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Shadow ribbon: a detailed study of complex chemical plants with a simple integrated approach

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A detailed shadow study of a complex chemical plants was accomplished by means of a very simple approach. The gathering of relevant information related to the 3D-distribution of obstacles was obtained with multivariate data treatment. The dispersion modelling of chemicals showed good agreement with experimental results.

Odor comfort and air composition in terms of health and safety for workers are important requirements for industrial areas. In the particular field of petrochemical, refinery, pharmaceutical and other chemical industries the air composition monitoring is a central concern in the health and safety assurance. Many authorities nowadays recognize the importance of odor comfort and air safety and require such studies before granting production permits.[1] Studies of odor comfort and air safety involve combining chemical analysis data with aerodynamic information of the location of interest at the industrial site. Pollution and odor dispersion models are routinely used in environmental impact assessments, risk analysis and emergency planning.[2] Since the transportation of chemicals is mainly due to the wind, a detailed wind field analysis is needed to perform dispersion modeling. In the specific case of the pollutant and odor dispersion modeling inside a chemical plant, a short-range modeling capability is required.[3] Apparatus with variable shape and height, streets with changeable width, wind canyoning, strong turbulence are only a few concerns of such kind of topic. Indubitably, a detailed knowledge of the tridimensional distribution of barriers, obstructions, obstacles, etc. is mandatory to obtain reliable models. Usually, information about field is obtained from maps and planimetries but, unfortunately, chemical plants are characterized by complex 3D-distribution of building, rack pipe, tanks, distillation columns, etc. resulting in very difficult conditions to model.[4] In this communication we present an integrated solution based on fast and low-cost in-field measurements to gather information needed for modeling.

We developed a multisensory device, named here *shadow ribbon,* based on physical and chemical[5] sensors: photoionization detector, GPS, compass and luminosity. It is able to obtain contemporary the position, the height and the permeability of the obstacles. The approach is based to the reconstruction of obstacles permeability from the shadow of them. We acquired a detailed shadow pattern during several moments of sunny days to gather information about wind permeability. We used such information to model the dispersion of chemicals in industrial plants.

In order to illustrate the presented approach, first let us take in account a small and very simple area of a model chemical plant composed of two bulky apparatus with a rack pipe connecting them as shown in Fig.1. The two bulky apparatus will have obvious effect on the airflow but even if on first approximation, the rack pipe can be neglected, tunnel wind simulation shown that the effect of the rack pipe on the airflow is significant in terms of turbulence. Since in the typical real chemical plants such kind of situation occurs often, it is worth to note that it causes noteworthy consequences on the chemicals dispersion in air. The aim of the presented approach is to gather such kind of information from the analysis of the shadow shapes.

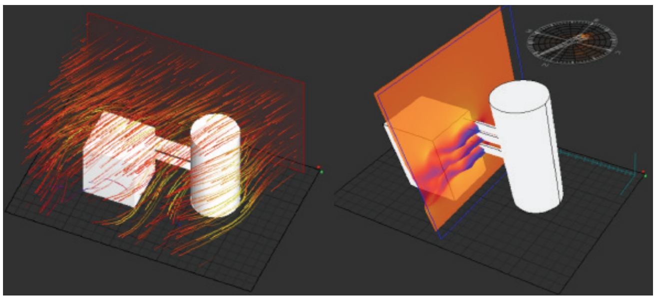

Fig.1 Wind Tunnel simulation of a small area of a model chemical plant composed of two bulky apparatus with a rack pipe connecting them as shown

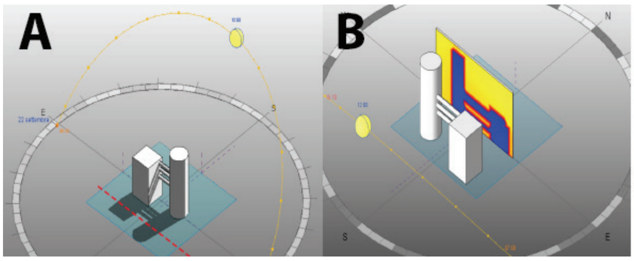

Fig.2 Simulated shadowing effect of same very simple industrial apparatus of Fig. 1 at noon in September at Latitude: 42° 19' North, Longitude:71° 05' West

