Selective Measurement of Volcanic Ash Flow-Rate

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***Abstract*— The ash fall-out following explosion activity of volcanoes like the Mount Etna, represents a relevant factor of risk for people and a serious hazard for air traffic. Researchers at DIEEI of the University of Catania are facing the challenge of developing a low-cost smart multisensor system for the monitoring of ash fall-out phenomena by measuring ash presence, average granulometry and ash flow-rate. Moreover, the system must be selective as respect to volcanic ash against others sediments such as dust, sand or soil. This paper is particularly focused on the methodology adopted for ash quantity estimation and discrimination from other types of sediments. The main idea is to use an array of coupled infrared diodes-phototransistors to estimate the level of ash collected in a tank and to measure the time interval between two subsequent levels. To implement the selectivity task the intrinsic magnetic property of ash particles is exploited. Experimental investigations have been performed using ash erupted by Etna volcano.**

Keywords— volcanic ash; ash fall-out; flow-rate; selectivity; multisensory architecture.

I. Introduction

The atmospheric dispersion of ash produced by the explosive activity of the Etna volcano is a relevant factor of risk for eastern Sicily and in particular for the Catania area. Ash fall-out causes extensive damages to roads, sanitation systems [1], agriculture, health [2] and daily activities of people living in the countries on the slopes of the volcano, but also a substantial hazard factor to air traffic [3] with consequently inconvenience for passengers and loss of profit for airlines. This is the case of the international Fontanarossa airport, the sixth major (in terms of number of passengers) airport in Italy, which in last years has been repeatedly declared inappropriate for take-offs and landings because of ash plumes spewed by the Etna volcano. During such crises, the decision to open or close the airport by the Italian Civil Aviation Authority is resulted from subjective assessments and therefore with high levels of uncertainty and risk.

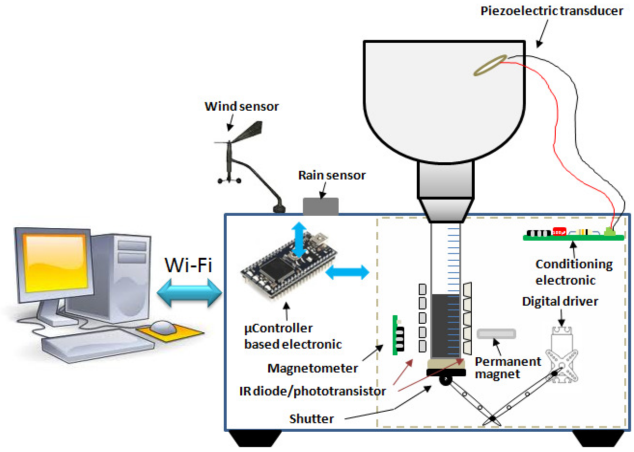
Traditional approaches for the monitoring of volcanic ash employ high cost instrumentation, typically based on satellites [4], X-Band dual-polarization radars [5] or ground thermal infrared camera (TIR) [6]. Such solutions are difficult to be installed and maintained and are often used to perform spot measurements. In order to properly face surveillance activities of volcanic clouds and ash fall-out the need for a distributed network of monitoring stations emerges.

Researchers at DIEEI are facing the challenge of developing a early-warning distributed network of self powered, low cost, μ-controller based multisensor nodes for the measurement of typical parameters of volcanic ash fall-out phenomena [7], [8]. The area covered is the one spreading from Etna volcano to the international Fontanarossa airport in Catania. This kind of information could be useful to implement an optimized planning of actions required to both restore the functionalities of the airport and to manage air traffic during the ongoing phenomenon. The research activity is conducted within the SECESTA project [9], the Italian acronym for "A sensor network for the monitoring of volcanic ash fall-out for the safety of air transport". The project is funded under the POR FESR Sicily 2007–2013 program and it exploits the synergic operations of research institutions (among which the DIEEI of Catania) and small–medium sized enterprises.

