Aerospace-based support systems and interoperability: the solution to fight illegal dumping

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Abstract

Every year in Italy, hundreds of illegal dumping activities are detected but it is believed that there could be up to 10 times more, where the majority go undetected and are never penalized. New administrative measures against illegal dumping need to be developed that involve patrolling for illegal dump sites and dumping activities, and developing new databases for documenting their existence. This paper introduces an aerospace-based support system to fight illegal dumping and to help local governments to study their environmental impact, mapping the results of the investigations as well as collecting site specific information. Currently a wide variety of aerospace platforms (satellites, aircraft, helicopters, unmanned aerial systems, etc.) are available to monitor environmental problems, but their real effectiveness is often limited due to the capability of the on-board sensors. The availability of a high altitude viewing platform provides broad coverage, but often the technical limitations of the sensors require a mission profile close to the target to acquire high resolution data. Currently, the Italian Aerospace Research Center is developing a system, entitled "Aerospace Interoperability Framework", that provides a complete framework composed of flight and ground segments, communication links, acquisition sensors, mission paradigm logic and scheduling, data acquisition paradigm and logic, and data processing. A detailed overview of this aerospace-

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based support system and criticalities associated with discovering illegal landfills will be introduced in this paper and, particularly, the improvements to the patrolling services by the administrative staff.

Keywords: illegal dumping, landfills monitoring, interoperability, unmanned aerial systems, airship, multi-rotor.

1 Introduction

Together with air and water, soil is an important environmental matrix for the existence of living species on the planet. Despite this, too often it is considered only as a physical basis to develop human activities.

Soil is a complex living body, continuously evolving and not well-known yet. It provides the humanity with vital elements but also a non-renewable and extremely fragile resource.

It may be subject to severe degradation processes (arising from incorrect agricultural practices, concentration of population and economic activities in localized areas, climate changing and variations of land use itself), that limit or totally inhibit the functionality. These processes are often highlighted only when they are irreversible, or in a state so advanced that it will be extremely expansive to restore. Clear examples are contaminated sites, a common problem to all industrialized countries. The presence of human activities (such as industries, mines, landfills and other structures that can result in local soil contamination phenomena, for spills, leaks, tanks, improper waste management, etc.) and any kind of pollution punctual sources are the most difficult to monitor (ISPRA [15]).

Because of the illegality of the phenomena it is difficult to size the problem correctly. In 2002 Italian State Forestry Corps made a census to catalogue Italian illegal dumping sites. By means of the census it can be possible to estimate the presence of 4866 illegal dumping that cover an area of 19Km^2. Only 21% of surveyed landfills have been reclaimed, more than 700 contain hazardous waste, but probably this figure is underestimated in fact in many cases dangerous wastes are buried or mixed with ordinary ones. Nowadays probably that figure is considerably increased (C.F.S. [16]).

Probably identifying the problem as soon as it occurs would reduce reclamation costs. So it's necessary a more frequent and more targeted monitoring of the area. In this paper we propose a survey technique that can detect even at a very early stage source-point pollution generated by the issue of illegal waste.

The necessary information required to discovery illegal dumping will be improved by monitoring the scenario using aerial platforms and specific sensors, and this 3rd dimension vision is capital to bring support for decision making avoiding major ecological emergencies.

Today we knows how to place helicopters or airplane above areas, but the cost of using these machines is very high and, most of the time, they rely on physical persons to transmit images, when possible.

Currently a wide variety of aerospace platforms (satellites, aircraft, helicopters, unmanned aerial systems, etc.) are available to monitor environmental problems, but their real effectiveness is often limited due to the single platform capability and the on-board sensors. The aim of the collaboration between the DISAM department of Parthenope University, the CIRA, and the University of San Diego is to establish certain, repetitive and "open" methods "friendly use" for every public administration branches.

2 Aerospace platform and sensors interoperability

The availability of a high altitude viewing platform provides broad coverage, but often the technical limitations of the sensors require a mission profile close to the target to acquire high resolution data.

In the military field the interoperability of different platforms is a pragmatic problem and is under standardization (STANAG, JAUS).

This standardization will only cover aspects of inter communication or data-exchange standardization for different platform.

But we are interested to have interoperability capability at system level (Figure 1) in order to push an increase of the system of the systems autonomy and performance. For the system of systems autonomy we mean a self organization fleet of different platforms carrying different sensors aiming to solve a common task.

