VOLCANIC ENVIRONMENTS MONITORING BY DRONES MUD VOLCANO CASE STUDY

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ABSTRACT:

Volcanic activity has often affected human life both at large and at small scale. For example, the 2010 Eyjafjallajokull eruption caused severe economic damage at continental scale due to its strong effect on air traffic. At a local scale, ash fall and lava flow emission can cause harm and disruption. Understanding precursory signals to volcanic eruptions is still an open and tricky challenge: seismic tremor and gas emissions, for example, are related to upcoming eruptive activity but the mechanisms are not yet completely understood. Furthermore, information related to gases emission mostly comes from the summit crater area of a volcano, which is usually hard to investigate with required accuracy.
Although many regulation problems are still on the discussion table, an increasing interest in the application of cutting-edge technology like unmanned flying systems is growing up.
In this sense, INGV (Istituto Nazionale di Geofisica e Vulcanologia) started to investigate the possibility to use unmanned air vehicles for volcanic environment application already in 2004. A flight both in visual- and radio-controlled mode was carried out on Stromboli volcano as feasibility test. In this work we present the preliminary results of a test performed by INGV in collaboration with the University of Bologna (aerospace division) by using a multi-rotor aircraft in a hexacopter configuration. Thermal camera observations and flying tests have been realised over a mud volcano located on its SW flank of Mt. Etna and whose activity proved to be related to early stages of magma accumulation within the volcano.

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1. INTRODUCTION

1.1 Aim of the study

Volcanic activity has often affected human life both at large and at small scale. For example, the 2010 Eyjafjallajokull eruption caused severe economic damages at continental scale due to its strong effect on air traffic. At a local scale, ash fall and lava flow emission can cause harm and disruption. Understanding of the behaviour of active volcanoes and evaluation of the associated hazards are actually scientific challenges as well as a civil protection need due to the large number of people living in active volcanoes areas (Clarisse, 2010).

One of the biggest problems when monitoring active volcanoes arises from the difficult access to summit areas because of logistic problems and because of volcanic hazard. In the last twenty years, the use of remote sensing techniques has become more and more popular and effective in measuring several volcanological parameters. In order to obtain both overall view of the behaviour of an active volcano or more local precise information, multiple scales approaches are used.

At satellite scale, remote sensing data are very useful in the monitoring of eruptive phases when the spatial scale is sufficiently extended to be covered by high temporal resolution satellite (e.g. MODIS, 1 km spatial resolution; e.g., Wright 2002). Despite their low temporal resolution, high spatial and spectral resolution sensors have proven to be very useful in providing accurate parameter estimations (e.g., Spinetti 2008). However, thanks to the extended time scale of eruptive phenomena, whose duration can last some months, high spatial resolution sensors like ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) have been useful for global scale mapping of volcanoes (Pieri, 2004), both during daytime and during the night, by measuring low-altitude volcanic emissions, as well as observing the growth of domes, the expansion of lava flows (Lombardo 2004) or thermal anomalies (Pieri 2005).

A different question is monitoring aimed at forecasting volcanic activity, which involves studies on the "precursor" signals. Major indicators of upcoming eruptions are: volcanic tremor and ground deformation (Glyn and Hazel 2002), thermal anomalies and gas emissions. Although not diagnostic by themselves, these parameters, when used in combination at well-monitored volcanoes, have resulted in successful predictions. However, volcanoes rarely maintain a stable level of activity in time and this is the reason why reliable forecasts should be made by well-organized volcano observatories which operate at local scale. Active volcanoes in Italy are continuously monitored by the networks of instruments held by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) which operates at both ground and airborne scale. At ground level, INGV has been using hand-held thermal cameras (since 2001) during both ground-based and helicopter-borne surveys for the surveillance and monitoring of Mt. Etna, Stromboli, Vulcano, Campi Flegrei and Vesuvius activity (e.g., Calvari et al. 2005; Chiodini et al. 2007; Spampinato et al. 2008; Harris et al. 2009, Lombardo 2003, Spinetti 2007, Coradini 2008).

One of the main drawbacks in the use of helicopter is their cost and risk for operators especially during crisis phase. For this reason, INGV started to investigate the possibility to use unmanned aerial vehicles for volcanic environment application already in 2004.

The UAV(Unmanned Aerial Vehicle), named Butterfly, was equipped with a visual pilot view camera that acquired continuously during the flight approaching the top of volcano (Saggiani, 2007, Amici, 2007,). Since that period of time, great efforts have been dedicated to develop a fixes-wing (Giulietti, 2011) flying system and in testing different configurations and payloads in order to look for the best responses to the extreme operating conditions i.e. active volcanic environments.