The idea behind this early-warning approach is the possibility to provide fast and well spatially distributed information on incoming phenomena at the expense of high accuracy furnished by high cost instrumentation. Anyway, in case of specific needs, accurate measurements can be performed by dedicated high cost instrumentation installed in critical sites evidenced by the early-warning system.

Basically, it can be affirmed that this approach in the field of volcanic ash monitoring is innovative in particular taking into account its capability to provide experts with a time continuous awareness on the ash fall-out phenomenon with a high degree of spatial resolution. The latter, along with low cost feature, are main advantages of the proposed solution. The sensing solutions proposed for ash granulometry classification [7], [8], selectivity and ash flow-rate estimation are really low cost and present high reliability due to the sensing architecture adopted.

While the sensing solution proposed for the ash granulometry classification has been addressed in [8], in this paper, authors addresses the methodologies adopted for ash fall-out quantification and discrimination from other types of sediments. The low cost approach proposed for the measurement of volume and then indirectly for the evaluation of the flow-rate, along with the methodology for ash discrimination represent dramatic solutions for the implementation of monitoring systems to be operated in harsh environments.



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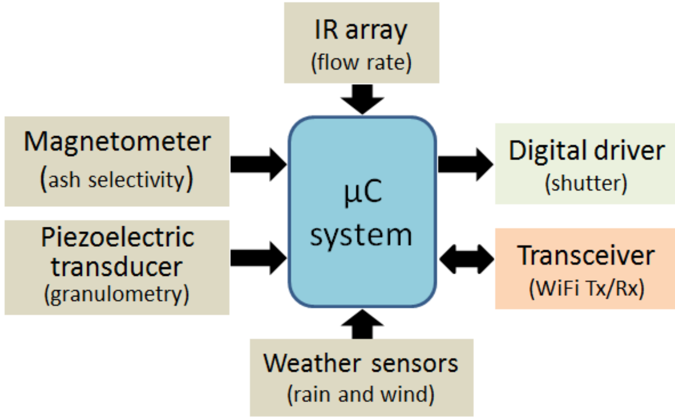

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Fig. 1. (a) Schematization of the multisensor node; (b) Schematization of the multisensory architecture.

I. THE SENSING STRATEGY AND THE EXPERIMENTAL RESULTS

The multisensor system for the monitoring of the ash fall-out phenomenon is in charge of measuring ash average granulometry [7], [8] and ash flow-rate. Moreover, the system must discriminate volcanic ash from others sediments such as dust, sand or soil.

A schematization of the node prototype and the microcontroller multisensor architecture, developed at the DIEEI laboratories, are shown in Fig. 1a and Fig. 1b, respectively. Basically, the system consists of an ash collector and a tank where a dedicated array of five coupled infrared (IR) diodes-phototransistors allows for the measurement of ash level collected in the tank to indirectly estimate the ash flow-rate. The piezoelectric sensor based system for the classification of ash granulometry is discussed in [8]. A shutter system, placed at the bottom of the tank and driven by a digital driver, has been developed to empty the tank when it is filled or before to start a new measurement session.

A schematization and a real view of the sensing architecture adopted for ash flow-rate estimation is shown in Fig. 2a and Fig. 2b, respectively. A cylindrical tank with a height of 10 cm and a diameter of 1.4 cm was used. The array of coupled IR diodes - phototransistors are placed along the main dimension (the height) of the tank, 5 mm spaced to avoid cross influence. In particular the aluminum gallium arsenide (AlGaAs) infrared emitting diode SEP8736 by Honeywell and the NPN silicon phototransistor SDP8436 by Honeywell have been employed. The devices are designed to mechanically match one each other and are characterized by a narrow emitting and acceptance angle, respectively, making them well suited to applications in which adjacent channel crosstalk could be a problem. A suitable conditioning circuit, schematized in Fig. 3, has been designed to operate the devices and to make output signals consistent with the microcontroller system.

By exploiting magnetic properties of volcanic ash, a digital magnetometer is used to discriminate volcanic ash from other sediments [9]. To this purpose a small low power digital magnetometer MAG3110 by Freescale Semiconductor with a sensitivity of 0.1 µT has been employed.

