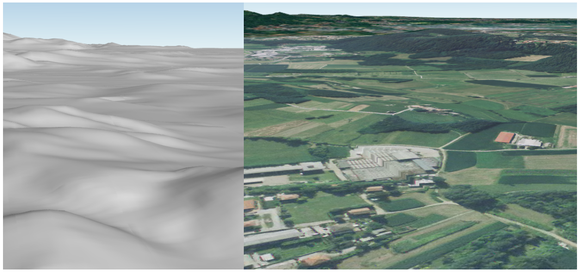

Figure 5: *A DEM (left) and an orthophoto (right)*

According to the mission goals the user can load different kinds of maps, also mixing them together, overlapping maps with different resolution and content, or even blending them using transparency.
Appropriate 3D models (e.g. buildings, facilities, etc.) can be loaded in the VE and used as spatial reference for mission planning if required.
DroneAGE supports different file formats both for raster (e.g. GeoTIFF, JPEG+TFW) and for vector data (e.g. ESRI Shapefile, GeoJSON), whereas 3D models can be loaded from KML files or from other formats (e.g. COLLADA, FBX, 3DS, OBJ, LWO, DXF).

DroneAGE can also access various Internet data services (e.g. OpenStreetMap, MapQuest) for "just in time" downloads of raster data (i.e. when and if the data is required for visualization in the VE).

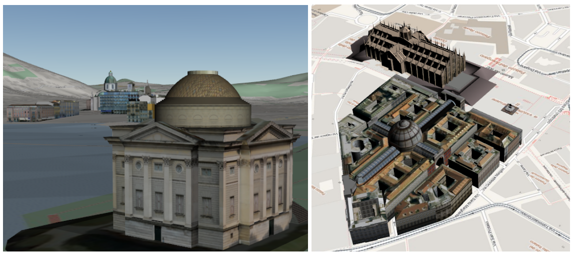

Figure 6: *3D models of buildings loaded as shown in the VE*

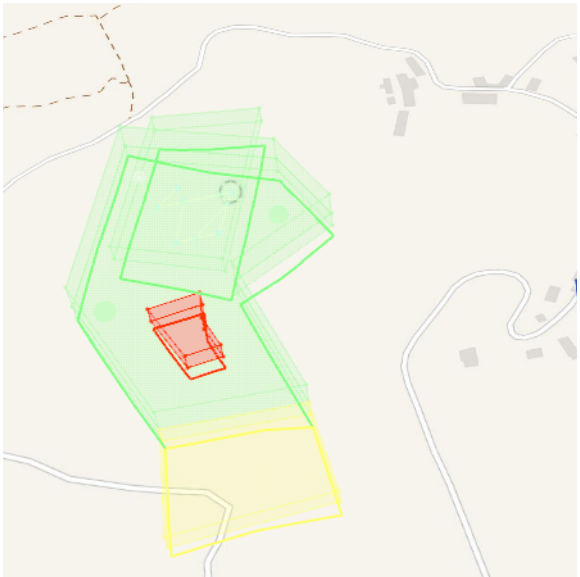

Figure 7: *DroneAGE: FS visualization on a street map*

Flight spaces, flight paths and safe landing places that have previously been saved, can be loaded from the local file-system and used as a starting point for a new mission scenario.
Flight space and flight paths can be edited both visually (dragging points in the VE) and numerically (editing coordinates with the 2DGUI), while a visual feedback is instantly provided from multiple perspectives (e.g. top, side). Different kinds of waypoints along the FP are distinguished through different visual representations.
When the mission planning has been completed, DroneAGE assists the flight control through its high level interface in conjunction with the software bundled the UAS for.
A connection to the ground control station is required and may be implemented through the integration of a proper software layer provided by the UAS vendor or the development of a specific module that must be compliant with the specifications of the UAS interfaces. This link permits the access to the telemetry data allowing virtual visualization of the flight in DroneAGE and detection of critical situations through visual warnings (and possibly audible ones), or the approach of specific locations that have been defined in the planning phase (e.g. waypoints or flight space borders).
Some of the features previously described, even if already designed, are still under development.