Fig. 2a shows the simulated shadowing effect of the very simple industrial apparatus at noon. The projected shadow indicates that between the two bulky structures there is a suspended rack pipe. The expected signal acquired by scanning the shadow ribbon across the red line is shown in false colors in Fig. 2b. The bulky apparatus are characterized by a sharp difference between light and dark zone; on the other hand rack pipe can be easily discriminated because of typical intermittent signals. Definitely, the key of our approach can be simply explained: by scanning the shadow ribbon across the streets of a model chemical plan we discriminate the bulky obstacles from the porous structures affecting chemical's dispersion. The study on a model chemical plan by means of shadow ribbon scanning through streets is presented here. [†] The shadow ribbon is 3 meters tall; scanning has been performed each 25 meters across the plant, in September at sunrise and at noon in order to characterize obstacles directed thought east west and north south respectively. According to the plant dimension hundreds of point measurements were acquired. Measurement has been acquires by using several shadow ribbons in order to acquire all of data within one hour. Each device is equipped with a PC-based data acquisition interface able to store light sensors data and GPS coordinates. [§] After the acquisition run all data were transferred from each PC embedded in the devices to a single workstation in order to perform further data treatment. Fig.3 shows typical signals acquired by means of shadow ribbon scanning close to an in air suspended pipe rack arranged in horizontal orientation.

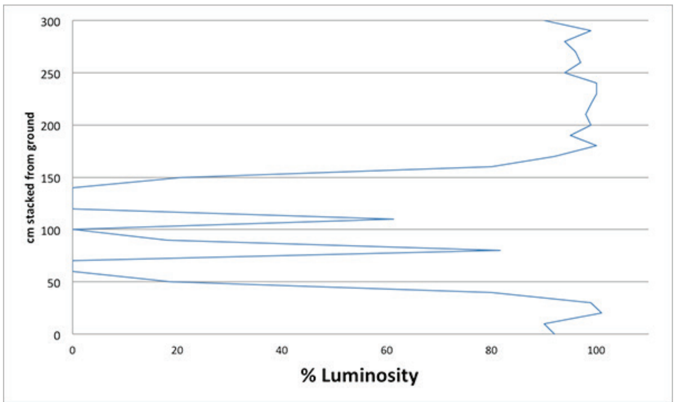

Fig.3 Shadow ribbon signal acquired scanning close to an in air suspended pipe rack arranged in horizontal orientation

The massive amount of data acquire by scanning the whole plant have been collected in a matrix and analyzed by the multivariate approach known as Principal Component Analysis (PCA).[6] Global positioning system coordinates represent the objects; lighting at several elevations from ground represents the variables.[¥] Fig. 4 shows the scores plot of the first three principal components. In such kind of plot a points' clustering represents likeness of objects (namely GPS coordinates) in terms of observed variables (i.e. shadows). Actually in the scores plot can be clearly discriminated at list 3 clusters. Clusters are related to the shadowing effect of i) fully shadowing bulky apparatus, ii) partially shadowing bulky apparatus starting from the ground and in air suspended, iii) no shadow of open areas. Last cluster is very large because of the large variability of such kind of data.

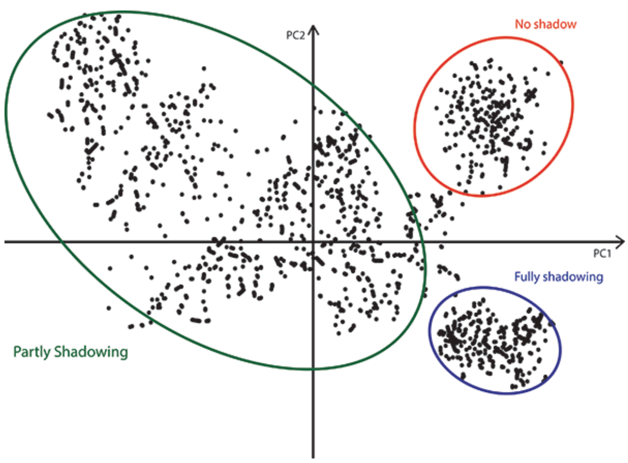

Fig.4 Scores-plot of the first versus the second principal component.