No one single aerial platform can provide both broad coverage as well as low altitude high resolutions measurements. Instead an integrated multi-vehicle system is needed that matches mission profile and sensor requirements. The aeronautical platforms for the acquisition of the information fly in a very critical environment: near ground and often in sub-urban area. In this scenario they

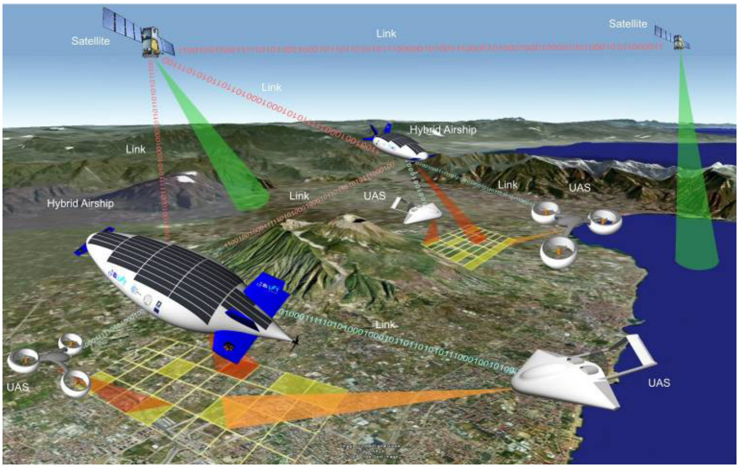

Figure 1: Interoperability concept outline.

ought to have high maneuverability for obstacle avoidance, and should be able to perform low velocity (possibly hovering) to easily track the target. The required altitude of the operation is low due to the moderate geographical extension of the interested area. Due to this consideration a fleet of Small Unmanned Airship and multi rotor sUAS as information acquisition platforms match the requirement.

The limits, mainly due to the size, of platforms sUAS and Airship may be overcome by shifting the complexity attribute from the individual platform to the system of systems controlling a fleet of single (simpler) platforms:

• considering a variety of aircraft to overcome the low autonomy and lower operating range of individuals.

•considering payload array cooperating and distributed on several platform to overcome the limit of a small payload capacity.

• adopting artificial intelligence technologies used in "swarm algorithms" to enable a single operator to control several aircraft.

• mitigating risks associated with harsh operating conditions (e.g. weather conditions) by the robustness of the swarm paradigm, allowing the system to be still effective even in case of loss of a single component (redundancy and resilience).

In this project as aerospace platform we are using also a Hybrid Airship and a multi rotor sUAV. The Airship: was developed at CIRA with the collaboration of University Parthenope. This Advanced Hybrid Airship (BI-Lift) (Figure2) is an innovative platform, to perform monitoring at low altitude, in the picture are listed some feature. Particularly, the Bi-Lift will allow the exploration of three-dimensional spaces without altering the measured parameters, returning geo-referenced data, guaranteeing minimal invasion and maximal safety for the operational context.

Multi Rotors are an emerging rotorcraft concept for unmanned aerial vehicle (UAV) platforms. The vehicle consists of four, six, eight, etc. rotors in total, with two pairs of counter-rotating, fixed-pitch blades located at same distance

SPECIFICATIONS

Length	10 m
Width	3,5 m (Dmax) – 2.2 m (Dmin)
Max Speed	50 Km/h
Payload	5 kg
Max weight (w/o helium)	20 Kg
Endurance	> 4 hours
Max. Altitude	1000 m
Control	RC/RPV/UAV

Plus:

- "Zero" emissions
- High maneuverability al low speed
- Easy handling
- Vertical take-off and landing
- Low cost management

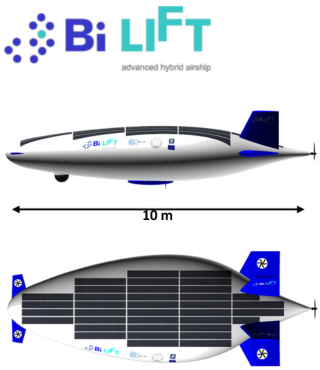

Figure 2: Advanced Hybrid Airship (BI-Lift).

from the center of mass of the aircraft. By enclosing the rotors within a frame, the rotors can be protected from breaking during collisions, permitting flights in obstacle-dense environments, with low risk of damaging the aircraft and the operators.

