Sensors and Actuators A 202 (2013) 13–22

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

A smart multisensor system for volcanic ash fall-out monitoring

B. Andò*, S. Baglio, V. Marletta, S. Medico

Dipartimento di Ingegneria Elettrica, Elettronica e Informatica (DIEEI), University of Catania, V.le A. Doria 6, 95125 Catania, Italy

ARTICLE INFO

Article history:
Available online 27 March 2013

Keywords:
Volcanic ash
Air transport safety
Multisensor system
Particle granulometry
ROC analysis

ABSTRACT

Ash fall-out following the explosive activity of volcanoes represents a factor of risk for people and a serious hazard for air traffic, especially if airports are close to the volcanic area. This is the case of the Fontanarossa airport located in Catania, in the south of Italy, close to the Etna volcano.

Researchers at DIEEI are facing the challenge of developing a low-cost smart multisensor system to monitor the ash fall-out phenomenon by measuring the average granulometry of ash particles and the ash flow rate. Moreover, the system must be selective in respect to volcanic ash against others sediments such as dust, sand or soil.

This paper is particularly focused on the methodology to be adopted for ash granulometry detection. The main idea is to use a piezoelectric transducer to convert ash impacts into electrical signals, which should provide information about the ash granulometry. Experimental results showing the suitability of the proposed approach are presented. Moreover, Receiver Operating Characteristic (ROC) analysis has been proposed as a theoretical support to properly implement the threshold mechanism aimed at ash granulometry classification.

1. Introduction

The atmospheric dispersion of ash released by the explosive activity of an active volcano is a relevant risk factor, such as hazard posed by the Etna volcano to the eastern area of Sicily in the south of Italy. Ash clouds cause extensive damage to roads, sanitation systems [1], agriculture [2], health [3] and the daily activities of people living on the slopes of the volcano, and also forms a substantial hazard to air traffic (civil, commercial and military) [4]. Monitoring of ash fall-out is of great interest to meet logistical needs, as well as to achieve a better understanding of such phenomena and their ruling mechanisms.

Due to the worldwide increase in volcanic explosion phenomena with consequent atmospheric ash dispersion, and in particular after the eruption of the Icelandic Eyafjallajokull volcano in 2010, the need of regulation for the safety of air transport has arisen. In response to this need, the International Civil Aviation Organization (ICAO) has issued guidance on managing flight operations into, or near, areas of known or forecast volcanic clouds [5].

During the eruptions of 2001 and 2002, the Fontanarossa airport in Catania (at that time the third major airport in Italy in terms of numbers of passengers) was repeatedly declared inappropriate for take-offs and landings due to volcanic ash fall-out, creating great inconvenience to passengers along with financial loss for airlines and airport operators. During such crises, the decision to open or close the airport by the Italian Civil Aviation Authority resulted from subjective assessments, and therefore contained high levels of uncertainty and risk. As a consequence a scientific and technical commission has been established with the aim of regulating flight operations at airports in the presence of volcanic ash [6]. The National Institute of Geophysics and Volcanology (Istituto Nazionale di Geofisica e Vulcanologia, INGV) was designated a primary source of information about eruptions that produce volcanic clouds.

To cope with this service INGV is equipped with systems for monitoring ash clouds and forecasting their space-time evolution [7]. The latter provides decision support for aeronautical authorities in order to significantly reduce the factors of unpredictability, and therefore the impact of this phenomenon on airport infrastructure and flight operations.

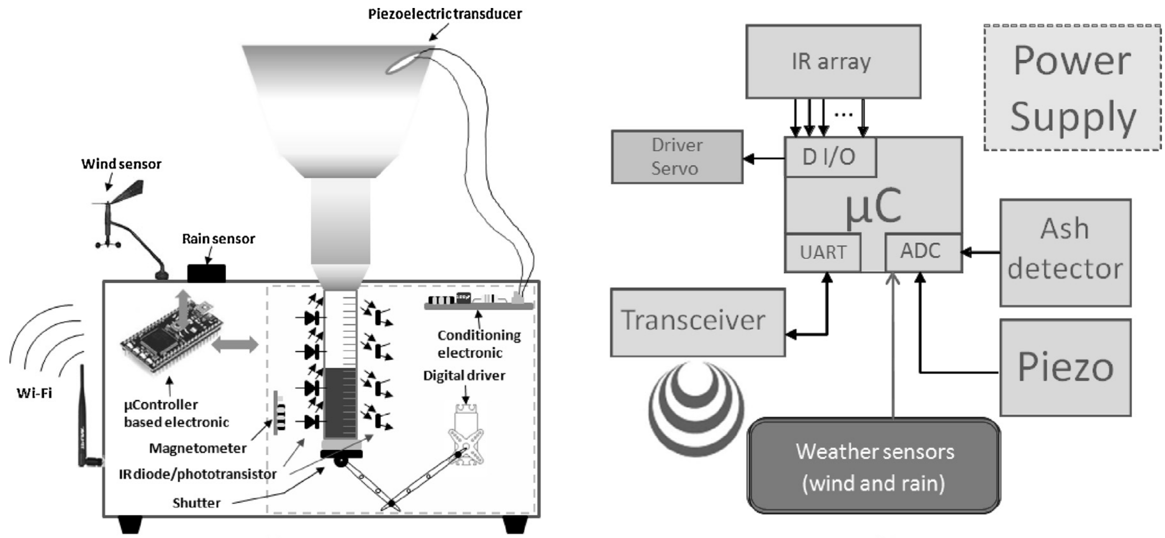
Traditional approaches for the monitoring of volcanic ash employ high-cost instrumentation, typically based on satellites [8] or X-Band dual-polarization radars [9]. Reliable instruments for ash granulometry classification, generally based on high-cost infrared cameras [10] and providing information on ash suspended in atmosphere, have been developed and deployed.