The device, contains a magnetic transducer for sensing and an ASIC for control and digital I2C communications. As shown in Fig. 2a, a permanent magnet has been placed in front of the magnetometer at a distance of 5 cm in order to produce a biasing magnetic field. The presence of ash particles in the tank will perturb the magnetic field, thus resulting in a variation of the magnetic sensor output.

Wind and rain sensors are also used to provide information on meteorological quantities. The latter can be used in models in order to foresight the space-time evolution of the observed phenomenon.

Signals coming from electronics adopted for sensor conditioning are acquired and pre-processed by the microcontroller (µC) based architecture which manage the communication with a server system by a wireless transmission protocol (IEEE 802.15.4).

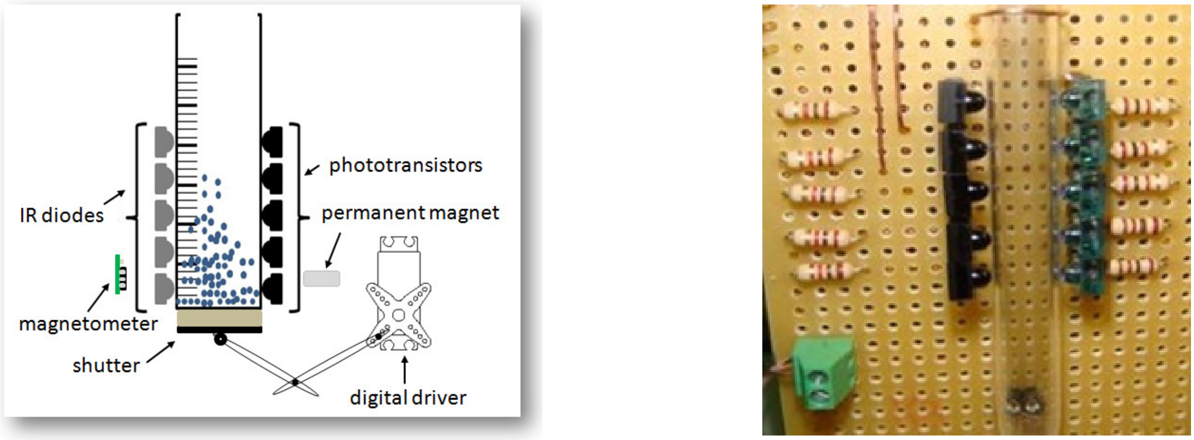
Nodes are supplied by the supply network, if available, or by alternative energy sources (photovoltaic and/or aeolic).

Finally, a further shutter system is placed on the top of the ash collector with the purpose of shielding the system against hostile agents (e.g. water, dust, sand, soil or bird droppings) which could damage the system. The opening of this shutter can be remotely controlled by operators, or automatically triggered when explosive phenomenon are observed.

A. *Ash fall out quantification*

The main idea is to use an array of coupled infrared (IR) diodes - phototransistors to estimate the volume, ΔV, of collected ash in the tank.

Known the time Δt_i required to fill two subsequent levels and the corresponding volume ΔV_i of collected ash (here expressed in ml), (i = 1 to 5), it is possible to update the flow rate estimation, ϕ, each time a new level of the tank is filled:



(a) (b)

Fig. 2. (a) Schematization of the system developed for estimation of the ash flow-rate; (b) A real view of the prototype developed.

$$\phi_i = \frac{\Delta V_i}{\Delta t_i} \, [\, ml/s \,] \tag{1}$$

Experimental surveys have been performed with the aim to characterize the sensor behavior in terms of ash volume required to activate each coupled IR detectors ΔV_i. To this purpose a continuous flow of ash was injected into the the tank. Experimental investigations have been performed using volcanic ash from Etna volcano with three typical different granulometries (small, medium and large) ranging from 0.4 mm to 2.0 mm [8]. A typical result is given in Fig. 4a which shows the device behavior for increasing volume of medium size volcanic ash.