Due to its specific capabilities, use of autonomous multi-rotor vehicles has been investigated for a variety of applications both as individual vehicles and in multiple vehicle teams, applied in to surveillance, search and rescue and mobile sensor networks domain. We have defined the requirement of the multi rotor platform and the development will be done by NaturalDrones company. They have realized a six motor multi rotor, product name is Stillfly. In the next picture you see the platform and some performance (Figure3).

In order to control a multitude of platform we have developed a decentralized coordination algorithm based on digital pheromones, an extension of the use of potential fields to guide swarms of robotic entities. We are using a class of decentralized coordination called "stigmergy," the work performed by agents in the environment guides their later actions. The information stored in the environment forms a field that supports agent coordination, leading to the term "co[ordination]-field" for this class of technique. The two selected platforms are able to perform vertical take-off and landing (VTOL) in order to be operated directly from mobile ground control stations in unprepared terrains with vehicles similar to those used by the rescue and intervention teams this are strong advantages in logistic and deployment to complement other type of platforms. They are intrinsically safe whereas the low kinetic energy due to the low velocity and the low weight.

3 Mission

3.1 Methods and basics

The best results in illegal dumping detection have been obtained from the combined use of two or more geophysical methods. Currently, the most used

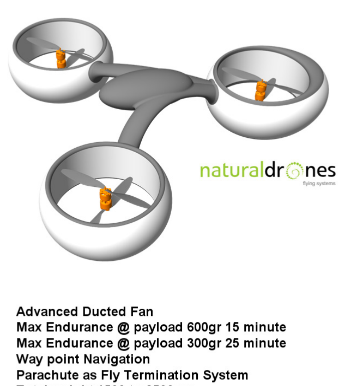

Figure 3: NaturalDrones Stillfly.

procedure to carry out investigations of piles of buried and illegal waste, utilizes synergic action of geoelectrical resistivity followed by ground penetrating radar technologies. First a tomographic research for localization of the mass followed by another research made with the GPR for site characterization. This procedure can provide excellent results for location, description of the allocation, size and type of storage. Morphology of the site to investigate could be a limit to the use of geoelectrical resistivity technology. Illegal dumps are often located in places considerably slope and hardly accessible by the operator. Another geophysical technique not widely used yet is the infrared thermography. Until a few years ago this type of research led to the cataloging simple images and consequently qualitative data.

Technological innovation in the infrared instrumentation field lets us choose a sensor with excellent technical specifications, high-definition, precision and sensitivity.

Each radiometric image has a resolution of 640x480 pixels; each pixel also corresponds to a value of temperature or emissivity (Figure 4) which is stored in a matrix (quantitative) ".csv" data. This matrix is easily re-usable for further processing with software tools such as MATLAB and Excel as well as infrared thermography software (ThermaCAM researcher, Reporter professional, Quick plot, etc). The instrument expresses its sensitivity and precision (45mK) not only in absolute and precise measures but above all in the differences between two adjacent measures which is essential in finding anomalies.

With regard to the ability to detect the smallest element in a scene (IFOV) this value depends mainly on the lens mounted on the sensor and on the distance from the target. For a 19mm lens and a 50 cm distance IFOV is 0.65 mm, with a distance of 100m the IFOV is 13 cm (see Figure 5). With a 76mm lens, however, the IFOV is 0.16 mm at a distance of 50 cm, 0.32cm and at a distance of 100m.

The image sensor acquisition frequency is 30Hz, this value makes possible to acquire images without smearing effect also if the operator is moving or the phenomena are evolving. The sensor is equipped with a GPS that allows the operator to geotag obtained images. Thanks to these characteristics is possible to use this sensor from an aerial platform, increasing in this way its effectiveness.

6,2	5,7	5,7	5,4	4,7	5,1
6,4	6,9	6,5	5,7	5,4	5
6,2	6,7	6,8	6	6	5,3
6,2	6	6,6	6,6	6,4	5,6
6	6	5,8	6,4	6,6	6,4
6	5,8	5,8	6,2	7,1	9,7
5,5	5,5	6	6,2	8,4	11,2

Figure 4: Measured temperature matrix.

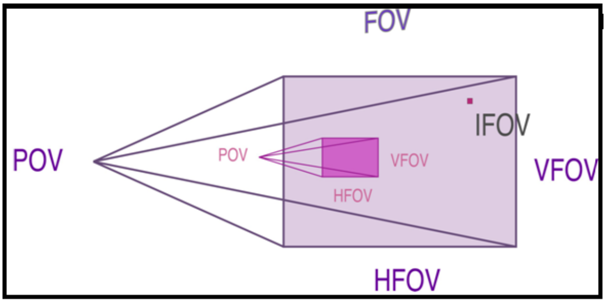

Figure 5: A graphic representation of: FOV = Field of View, POV = Point of View, VFOV = Vertical Field of View, HFOV = Horizontal Field of View and IFOV = Infinitesimal Field of View.