These solutions allow discrete measurements at a restricted number of monitoring stations, thus guaranteeing a low spatial resolution. Moreover, such systems are difficult to install and maintain and are often used to perform spot measurements.

DOI of original article: http://dx.doi.org/10.1016/j.sna.2013.01.056.

* Corresponding author. Tel.: +39 095 7382601; fax: +39 095 7387965.
E-mail addresses: bruno.ando@dieei.unict.it (B. Andò), salvatore.baglio@dieei.unict.it (S. Baglio), vincenzo.marletta@dieei.unict.it (V. Marletta), stefaniamedico@gmail.com (S. Medico).

0924-4247/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.sna.2013.03.027



(a) (b)

Fig. 1. (a) Schematisation of the multisensor node; (b) schematisation of the on-board electronics.

In order to properly confront surveillance activities of volcanic clouds and ash fall-out the need for a distributed network of monitoring stations has emerged.

Researchers at DIEEI in Catania are developing an early warning distributed network of self-powered, low-cost, µ-controller based multisensor nodes for the monitoring of ash fall-out in the area spreading from the main craters of the Etna volcano to Fontanarossa airport [11]. The sensor network will provide information on ash fall-out (presence, average granulometry, ash flow rate) that is useful to predict the time-space evolution of such phenomenon.

The idea behind the 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. Furthermore, in cases of specific need, accurate measurements can be performed by dedicated high-cost instrumentation at critical sites evidenced by the early warning system.

Fundamentally, it can be confirmed that this approach in the field of volcanic ash monitoring is innovative, in particular when taking into account its capability to provide experts with a time continuous awareness of the ash fall-out phenomenon with a high degree of spatial resolution. The latter, along with its element of low-cost, are the main advantages of the proposed solution. The research activity is conducted within the SECESTA project, 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 institutes (among these DIEEI of Catania) and small-medium sized enterprises.

A number of monitoring nodes will be installed along the direction between craters and the airport to build a Wireless Sensor Networks aimed to monitor volcanic ash fall-out. The WSN will be developed, by a small-medium sized enterprise with the collaboration of the National Institute of Volcanology, Catania Section.

This paper focuses on the sensing methodology adopted for ash granulometry detection. The main idea is to use a piezoelectric transducer to convert ash impacts into electrical signals whose properties are strictly dependent on ash granulometry.

Apart from the already-mentioned advantages of the general approach followed by the overall monitoring system, the sensing solution proposed for ash granulometry classification is truly low-cost and it offers high reliability due to the sensing architecture adopted.

Concerning the importance of the monitoring of the ash granulometry, it must be remarked that an awareness of ash dimensions and its distribution throughout the area of interest are fundamental information in the process of forecasting the time-space evolution of ash clouds and fall-out. Forecast mechanisms are usually implemented by models taking into account both the meteorological quantities (e.g. wind speed and direction) and the characteristics of ash fall-out (flow and granulometry) [7].

In the next section an overview of the multisensor node is given. A detailed description of the sensing strategy developed for ash granulometry estimation is provided in Section 3 along with theoretical considerations and experimental results. The methodology for particle classification based on Receiver Operating Characteristic (ROC) analysis is presented in Section 4, while concluding remarks are given in Section 5.

2. Multisensor node

Although this paper mainly addresses solutions adopted for the classification of ash particles, in this section basic information on the whole structure of the developed multisensor node are given for the sake of completeness. The goal of the multisensor architecture developed at DIEEI laboratories in Catania is the implementation of a self-powered, µ-controller platform for the monitoring (presence, granulometry, flow rate) of ash fall-out in areas extending from volcano craters to airports.

Schematisations of the multisensor node and the on-board electronics are shown in Fig. 1, while a true image of the laboratory prototype developed is displayed in Fig. 2. Basically, the system consists of a funnel-shaped structure to convey falling ash to a tank. A dedicated array of coupled infrared (IR) diode-phototransistors allows for the monitoring of ash levels in the tank in order to indirectly estimate the ash flow-rate.

A piezoelectric sensor is placed within the funnel-shaped structure with the purpose of converting the impacts of ash grains into electrical signals. As outlined in Fig. 3, the piezoelectric transducer is placed with a slope of 45° with respect to the direction of fall (vertical axis) to reduce multiple impacts of the same ash particle due to undesired bounces. More details about the proposed sensing solution and the conditioning electronic will be given in Section 3.