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An Optical Sensing System for Atmospheric Particulate Matter

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Abstract. Atmospheric particulate is one of the main responsible for the environmental pollution of highly populated cities. The particulate matter can be considered an aerosol of many particles, with different shapes, morphologies and sizes down to few micrometers. These small particles are responsible for climate changes and, when inhaled, can reach the lungs causing respiratory and cardiovascular diseases. Usually commercial sensors are based on passive filters and are designed to measure only particles whose size is below a certain value. Therefore, a measuring system capable of assessing the quality of air and evaluating not only the amount of particles, but also the size distribution of the particulate matter in urban atmospheres could be extremely helpful. This paper describes a simple and cheap optical solution, which is able to detect the total amount of solid pollution particles and classify them according to their average size, giving a fast response to the users.

Keywords: Optical system, Atmospheric particle distribution, particulate matter, PMxx, air pollution monitoring

1 Introduction

Nowadays, atmospheric particulate matter is one of the most dominant factors in air pollution, especially in large cities and industrial sites. Particulate matter (PM) consists in a complex mixture of small solid particles dispersed in air, which have heterogeneous physical-chemical characteristics and whose size largely vary from hundreds of micrometers down to the sub-micrometer range.

Particulate matter is released in the atmosphere both by natural and anthropic sources. Anthropic sources are typically associated to the human industrial activities and to the combustion of fossil fuels and biomasses. Instead, the principal natural sources of particulate in air are erosion of the Hearts crust, sea-salt sprays, volcanic activities and pollen produced by vegetation [1].

Main problems related to the increase of particulate matter in the atmosphere involve its negative effects on the human health and on the climate change.

In particular, a great correlation between the level of atmospheric particulate matter and the onset of respiratory system diseases, such as asthma, emphysema and lung cancer, has been demonstrated. Especially ultra-fine particulates (with average size lower than 2.5 μm) can deeply penetrate in tissue and also enter in the blood stream causing cardiovascular problems and intoxication [2]. The World Health Organization (WHO) has estimated that about two millions of people die every year for particulate matter pollution [3, 4]. The European Union establishes health based standards for the different pollutants present in the air and since 2008 introduced PM2.5 exposure limits; in 2010 the average exposure indicator (AEI) for PM2.5 has been assessed to be over 20 μg/m^3, but actually appropriate measures have to be taken for achieving 18 μg/m^3 by 2020.

Measuring particulate matter, taking into account the particle size distribution in a easy and cheap way, is therefore a big challenge.

In principle, measuring the particulate amount is easy and the gravimetric technique is usually employed. A sampler aspirates a constant air flow through a sampling head; the particulate fraction is collected by a filter. The filter is weighted in fixed temperature and relative humidity conditions (20°C; 50% RH), before and after the air exposure, and the particulate concentration, expressed in μg/m^3, is calculated by dividing the total mass of the collected particles for the volume of the sampled air.

The desired dimensional particulate fraction (PMxx) is selected by using a passive filter, which is positioned in front of the weighted one. The passive filter has a mesh suitable to stop particles whose sizes are greater than those required. This way, only particles having dimension smaller than the passive filter mesh are effectively collected and measured, and for example the so-called PM10 value can be easily obtained.

The described solution is currently employed in most of the commercially-available measuring systems, but suffers from some drawbacks: the measurements can be obtained only after some time, the weighting sensitivity must be at micro-gram level, the weighting procedure is complex and requires a long conditioning procedure to prevent temperature and humidity from affecting the measurements. In addition, if the particulate amount at different sizes is requested several measuring units are required thus increasing the overall cost. Several other simple and low-cost solutions [5, 6], based on solid-state lasers and photo-diodes, have been proposed. However, generally, these devices are capable only to count the particles, without determining their size distribution. A solution suitable to discriminate among different sizes is therefore still required.