Figure 1. Butterfly radio controlled UAV approaching Stromboli top craters on 2004 flight (left) and pilot camera view (right) of the Stromboli volcano gas plume (Saggiani, 2007).

In this paper we report on a thermal test carried out by a relatively low cost hexacopter which flew on the Salinelle's mud volcano area, located on the lower SW flank of Mt. Etna (Italy). This area, characterised by favourable weather conditions and good accessibility, is not extensively and continuously monitored because of the unstable muddy surface that prevents operators from approaching the largest and most active degassing vents. The hexacopter was equipped with a thermal camera and real time acquisition system and flew over a selected area of le Salinelle. On ground thermal images were acquired for comparison.

1.2 Le Salinelle mud volcano

The Salinelle mud volcanoes are located at the North West (NW) boundary of the town of Paternò, on the low SW flank of Mt. Etna. The most active vents are those located close to the local football stadium (figure 2). The emitted fluids generally consist of hydrocarbons (mainly CH_4) and hypersaline water, variably charged with mud that often pond in pools (from centimetres to meters in diameter). The mud and water mixtures are highly variable, and in some cases mud is the only fluid erupted with gas, and it builds cones up to a few meters high and with a base diameter up to about ten meters. Emitted waters have rather uniform and constant chemical. The chemical abundance of major species in solution (on equivalent basis) is Na»Ca>Mg>K and Cl-»HCO3->SO4= (Chiodini et al., 1996; D'Alessandro et al., 1996; Aiuppa et al., 2004).
Mud can often build cones up to a few meters in height and with a base diameters up to ~10 ten meters. Water outlet temperatures are normally between 10 and 20 °C, but occasionally increase to 40-50 °C. Such anomalous temperature values are always accompanied by increases in gas efflux.
In the past many paroxysms occurred in the degassing activity of the Salinelle. Silvestri (1866, 1878) reports of intense eruptive events occurred in early 1866 and late 1878. This phenomena included fountains of muddy water up to 3 m high and water temperature increases up to 46 °C, that the author associated with local seismic events that occurred some days/weeks prior to the gas eruptions. During the past 15 years similar increases in degassing activity have also been recorded at the Salinelle. These events normally lasted two to four months. The main component of the gas escaping from the studied sites is CO_2. In all of the sites, air components are very

low or are absent. Methane is normally the second most abundant gas species, although with highly variable amounts among the sites. Other minor species emitted include N_2, He, H_2, CO, H_2S, Rn and other light hydrocarbons.
Usually when vents are directly accessible water/mud temperature measurements are carried out using thermocouples or using laser devices from a distance. However most of the time, it is not possible to obtain the temperature map of the whole field due to the great number of active pools.

Figure 2. Le Salinelle mud volcano as seen by Google Earth (Lat 37.57298 Lon 14.89028) size in meters. The white star correspond to the location of take off and landing

In this context the use of UAV can offer a good opportunity e to observe the overall thermal changes of the entire area and the pool spatial distribution.

2. METHODS

2.1 The UAV system

The UAV system is a multirotor system (hexacopter, figure 3) powered by two battery pack, each one including six- lipo cell powering a flight autonomy of ~15 minutes. The six motors of the hexacopter tolerate a max payload's weight of 1.7 kg and permit an emergency landing of the hexacopter in case of a single motor/propeller failure.
The flight altitude of the drone is limited by the national regulation and the drone has to be always in line of sight.
The flight control system stabilises the drone for a manual control by the pilot using standard radio control and also allows several flight mode configuration, hold over a fixed point and single waypoint autonomous flight.

Figure 3. Hexacopter equipped with a thermal camera ready for the vertical take off.

2.2 Payload: Thermal EYE Camera

The payload mounted on the hexacopter for the flight experiment above the Salinelle mud volcano, is a thermal EYE 3600AS (TE 3600AS) designed for Original Equipment Manufacturers (OEMs). The TE 3600AS camera uses a proven Amorphous Silicon (AS) microbolometer technology. The 30 μm pitch detectors make possible a lightweight (67g), long wavelength passive infrared camera core (spectral response 7-14μm), thermal sensitivity less than 50 mK and saturation temperature of 600°C. The thermal camera can record at frame rate of 25Hz real time and generates PAL video output.
A colour palette may be selected to colour the image and the camera can be configured to display the temperature of the object in the middle of the frame.
In order to fix the TE 3600 AS on UAVs systems a specific frame has been designed and realized by MDV. The design of the frame is for low weight unmanned aircraft; the shape, the material (aluminium) and the fixing system are optimized to obtain safe and easy mounting and dismounting operations of (figure 4).
On the frame, two output connectors are available A standard female USB connector allowing the GUI communication and a DB9 connector reporting all camera pins, including analogue video output and power.
Operating temperature range of both thermal camera is -20 to +85 ℃, although the acquisition system cannot work in the extended temperature range but only between 0 and 60 ℃.