5. Conclusions

The main goal of DroneAGE is to achieve an interface that improves the pilot *situation awareness* without distracting or overloading him with information: the VE represents "intangible" information that is crucial to UAS flight in a natural and intuitive way. The system is still in early stages of development but its architecture and the middleware adopted encourages extensions. The VE may be enhanced integrating visual recommendations or warnings to highlight dangerous situations.

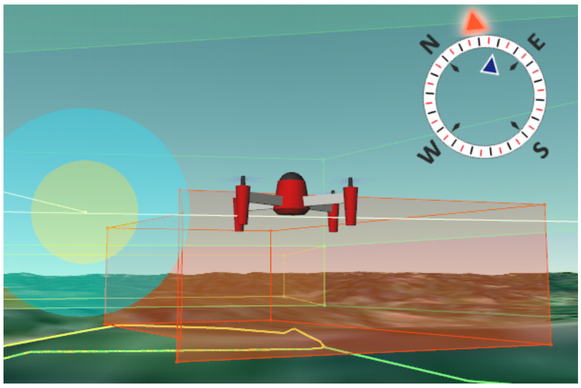

Figure 8: *Concept of a visual warning (the red arrow stresses NFZ proximity)*

The opportunity to use various data sources (both online and offline) makes DroneAGE a versatile tool for RS missions support as well as an advanced interface for flight control. DroneAGE does not depend on a single external service, neither it is bound to maps provided by a specific external tool; conversely it is compatible with different data formats: third party orthophotos, DEMs and other raster or vector data.
The software has been designed and developed with flexibility in mind: it may potentially be used in different scenarios such as the management of emergencies (e.g. fires, floods, landslides) and, in general, in any application area in which UASs have been adopted.

6. Future works

In the future efforts will be put on the issue of DroneAGE integration with third party software and hardware.

DroneAGE should be able to support different UASs typologies and models, possibly supporting missions involving multiple UASs. In this scenario each UAS should be associated to a specific FP and FS.
Automatic path planning strategies might be integrated as well to ease flight trajectories optimization on the base of constraints such as desired coverage area and obstacles avoidance [BCC*11], [EL14].
Custom wireless communication patterns/architectures/ technologies might be exploited to increase reliability, area coverage and responsiveness especially when UAV fleets are involved; benefits would pertain flight and sensor control, data retrieval and in progress mission evaluation [AAD*13].
An interesting improvement could be a tighter integration with data post-processing software to visualize results in the VE (e.g. 3D models, point clouds, georeferenced orthophotos) for evaluation, interpretation, correlation and proper reaction.
On the hardware side, the use of a see-through HMD might allow simultaneous view of the real scenario and virtual superimposed information relevant to the operator. Mobile devices (e.g. tablets, smartphones) may be evaluated as input/output devices and for use in the field.

7. Acknowledgements

The authors would like to thank Aermatica for having shared its experience in design, manufacture and marketing of UASs, for having contributed to the definition of the needs of the sector and to actively cooperate on interaction/interface issues between DroneAGE and ANTEOS.
The authors wish to thank the graphic designer Nicola Colosio for his contributions to the graphical design of DroneAGE.
The authors also thank Regione Lombardia: this work has been conducted in the frame of Progetto Space4Agri supported by AQ-Regione Lombardia-CNR, Convenzione Operativa n. 18091/RCC, 05/08/2013).