2 Proposed architecture

The particulate matter measuring system realized at Politecnico di Torino can be considered a hybrid between an optical particle detector and a classic gravimetric meter. This device is able to detect in quasi-real time the atmospheric particulate matter and to classify it according to the average particle size. Fig. 1 shows, as

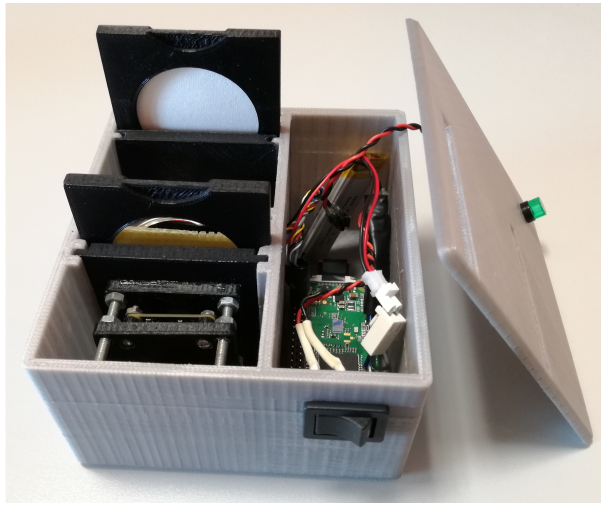

Fig. 1. Prototype of the particulate matter measuring system.

an example, one of the realized prototypes, which contains all the components described in fig. 2.

Fig. 2 shows the block diagram of the measuring system. A small air pump forces a know and constant flow of air through a glass-fiber filter (Grade GF 10 Glass Filter by *GE Healthcare's Life Sciences*) and the particulate matter is captured on its surface. The filter is able to trap particles down to 2.5 μm.

A collecting chamber, realized in ABS by a 3D printer, acts as filter holder and is connected to the pump outlet in order to force the air flow onto a defined area of the filter surface. The collecting chamber provides also a back-lighting system designed to illuminate the filter with a set of seven LEDs at different wavelengths from IR to UV.

The results reported in the following are obtained by using a uEye$^{(TM)}$ video camera with a resolution of 3840×2748 pixels, to take picture of the filter surface. The camera is equipped with a dedicated low-cost optics to focus a small filter area (500 x 500 μm^2). This setup allows reaching a resolution of about 1 μm/pixel, but other cheaper devices can be easily employed.

The images are taken by changing the lighting wavelength. A RaspberryPI is used to control both the camera and the lighting system, and to perform the imaging processing in order to identify the particulate particles present on the filter surface, which appears as dark spots.

The figure also shows the block implementing the wireless connection, which is still under development, and takes advantage of a cloud architecture [7, 8] and of an specific architecture [9–11] already developed by the authors. Eventually, a lithium battery supplies the energy for the entire system so that a completely portable device can be arranged.

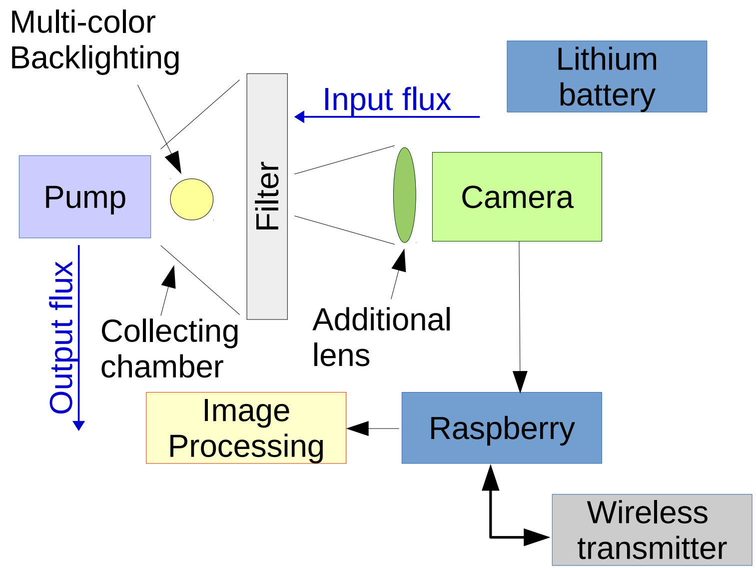

Fig. 2. Block diagram of the proposed measuring architecture.