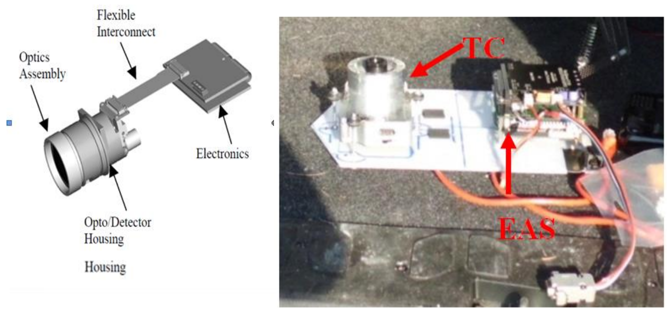

Figure 4. Thermal Camera (TC) 3600 scheme (left); TC and embedded acquisition system (EAS) final configuration (right).

2.3 Acquisition system

A custom solution for the acquisition system based on commercial components was developed.
The embedded acquisition system (Turci, 2011) is based on four PC-104 compliant stackable modules: power supply, frame grabber, PC and Wi-Fi module:

1 Power supply module consists of DC-DC converter offering up to 75 Watt. It can power all stacked modules over PC-104 bus using a low weight 3 cells Lithium Poliymer battery (weight of 205gr).
2 Frame grabber module is a real time PAL/NTSC Frame Grabber and live video overlay controller for PC/104+ bus.
3 PC module consists in a low power consumption embedded PC running Windows XP operating system. Using specific driver it is possible to acquire each frame from the video grabber module and store the resulting video in the 4 GB compact Flash which also hosts the operating system

4 Wi-Fi module allows operating the embedded PC in wireless connection. The resulting embedded system is integrated in a compact cubic configuration (12cm x 11cm x 8 cm, and weight of 600 gr) as showed in figure 3.

3. EXPERIMENT AND DISCUSSION

The 26 June 2012 experiment at the Salinelle mud volcanoes was conducted in the late afternoon as to avoid the maximum Sun effects (reflection and heat release from the ground; e.g., Spampinato et al., 2011).

The system has been pre-assembled while payload configuration and system connection have been realised in situ.

A calibrated Forward Looking InfraRed (FLIR) thermal camera was used for cross-comparison with the data acquired during the flight experiment. The FLIR camera was a A310 model consisting of a 320 x 240 microbolometer detector array sensitive to the 8-14 µm wave band, with dynamic range of 0 to +350 °C and accuracy of ±2% of reading (see flir.com for more details).

The area of interest is easily to access however extra care must be paid since no protection or warning signs are present to alert about the mud volcano. The selected site for the vertical take off and landing is indicated with the white star in figure 2.

The hexacopter flew above the area of interest (figure5) acquiring thermal images in continuous for about 15 min.

Figure 5. Visible image of the investigated area.t The white surface is due to the presence of salt deposit while the darker are the muddy.

The acquisition system worked properly although the quite extreme ambient temperature (up to 32.2 °C according to http://www.meteosicilia.it/).

A thermogram acquired by FLIR camera in the same area covered by the drone was used for cross-comparison. From the recorded video, six frames acquired by TC3600 (figure 6a) have been selected in correspondence of different areas as indicated in figure 6b. The temperatures measured by TC3600 and expressed in decimal degrees was converted in degrees Centigrade before comparison with FLIR apparent temperature.

For each frame acquired by the TC3600, we have selected a corresponding area in the FLIR frame. For each area we have calculated minimum, maximum and average temperature respectively as showed in figure 7.

The central thermal spot acquired by TC3600 are plotted on the same graph for comparison. Overall comparison shows a good agreement (0.64 correlation) with mean. Deviation from mean values for point 3 and point 4 can be interpreted as high percentage of hot pixel in the selected FLIR area for this point compared to in flight acquired frame.