In order to evaluate the volume between consecutive couples of IR diodes-phototransistors, a graduated tank with a resolution of 0.1 ml was used to inject ash particles in the tank. Experiments have been repeated 10 times for every level (number of IR diode) and for the three granulometries. An on purpose developed NI LabVIEW® Virtual Instrument (VI) has been used to observe the state of coupled IR detectors and to monitor ash level in the tank.

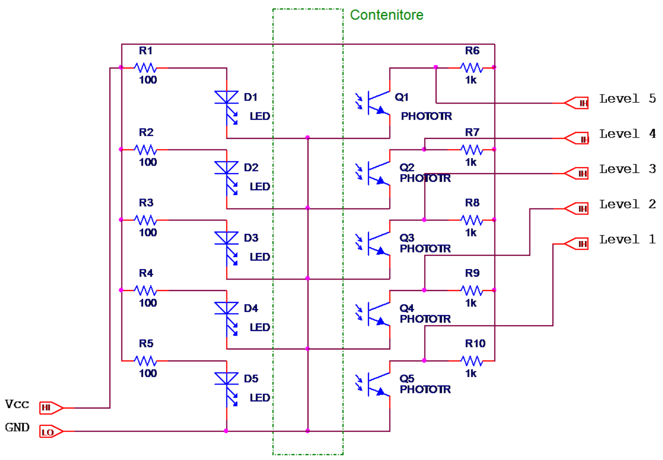


Fig. 3. Conditioning circuit of the flow-rate sensor.

By computing the amount of ash introduced in the system (as the difference between the initial and the final amount in the graduated tank) an estimation of ash volume values, ΔVi, was performed.

A calibration diagram of the system is shown in Fig. 4b together with a fitting linear model. The constant term in the model is due to the experimental setup with particular regard to the initial volume to be filled for the activation of the first couple of IR diode - phototransistor. An uncertainty band with a coverage factor of 3σ, where σ = 0.11 ml is the standard deviation, is also represented.

As mentioned above the flow-rate ϕ can be estimated by model (1). Furthermore, the uncertainty of the flow-rate measurements can be estimated by the following relationship:

$$u_c^2(\phi) = \left(\frac{\partial \phi}{\partial V}\right)^2 u^2(\Delta V) + \left(\frac{\partial \phi}{\partial \Delta t}\right)^2 u^2(\Delta t) = 0.19\, ml/s \tag{2}$$

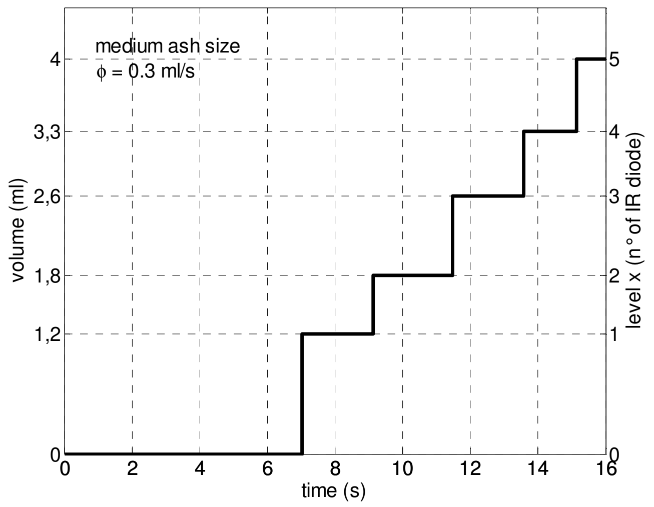
where $u^2(\Delta V)$ and $u^2(\Delta t)$ represent uncertainties of volume and time interval measurements, respectively.

B. *Volcanic ash discrimination*

The methodology proposed to confer selectivity features to the monitoring system is to exploit intrinsic magnetic properties of ash particles [10].

In fact basaltic volcanic particles show a paramagnetic behavior and therefore they can be recognized from other sediments by a magnetic sensing strategy.

Preliminary experiments to validate the proposed approach based on the use of a digital magnetometer and a biasing magnet have been performed by using Etna volcanic ash. Fig. 5 shows a typical signal given by the magnetometer when 0.6 ml of volcanic ash is placed between the sensor and the permanent magnet. As it can be observed, the presence of the volcanic ash produces a visible variation of the output signal A low pass filtering of the signal can highlight the variation by filtering the high frequency noise (dashed line).