The image processing software is written in the Python language and takes advantage of the free OpenCV library [12]. The OpenCV library simplifies the image processing making the identification of the particulate particles and the estimation of their size easy. The low-cost lens employed to focus the image and the simple lighting system let to capture a focused and uniformly lighted image only in the center of the acquired area. Even though this limits the number of captured spots, such a selection let to both open the system to a much cheaper approach and to greatly limit the processing time. By using an image portion of 250 kpixels (i.e. 500×500 pixels corresponding to about 500×500 μm) it is possible to limit the processing time of each image to less than 1 s.

The processing selects an image area, converts it to gray-scale using the most solicited color channel according to the lighting wavelength, performs a Gaussian blur to reduce the visual impact of the mesh composing the glass filter, increases the details using a moving kernel then identifies the spots and employs a minimization process to find their equivalent diameter.

Fig. 3 shows an example of the described imaging processing. Picture A shows the glass-fiber filter after 24 hours of exposure to contaminated air. Only the center area (about 37 mm in diameter in the described case) is interested by the air flow and becomes dirty and gray colored, while the external area remains white. Image B shows the 500×500 pixel image taken, on the filter center, by illuminating it with the UV wavelength. The image is recorded by the camera as a blue image and this channel is used for the subsequent processing. Image C is the gray-scale converted image, while image D is the same area

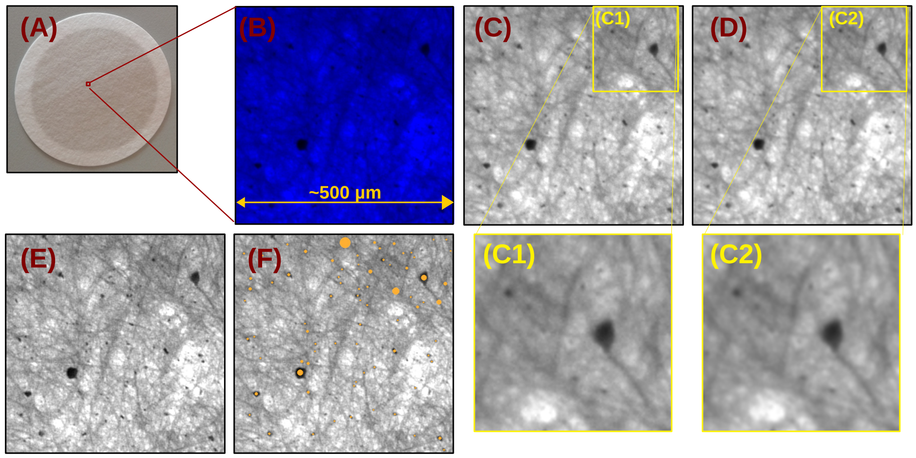

Fig. 3. Example of the image processing steps. The example refers to an image of the glass-fiber filter, after 24 hours air exposure, taken by using a wavelength of about 370 nm corresponding to the UV lighting.

after the Gaussian blurring. On the bottom, pictures C1 and C2 shown the corner areas of the previous two pictures at higher magnification. These last two pictures highlight how the blurring reduces the visual effect of the glass-fiber filter, without changing the aspect of the particulate spots. Finally, image E is the sharpened version of image D and image F shows the spot identification performed by the software.

As already pointed out the entire imaging processing is performed by the Raspberry embedded PC in less than 1 s, so that the entire processing for the seven wavelengths requires less than 7 s. By illuminating the filter with different wavelengths is in principle possible to try to identify different particulate particles taking advantage of the different level of transparency at different wavelengths.

Fig. 4 shows as an example two images of the same area of the glass-fiber filter, taken by using a red lighting (625 nm) and UV lighting (350 nm) after 12 hours of air exposure. The circles put in evidence the different light transmittance of some particulate particles at the two wavelengths. The difference in contrast of the particulate particles is clearly visible.

3 Results

The proposed system has been tested during some measuring campaigns performed in the metropolitan area close to Politecnico University in Turin, a city in the North of Italy. In the case described here, the measuring system has been positioned at a height of about 1 m very closed to a high traffic road.