References

[Aer14] AERMATICA: *AERMATICA obtained the first Permit to Fly issued in non-segregated airspace for RPAS in Italy.* Available from: http://www.aermatica.com/aermatica-ottiene-per-anteos-il-primo-permesso-di-volo-in-spazio-aereo-non-segregato-rilasciato-in-italia-per-un-apr/ [Accessed 26th June 2014]. 2

[AAD*13] ACEVEDO, J.J., ARRUE, B.C., DIAZ-BANEZ, J.M., VENTURA, I. ET AL.: Decentralized strategy to ensure information propagation in area monitoring missions with a team of UAVs under limited communications. *2013 International Conference on Unmanned Aircraft Systems (ICUAS). Atlanta, GA 28-31 May 2013*. doi:10.1109/ICUAS.2013.6564734. 6

[BBC*13] BRIVIO P.A., BOSCHETTI M., CARRARA P., RAMPINI A. ET AL.: Metodologie aerospaziali di Osservazione della Terra a supporto del settore agricolo in Lombardia. *17ª Conferenza Nazionale ASITA. Riva del Garda 5-7 Nov. 2013*. 2

[BCC*11] BARRIENTOS, A., COLORADO, J., CERRO, J. D., MARTINEZ, A., ET AL.: Aerial remote sensing in agriculture: A practical approach to area coverage and path planning for fleets of mini aerial robots. *Journal of Field Robotics, 28*, 5 (Sept. 2011), 667–689. doi:10.1002/rob.20403. 6

[CRV*05] CIAIS, P., REICHSTEIN, M., VIOVY, N., GRANIER, A. ET AL.: Europe-wide reduction in primary productivity caused by the heat and drought in 2003. *Nature, 437*, 7058 (Sept. 2005), 529–533. doi:10.1038/nature03972. 2

[Dig14] DIGIA: *Qt Project.* Available from: http://qt-project.org/ [Accessed 2nd July 2014]. 4

[Ena14] ENAC: *ENAC Home Page* Available from: http://www.enac.gov.it/Home/ [Accessed 17th July 2014]. 2

[Ena13] ENAC: *Regolamento "Mezzi Aerei a Pilotaggio Remoto".* Available from: http://www.enac.gov.it/repository/ContentManagement/information/N122671512/Regolamento_APR_ed.1.pdf [Accessed 17th July 2014]. 2

[EL14] ERGEZER, H., LEBLEBICIOGLU, K.: 3D Path Planning for Multiple UAVs for Maximum Information Collection. *Journal of Intelligent and Robotic Systems, 73*, 1-4 (Jan. 2014), 737–762. doi:10.1007/s10846-013-9895-6.

[Mir08] MIRANDA, G: *Simulatore di interfaccia uomo-macchina per il controllo di UAV*, Ph.D. Thesis. University of Bologna: Italy (2008). 1

[Mul13] MULLA, D. J.: Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. *Biosystems Engineering, 114*, 4 (April 2013), 358–371. doi:10.1016/j.biosystemseng.2012.08.009. 1

[Osf14] OSFIELD, R.: *The OpenSceneGraph Project Website.* Available from: http://www.openscenegraph.org/ [Accessed 2nd July 2014]. 4

[Pel14] PELICAN MAPPING: *osgEarth. Terrain on demand.* Available from: http://osgearth.org/ [Accessed 2nd July 2014]. 4

[TLDP13] TORRES-SÁNCHEZ, J., LÓPEZ-GRANADOS, F., DE CASTRO, A. I. & PENA-BARRAGÁN, J. M.: Configuration and specifications of an unmanned aerial vehicle (UAV) for early site specific weed management. *PLoS ONE, 8*, 3 (March 2013), e58210. doi:10.1371/journal.pone.0058210. 2

[VGMS11] VIGANÒ, G.P, GRECI, L., MOTTURA, S. & SACCO, M.: GIOVE Virtual Factory: A New Viewer for a More Immersive Role of the User During Factory Design. *Digital Factory for Human-oriented Production Systems*, Springer London, 12 (2011), 201–216. doi:10.1007/978-1-84996-172-1_12. 2

[VMG*04] VIGANÒ, G. P., MOTTURA, S., GRECI, L., SACCO, M. ET AL.: Virtual Reality as support tool in shoe life cycle. *International Journal of Computer Integrated Manufacturing, 17*, 7 (2004), 653–660. doi:10.1080/0951192042000273131. 2