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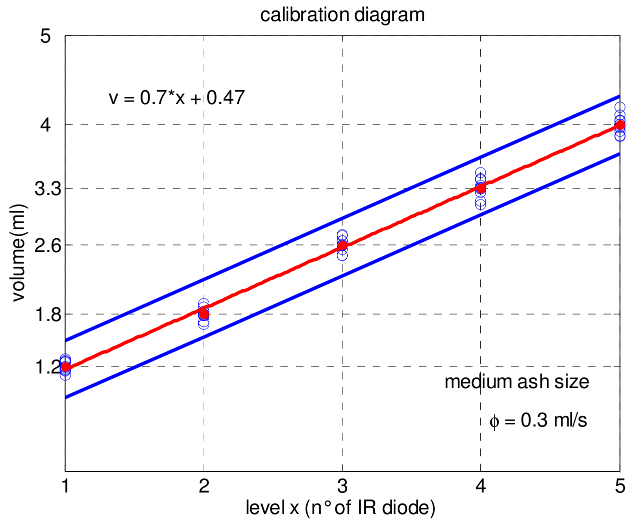

(b)

Fig.4. (a) The device behavior for increasing volume of medium size volcanic ash in the tank with a flow-rate Φ=0.3 ml/s; (b) Calibration diagram of the sensor developed for the ash flow-rate estimation. A coverage factor k = 3σ, with σ = 0.11ml has been used.

Experiments have been conducted to exclude the possibility that variations are due to the operator or exogenous sediments.

The response of the magnetometer to a variable flow of volcanic ash is shown in Fig. 6. The following pattern was considered: a initial very slow flow followed by a higher flow, a pause and finally the tank emptying.

II. Conclusions

In this paper a low-cost smart multisensor system for the monitoring of ash fall-out phenomenon developed by researchers at DIEEI of the University of Catania, has been presented. In particular the paper focuses on the methodology adopted for the ash flow-rate estimation and discrimination from other types of sediments.

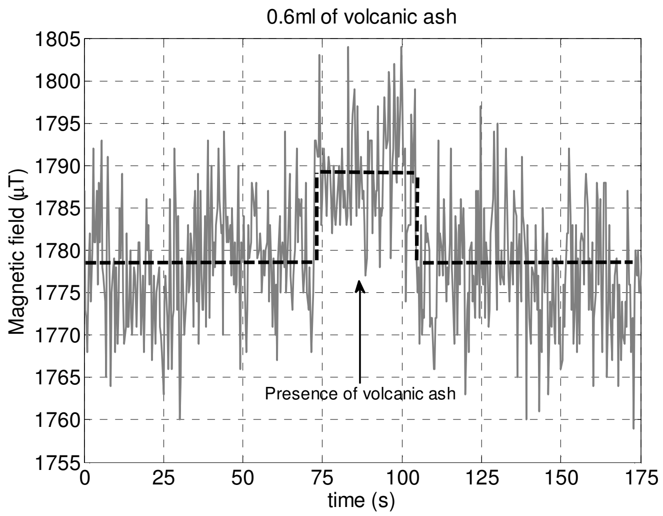

Fig. 5. Signal from the magnetometer when 0.6 ml of volcanic ash is placed between the sensor and the permanent magnet. The presence of the volcanic ash produces a visible increasing of the average of the signal (dashed line).

The main idea is to use an array of coupled infrared (IR) diodes - phototransistors to estimate the volume of ash collected in a tank and to measure time intervals between activations of consecutive IR devices.

Despite it is not innovative, it becomes a useful low cost and easy to implement solution when joined with both the selectivity of the sediments and the possibility to implement an emptying mechanism of the collecting tank.

Experimental results showing suitability of the proposed methodologies are presented.