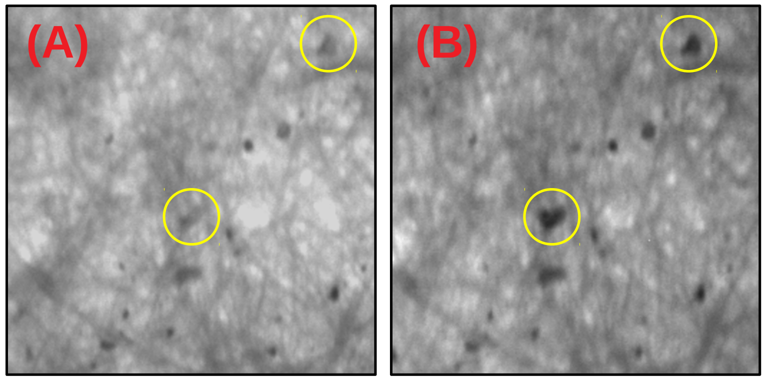

Fig. 4. Example of two images of the same area of a glass-fiber filter after 12 hours air exposure, taken with different wavelengths.

Fig. 5 shows as an example, the images collected on the glass-fiber filter exposed for 12 hours to the urban atmosphere.

Fig. 5-A shows the image taken on the glass-fiber filter; fig. 5-B shows the result of the imaging processing described in the previous section; eventually fig. 5-C show the particle size distribution. The total air volume fluxed through the filter is of about 0.3 m^3. The total particle counts in the measured area is of about 80 and the obtained size distribution is reported in the histogram, which highlights the presence of a lot of particles with size in the order of $5 - 10$ μm.

4 Conclusions

The proposed optical sensing system represents a simple and easy way to estimate the particulate particle size distribution in urban atmosphere. The designed and developed prototype is capable of determining particle size down to about 3 μm. Actually, this limitation is due to the glass-fiber filter mesh.

In the prototype implementation a high resolution camera is used, but the measuring campaigns carried out till now highlighted that a resolution of 512×512 pixels is sufficient for providing reliable results, without increasing the cost of the entire measuring system.

The preliminary results obtained by illuminating the glass-fiber filter with the IR-UV multi-lighting system, allows concluding that this low cost spectrometer is promising to provide information on the different nature and chemical composition of the particulate matter, even though more experiments are required to define these capabilities.

The authors are actually working in order to improve the system performance, both reducing the measuring system size and increasing the capability to send the collected data via blue-tooth and LoRa protocols.

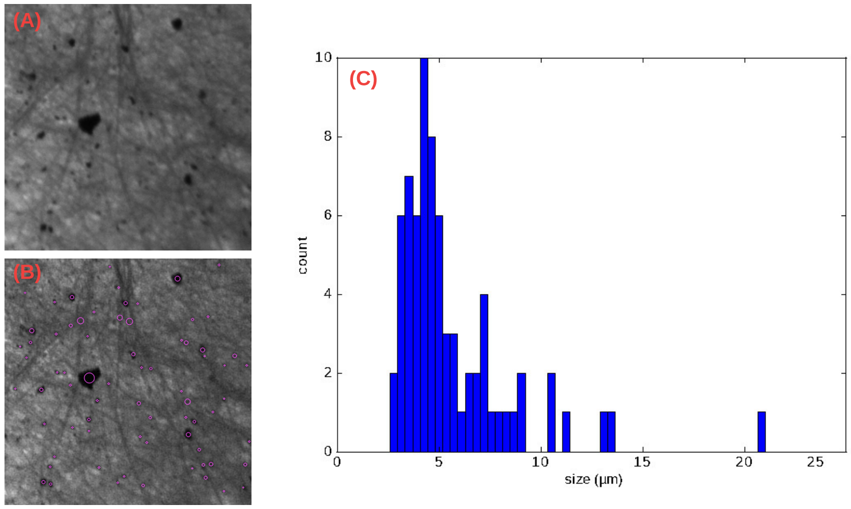

Fig. 5. Example of particulate size distribution obtained by sampling the air for 12h close to a high traffic road near Politecnico University, in the center of Turin (Italy).

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