The advantages of using aerial platforms are represented mainly by: the increased field of view with the result of being able to patrol large areas quickly; the ability to reach areas otherwise unreachable; the coolness of the matrix we are investigated, a quick display of the extension of the survey phenomena; operator safety who doesn't have to expose directly to the risk of contamination. Infrared Radiometric Thermography is a passive non-invasive method that exploits the characteristic that everybody, struck by a source of energy (solar radiation) emits an amount of energy (Planck's law) which is proportional to the temperature of the body itself (Boltzmann law) and varies with forming material. Like all geophysical methods, thermography surveys anomalies (in this case thermal) to locate the phenomenon. Evaluation of thermal inertia is a measure of the thermal response of different bodies to daily and seasonally temperature changes.

The thermal inertia assessment allows objects to be identified, such as deposits of industrial waste in the form of sludges or slimes and masses of buried materials. Obviously, the greater the difference in thermal inertia between the buried bodies and the surroundings, the greater the depth at which the phenomenon can be highlighted.

Regarding the detection of landfills containing organic matter, the warm local production realized by bacteria for digestive processes is used. The main products of this digestion are biogas and leakage. In an illegal dump, and thus in the absence of facilities for conveying biogas, this gas mixture, which has a temperature of 30-40 °C, rises through layers of organic substance and soil; the effect is a ground surface warming that can be identified as a positive anomaly in thermography. The first phase of thermography investigations describes thermal anomalies found in the body of the dump, and in its closer neighborhood. For each anomaly, shape, size, sign and the intensity of the signal must be shown. The calibration of the real meaning of the anomalies found is up to expert researches and to measurements which must be conducted on site. The ultimate aim is to specify areas of potential interest for further analysis.

4 Results

Broadly speaking, a weak anomaly in a homogeneous field is much more significant than absolute high or low values. With this methodology we are able to:
-Assess the extent of storage of waste (Figure 6):

By means data as height, inclination corner between sensor and target, FOV, HFOV and VFOV, the perimeter of interested area is calculated.
-Identify and locate any possible accumulation areas for leachate and/or any possible leak of biogas that can compromise the quality of the air resulting in pollution (Figure 7);

Figure 6: Overlap of satellite view. The perimeter calculated is 1,67 Km using FOV and POV data.

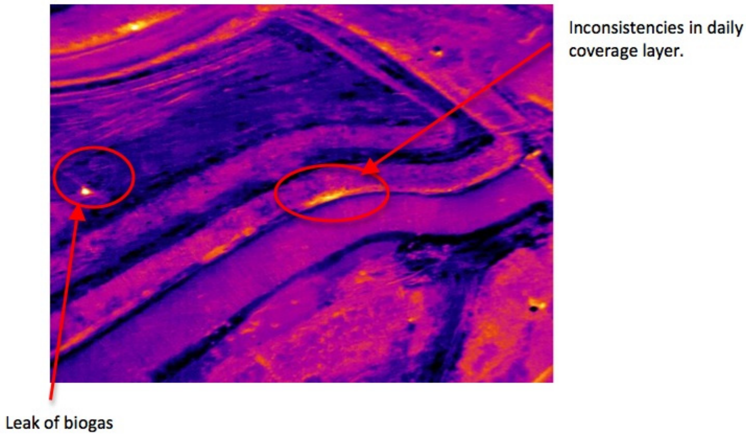

Figure 7: Thermal anomalies.

-Identify and locate any presence of bins and the like;
-Identify any possible connection between overlapping landfills (Figure 8), is possible to notice two different warm distributions between controlled landfills and uncontrolled ones. It can possible to evidence the neat thermal pattern detect in a controlled landfills and the heterogeneous ones in a heap waste.
-Assess integrity of waterproofing (Figure 9);
-Identify any possible inconsistencies (not homogeneous aspect) in the daily coverage layer (Figure 9);
-Identify any signs of groundwater pollution caused by landfill (Figure 10);
-Identify any possible breeding grounds of fire: because of smoke is transparent at infrared wavelength (Figure 11).