The classification gained by the principal component analysis has been transferred to the plant planimetry by means of GPS coordinates reporting obstacles characterized by different wind permeability deduced by the shadow study. By means of the innovative approach proposed here it is easily feasible reconstructing maps of bulky obstacles, porous areas and open patch zone in order to perform accurate chemicals dispersion modeling. We used a Gaussian Puff model to predict the chemical dispersion through the plant.[7] Centers of mass of the individual puffs are moved along the trajectory generated according to the wind field and the Puff is diffused according to a Gaussian shape each step of iteration. Mass transport depends on the wind and spreading of chemicals depends on the σ of the Gaussian curve. The concentration within a Puff falls off from the center according to a Gaussian or normal distribution. Taking the x-axis along the direction of mean wind flow U (m/s), the y-axis as crosswind and the z-axis as vertical, the Gaussian Puff model has the following form:

$$C(x,y,z,t) = \frac{Q}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} exp\left\{-\frac{(x-Ut)^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} - \frac{z^2}{2\sigma_z^2}\right\}$$

where C is the chemical's concentration (g/m^3), Q is the mass of chemical released (g) at time $t=0$(s), and the source location is taken to be the origin. The spread of the Puff is determined by the dispersion coefficients, σ_x, σ_y and σ_z (m). Such parameters depend mainly on distance travelled by the Puff, the wind condition and orographic complexity of the field where chemicals are dispersed.[8] Gaussian model is appropriate to proof the applicability of new approach, because complex structures in the plant increase the pollutant dispersion coefficients. We used Puff model in order to verify the correlation between the shadowing effect of complex structure and the Puff spreading. By using the volatile organic compounds (VOCs) sensors embedded on the devices we mapped their concentration at ground level. According to our results the main source of VOCs is a waste decantation tank. Therefore we modeled the dispersion of chemicals through the plant. By means of iterative calculation we were able to obtain a good estimation of detected organic volatile compounds (Fig.5).

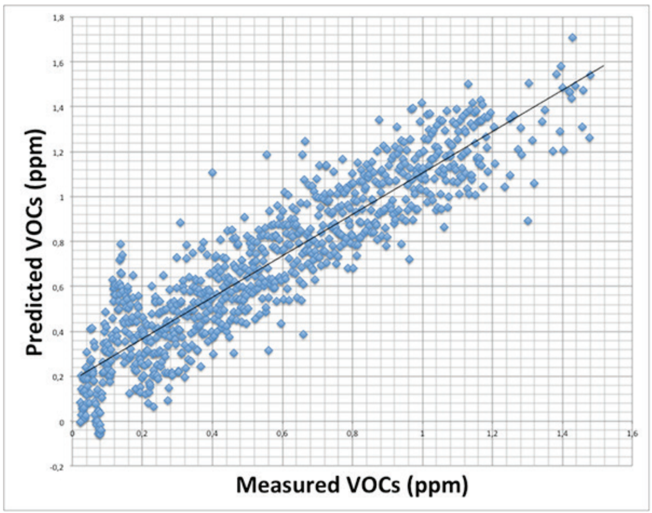

Fig. 5 Plot of measured versus predicted volatile organic compounds

We found a relation between the dispersion coefficients and the obstacles porosity obtained by shadow study. We obtained tree level of dependence. In the case of open patch, σ depends from the wind speed and distance travelled by the Puff. The bulky apparatus and buildings obtained from the shadow study have perfect reflecting surfaces and σ values are increased according to the dimension of the obstacles. Porous areas recognized by means of shadow ribbon are characterized by high dispersion coefficients values because of induced turbulence. Even if results obtained from the modeling show a worthy agreement with experimental result, lake of goodness fitting is likely due to the presence of several other VOCs sources in the actual chemical plant. Anyway, our principal aim here is to demonstrate the powerful of our innovative approach in the modeling of chemicals in complex industrial plans.

Conclusions

A simple approach based on the detailed shadow study of a complex chemical plants was presented. A multisensory device, named shadow ribbon, was developed on purpose to acquire shadow data in several illumination conditions. Multivariate data analysis allowed selecting the areas of the plant characterized by open patches, bulky obstacles and porous apparatus. Information gathered were used to model dispersion of chemicals having good agreement with experimental results.

Notes and references

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† Shadow ribbon was assembled on purpose. Light sensors (Avago Technologies) were purchased from RS-components. VOCs detector was purchased from Alphasense, UK. JUPITER SE880 was used as GPS module.

§ Devices are equipped with a fanless ragged industrial box PC (ARK-3360F-D5A1E from DIGIMAX, Italy) and a data acquisition DAQ interface based on an open-source electronics prototyping platform Arduino-based (Arduino-ONE, www.arduino.cc)

¥ PCA was performed involving hundreds shadow-ribbon scans by means of SIMCA-P software (Umetrics, www.umetrics.com). Before multivariate analysis, the intensities of all the signals in the data set were normalized in order to eliminate any systematic differences. The dataset was also mean-centered to ensure that the differences in samples were due to variation around the means and not to the variance of the means.

Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.1039/c000000x/

1 Directive 2008/1/EC, *Official Journal of the European Union*, 2008, **L25**, 51.
2 F. Istvan, K. Georgiev, Á. Havasi, *Advances in Air Pollution Modeling for Environmental Security*, NATO Science Series: IV, 2005, **54**; R. S. Joséa, J.L. Pérez, R.M. González, *Environmental Modeling & Software*, 2007, **22**, 297.
3 R. M. Harrison, M. L. Williams, *Pollution: Causes, Effects and Control* , 2001, **4**, 246; I. J. Keyte, R. M. Harrison, G. Lammel, *Chem. Soc. Rev.*, 2013, **42**, 9333; B. Zou, J. Wilson, F. Zhan, Y. Zeng, *J. Environ. Monit.*, 2009, **11**, 475; Y. Miao, S. Liu, B. Chen, B. Zhang, S. Wang, S. Li , *Adnvanced in Atmospheric Science*, 2013, **30**, 6, 1663; Young-Ji Han and Thomas M. Holsen, Philip K. Hopke, Seung-Muk Yi, *Environ. Sci. Technol.*, 2005, **39** (6), pp 1715–1723
4 L. Matejicek, Z. Janour, L. Benes, T. Bodnar, E. Gulikova, *Sensors,* 2008, **8**, 3830, D. K. Heist, L. A. Brixey, J. Richmond-Bryant, G. E. Bowker, S. G. Perrya, R. W. Wienere *J. Environ. Monit*., 2009, **11**, 2163-2170; Skote, M.; Sandberg, M.; Westerberg, U.; Claesson, L.; Johansson, A.V. *Atmospheric Environment,* 2005, **39**, 6147.
5 A.Auditore; S. Baglio; P. Barrera; A. Licciardello; N. Savalli; N. Tuccitto, Proc. SPIE 5467, *Fluctuations and Noise in Biological, Biophysical, and Biomedical Systems II*, 265 2004; N. Tuccitto, V. Ferri, M. Cavazzini, S. Quici, G. Zhavnerko, A. Licciardello, M Rampi, *Nature Materials,* 2009, **8**, 41.

6 L. Denis, F. Renaux, D. Cossement, C. Bittencourt, N. Tuccitto, A. Licciardello, M. Hecq, R. Snyders, *Plasma Processes and Polymers,* 2011, **8**, 127; A. Auditore, N. Tuccitto, S. Quici, G. Marzanni, F. Puntoriero, S. Campagna, A. Licciardello, *Applied Surface Science,* 2004, **231–232**, 314; Tuccitto, N., Torrisi, V., Cavazzini, M., Morotti, T., Puntoriero, F., Quici, S., Campagna, S. and Licciardello, A. *ChemPhysChem*, 2007, **8,** 227; N. Tuccitto, V. Torrisi, I. Delfanti, A. Licciardello, *Applied Surface Science*, 2008, **255**, 4, 874; A. Torrisi, N. Tuccitto, G. Maccarrone, A. Licciardello, *Applied Surface Science,* 2008, **255**, 1527; *International Journal of Mass Spectrometry*, 2010, **289**, 150; N. Giamblanco, G. Zhavnerko, N. Tuccitto, A. Licciardello, G. Marletta, *Soft Matter*, 2012, **8**, 8370

7 P. de Haan, M.W. Rotach, *Int. J. Environment and Pollution* 1995, **5**, 3

8 Slade, D.H. *Meteorology and Atomic Energy. U.S. Atomic Energy Commission No. TID-24190*, Springfield, VA: National Bureau of Standards, U.S. Department of Commerce, 1968.

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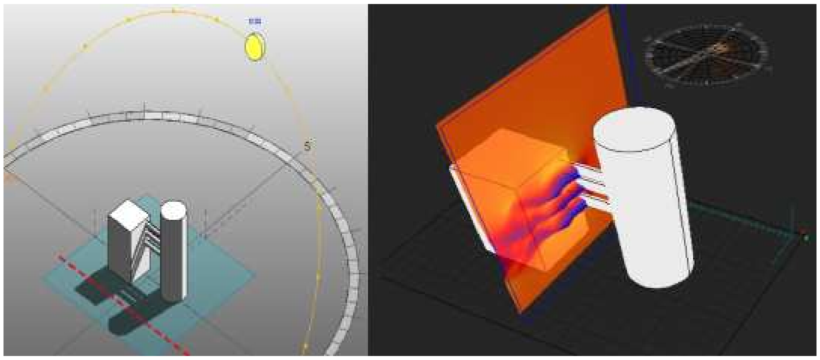

A multisensory device, named shadow ribbon, to acquire shadow data in order to study pollution dispersion in complex chemical plants