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Dust detection and analysis in museum environment based on pattern recognition

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ABSTRACT

Air quality monitoring is an essential task in indoor environments, which require particular attention especially if they are affected by a considerable flow of people, as in museum environments. In the latter case, air quality is not only important for the health and safety of persons, but also for the protection of artworks, which may be damaged from dust, in the form of particulate or fibres. In this paper, we describe a new approach for the detection and analysis of dust by means of machine learning and pattern recognition. The proposed technique relies on a classification algorithm, which aims to identify the characteristics of dust especially in terms of shape and accumulation speed. This information is useful to design efficient countermeasures to reduce the harmful effects of dust and to determine its origin as well.

1. Introduction

Artworks preservation is one of the most relevant topics in the cultural heritage context and it involves a multitude of scientific discipline due to the several correlated kind of issues involving the works of art. The research on artworks conservation, protection and maintenance topics scientifically started in the late 19th century [1,2], especially in order to improve the exposure and access conditions of the cultural heritage. During the twentieth century, the preservation and protection of cultural heritage became a priority, especially because of the numerous created exhibitions, galleries, and museums, as well as measures correlated to the transport and handling of artworks [3,4].

Conservation and maintenance of the artworks in exhibition environments, especially in indoors and, hence, in museums, mainly depends on the performed for the control of environmental conditions (ventilation, temperature, light, wetness, pollution, etc.). The study of the environment parameters effects on cultural heritage is receiving an increased interest in the last decades by the research community, which is engaged both in laboratory tests in order understanding material properties and in *situ* projects in order to assess the complexity of the risks (physical, chemical and biological) [5–8]. These studies aim to define a set of standard procedures for designing specific countermeasures, since there is still no ultimate model for the creation of appropriate museum environments.

Many efforts concern the measurement of air pollutants, which represent the major cause of artworks damages in indoors as museums, galleries, churches, or in microenvironments as showcases or storage boxes. This is critical for exhibition spaces located in cities, where the anthropic activities strongly increase the air pollutants both in quantity and in variety. In this regards, Ghedini et al. [9] investigated the urban air pollution on outdoor monumental heritage, studying the atmospheric aerosol

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composition, in order to contribute to the formulation of guidelines for a suitable safeguard of cultural heritage. Similarly, Lopez-Aparicio et al. [10] described the relationship between indoor and outdoor pollutants concentration and its correlation with the natural ventilation system and with the visitors' activities, allowing distinguishing between the origin of main sources. Table 1 briefly shows the most common and harmful air pollutants and their typical effects on artworks and materials [11].

The standard classification systems do not provide specific classification schemes for particulate and fibres. In fact, the only parameter that allows a partial standardized classification of the particulate is the size: PM_{10} is defined as particles, which pass through a size-selective inlet with a 50% efficiency cut-off at 10 μm aerodynamic diameter. Similarly, for $PM_{2.5}$, which cut-off is at 2.5 μm aerodynamic diameter. The local authorities and the international organizations have enacted specific regulations and instruments for controlling the indoor air quality and the levels of pollutants and harmful agents in specific contexts, e.g., for the air filtering, where is defined a classification of dust according to the size with regard to the efficiency of the filters [12–14]. However, these methods are not comparable to the one proposed in this paper because they consider the dust under the point-of-view of the specific context. Rather, the approach proposed in this paper particularly aims achieving a qualitative analysis of dust in the museum environment, especially in terms of size and shape, in order to better design the maintenance and conservation tasks.

The dust origin is directly related to human activities affecting the museum environments, both for endogenous (presence of visitors or construction works) and exogenous factors (road traffic and combustion coming from industrial or agricultural activities). Apart from the size, the critical feature of the dust deposit is the chemical composition, since it implies the type and amount of damage generated on the artworks (as described in Table 1). The pollutants concentration ratio mainly depends on the dust source, in terms of outdoor and indoor environment. In fact, the dust composition varies according to the particular considered environment, especially due to the contamination of the indoor environments coming from the outdoor (introduced by the users and the natural/artificial air flows). For instance, our image capturing step was carried out in an indoor environment in Rome (Italy). Referring to some research studies [15] as well as to the daily analysis carried out by government agencies responsible for environment (ARPALAZIO and ISPRA for the area of Rome), the captured dust will consist of organic compounds (about 60%) and a mixture of inorganic materials such as metals. Knowing the chemical composition allows to trace the origin of pollutants, in terms of provenance macro-sphere (biosphere, atmosphere, human activities, soil, etc.).

Damages due to the dust deposition can be both tangible (from the vision point of view, i.e. alteration of the perception and of the colours) and intangible (corrosion, biological contamination and deterioration due to humidification). As previously mentioned, these issues mainly depend on the environmental conditions that can favour the cementation of dust on the artworks, on the moisture and on the annual period in which the phenomenon occurs, as well as on other micro-climatic conditions [16]. Rugosity and electrostatic forces similarly favour the superficial adhesion. In particular conditions, the high catalytic ability of the particulate can generate acids capable of corrosion on surface materials. Nevertheless, the deposit of unburned carbon particles is the primary cause of artwork surface fouling, which can be harmful for the paintings (changing for example their colours) but also for other materials for which abrasion can be caused [17]. Moreover, the effects of dust are initially limited to the change of artworks colours, which does not allow the visitor to appreciate the true colour. Gradually, its chemical–physical action can permanently damage the artworks, especially if this happens in presence of water and in case of a high temperature. Moreover, dust may

Table 1
The most common pollutants agents and their effects on artworks.

Pollutants agents	Effects
Carbon oxides (carbon monoxide and dioxide)	Limestone and frescoes disjointing
Sulphur derivatives (sulphuric acid, hydrogen sulphide, sulphur dioxide)	Organic materials and metals corrosion
Ozone	Rubber flaking, textiles degradation; unsaturated organic compounds (leather or natural pigments) destruction; copper and silver accelerated sulphuration
Halogenated compounds (fluorides, chlorides and related acids)	Metals oxidation and corrosion; glasses matting; ceramics, terracotta, and siliceous stones decomposition
Volatile Organic Compounds (VOC) (alkanes, cycloalkanes, aromatic hydrocarbons, chlorinated, aldehydes)	Ceramics and calcium (corals and shells) degradation; metals oxidation and corrosion; synthetic objects degradation
Airborne particulate (dust, soot, residues of tobacco, smoke, textile fibres)	Surfaces fouling and corrosion
Biological contaminants (microorganisms, algae, protozoans, fungi, bacteria, insects and vegetal organic materials)	Canvas, woods and tissues paintings photography and paper degradation