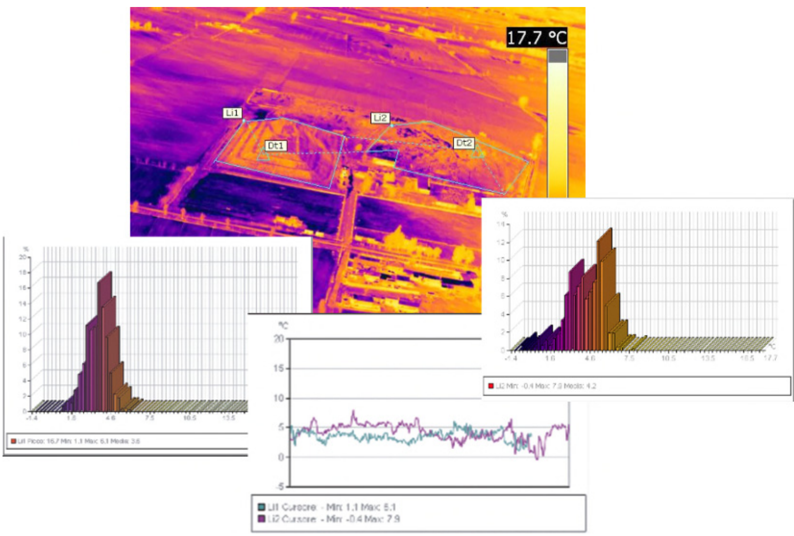

Figure 8: Data processing with thermal software shows two different warm distributions.

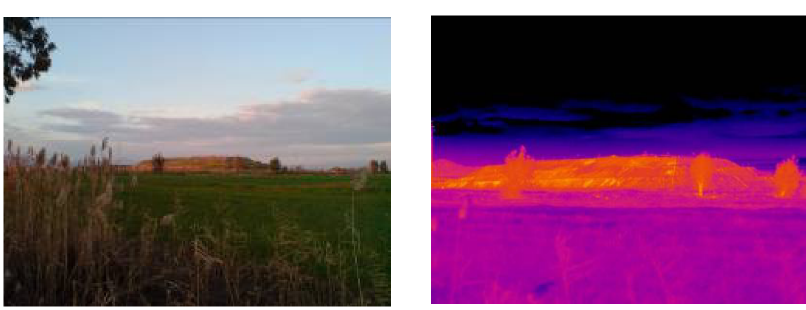

Figure 9: Positive anomalies that indicate a non-homogeneus daily cover and a part of the geomembrane that is not fully fashioned.

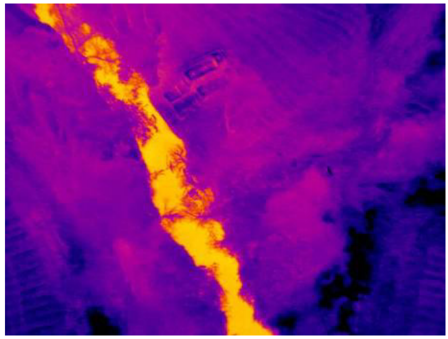

Figure 10: A river close to landfill, which is potentially a pollution target.

Figure 11: A visible and infrared image overlap to detect a fire border.

5 Conclusions

The cases studied for the purposes of this contribution, validated aerial infrared thermography as optimal tool to support the detection and monitoring of illegal dumping. By using infrared thermography, specialized aerial platforms and advanced techniques of data analysis and visualization we can discover several environmental problems and locate pollution point sources. As outlined above, there are many effectiveness uses for aerial infrared thermography in the field of environmental monitoring; it is very easy, compared with standards methods of pollution-source detection, to discover illicit discharges and other “anomalies” on the soil. The aerial infrared thermography and interoperable systems also exceeds the current limits of traditional methods of detection where we have small size sources of pollution and the contamination of a wide area. The choice of a specific platform that float in the “air” matrix, permit the data grabbing from a privileged point of view for phenomena in action in the other matrices, increasing the FOV (field of view) in the acquired scene and with a direct thermal comparison of the targets with other objects in the scenario. A specific aerial platform (Hybrid LTA), developed in cooperation with Italian Aerospace Research Center, will increase the performance of the standard aerial system to support this advanced monitoring system; moreover, this type of platform will allow the exploration of three-dimensional spaces without altering the measurement parameters, returning geo-referenced data, guaranteeing minimal invasion and maximal safety for the operational context. The interoperable systems guarantee the possibility to make a detailed survey, where important anomalies are detected, customizing, as necessary, the platform with the best sensor to perform in situ measures.

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