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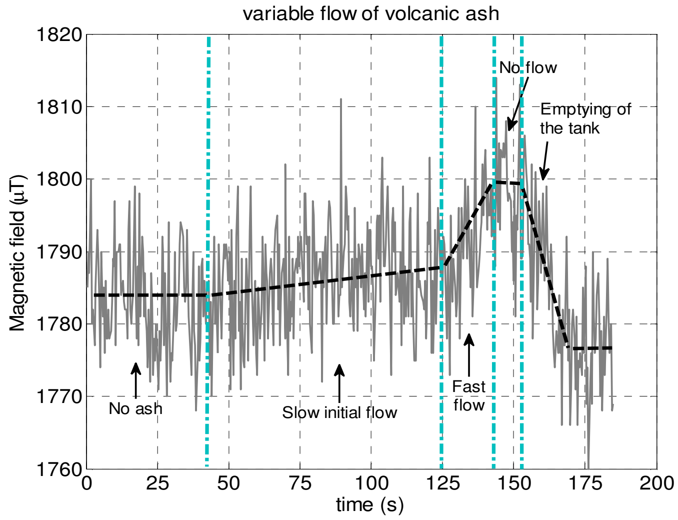

Fig. 6. Signal from the magnetometer for a variable flow of the volcanic ash.

REFERENCES

[1] W. H. Mayer, "The mitigation of ashfall damage to public facilities: lessons learned from the 1980 eruption of Mt. St. Helens", Washington Federal Emergency Management agency, Region X, 1984.

[2] C. Horwell, P. Baxter and alt., "The health hazards of volcanic ash – A guide for the public", on line at www.ivhhn.org.

[3] Flight Operations Briefing Notes – Operating Environment – Volcanic Ash Awareness, Rev.01, on line at www.airbus.com, Sep. 2006

[4] F. Marchese, R. Corrado, N. Genzano, G. Mazzeo, R. Paciello, N. Pergola, V. Tramutoli, "Assessment of the Robust Satellite Technique (RST) for volcanic ash plume identification and tracking", Use of Remote Sensing Techniques for Monitoring Volcanoes and Seismogenic Areas, USEReST 2008. Second Workshop on, pp. 1-5, 2008.

[5] F.S. Marzano, E. Picciotti, G. Vulpiani, M. Montopoli, "Synthetic Signatures of Volcanic Ash Cloud Particles From X-Band Dual-Polarization Radar", Geoscience and Remote Sensing, IEEE Trans. on, Vol. 50, N. 1, pp. 193 – 211, 2012.

[6] S. Corradini, C. Tirelli, G. Gangale, S. Pugnaghi, E. Carboni, Theoretical Study on Volcanic Plume SO_2 and Ash Retrievals Using Ground TIR Camera: Sensitivity Analysis and Retrieval Procedure Developments, Geoscience and Remote Sensing, IEEE Transactions on vol. 48, no. 3, part 2, pp. 1619-1628, 2010, doi: 10.1109/TGRS.2009.2032242

[7] B. Andò, S. Baglio, V. Marletta, "A Smart Multisensor System for the Ash Fall-Out Monitoring", Procedia Engineering, Volume 47, pp. 766-769, Elsevier, Proc. of the XXVI European Conference on Solid-State Transducers EUROSENSOR 2012, Kraków, Poland, September 9-12, 2012.

[8] B. Andò, S. Baglio, V. Marletta, S. Medico, A Smart Multisensor System for Ash Fall-Out Monitoring, In Press, Accepted manuscript, Sensors and Actuators A: Physical, DOI: 10.1016/j.sna.2013.01.056, url: "http://www.sciencedirect.com/science/article/pii/S0924424713000782", 2013.

[9] SECESTA project, 4.1.1.1 - POR FESR Sicilia 2007-2013, (CUP. G53F11000040004), http://secesta.pmftraining.eu.

[10] B. Ando, S. Baglio, N. Pitrone, C. Trigona, A. R. Bulsara, V. In, M. Coltelli, S. Scollo, "A novel measurement strategy for volcanic ash fallout estimation based on RTD Fluxgate magnetometers", Instrumentation and Measurement Technology Conference Proceedings. IMTC 2008. IEEE, pp. 1904-1907, 2008.