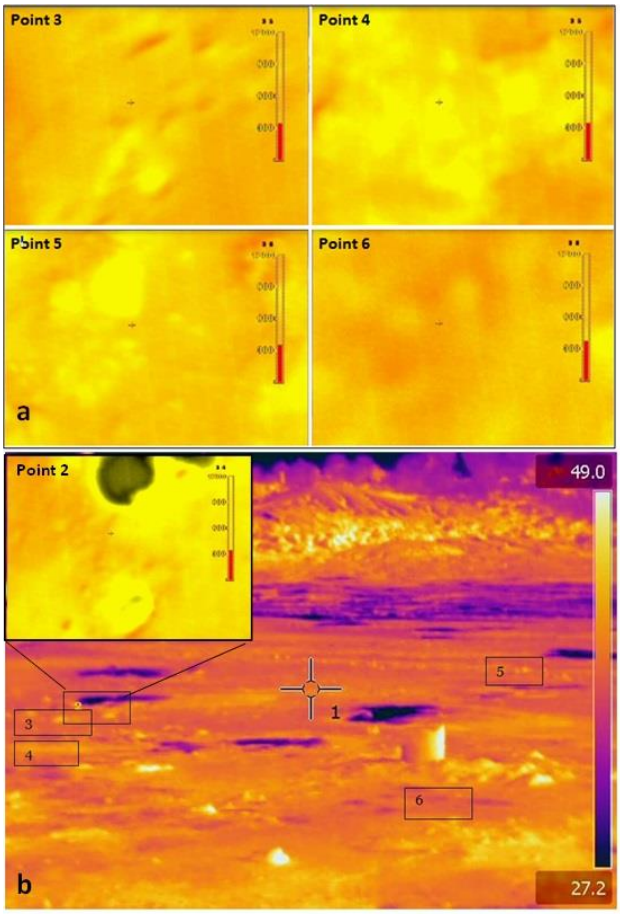

Figure 6. a) Thermal images acquired by TC3600 in six areas of interest are indicated as point 2, 3,4,5,6. A colour ramp scale shows the minimum and maximum temperature of each thermal frame. The temperature in the centre of image (cross) is showed at top of colour ramp. The FLIR thermogram and the corresponding areas are showed (b).

The best agreement was obtained in correspondence of point 2. In fact, due to the presence of a very characteristic shaped cold pool in both TC3600 and FLIR frame, a sub-area has been localised in correspondence of centre spot.. The obtained mean value for this sub-area is showed in figure 7 with a green star.

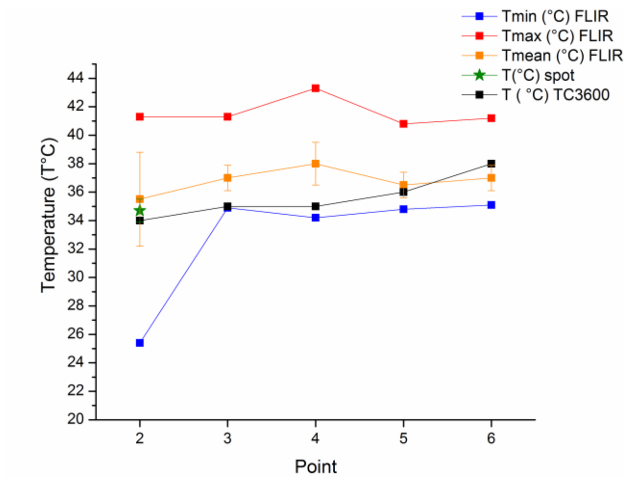

Figure 7. TC3600 thermal spots (black) are compared with FLIR apparent temperature values: maximum temperature are in red, minimum temperature are showed in blue and mean

temperature with standard deviation are in orange. The green star indicated the FLIR temperature in correspondence of the TC 3600 spot point 2.

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CONCLUSIONS

This study represents one of the first efforts for proving that research and monitoring of active volcanic areas may benefit from the use of UAV systems. In 2004, a wix wing UAV system flew for the first time above Stromboli volcano. Visible images of the plume were acquired and the feasibility of using this new cutting edge technology for volcanoes monitoring and study was demonstrated. From that period of time UAVs systems have improved and evolved. They even have changed their name: actually they are named Remotely Piloted Aircraft (RPAS) including all kind of platform and they represent the future of cost-effective precision remote sensing.
In this work we have integrated and tested a low weight thermal camera into an multirotor system (hexacopter). An embedded real time acquisition system has been designed, developed and tested on Le Salinelle mud volcano located in the southwest boundary of Mt. Etna volcano. It is noteworthy that this was the first experiment, as our knowledge at the that period of time) conducted at an European mud volcano by UAV (or better RPAS) systems equipped with thermal cameras. The experiment was successfully performed in June 2012.
The system performed very well under extreme environment. At thermal video was recorded and transmitted in real time from take off to landing when the acquisition was stopped. This allowed to test the real time monitoring and the post processing operations. Six frames (thermogram) from acquired video in correspondence of recognizable areas on FLIR ground thermal camera acquisition were selected. Temperatures acquired in flight have been compared with in situ ones.
A good agreement in values has been found.
Scientifically, the experiment was promising since the cross-comparison of thermal information (both in-flight and in-situ) proved the opportunity to carry out more quantitative mapping of the area. Furthermore it proved as drone can be a relevant support at monitoring operations that in certain circumstances are difficult and dangerous to be performed.

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