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New prototype of very compact LIDAR for atmospheric particulate monitoring

Giulia Pica
Consortium for Research on Advanced Remote Sensing Systems, Naples, Italy
giupica@unina.it

Antonella Boselli
CNR IMAA (PZ), INFM, Italian Institute for the Physics of the Matter, Naples, Italy

Francesca Castaldo
PROMETE, INFM Spin off Company, Naples, Italy

Roberto Fusco, Stefania Mattei & Maria Rosaria Santovito
Consortium for Research on Advanced Remote Sensing Systems, Naples, Italy

Wang Xuang
INFM, Italian Institute for the Physicsof the Matter, Naples, Italy

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ABSTRACT: During the last decades big efforts have been made world-wide to reduce or at least to put a stop to the increasing of air pollution. Among all remote sensors for the atmosphere lidar in recent years has achieved an important role in observing earth's atmosphere by monitoring aerosol concentrations which can give information on air pollution mechanism. Moreover, with recent technological advances in lasers and detectors, portable lidars have been built in order to perform aerosols *in situ* measurements. In this context, the CO.RI.S.T.A. led a research project funded by the Italian Ministry of Research and Technology, to realize a lidar system for monitoring of particulates in atmosphere. The main goal of the project is to get a compact, inexpensive, easy-and-safe to use lidar system. The lidar system realised is provided with an optical apparatus of emission/reception in bistatic configuration composed of a Cassegrain telescope and a beem-steerer, a Nd:YAG laser and two acquisition channels. Thanks to its limited size and light weight the system can be easily moved for *in situ* measurements. Preliminary intercalibration measurements of the prototype will be shown.

1 INTRODUCTION

During the last decades big efforts have been carried out world-wide to reduce or at least to put a stop to the increasing of air pollution: air control units have been implemented at industrial plants, catalysts at the cars, traffic of vehicles has been forbidden in the downtown to reduce the impact of the air pollution on the population.

Among all remote sensors for the atmosphere, the lidar technique in recent years has achieved an important role in remotely monitoring and characterising optical properties of atmospheric aerosol and pollutant particles with a high spatial and temporal resolution, providing also information on atmospheric transmissivity, density and temperature profiles (Collis R.T.H., Russel P.B., 1976, Ambrico P. F., 2000)

Moreover, with recent technological advances in lasers and detectors, lidar technology has great promise for future observations from platforms such as unattended airborne vehicles or commercial airlines because the systems can be very compact. (John R. Henderson , 1996, J.D. Spinhirne, 1995)

In this context, the CO.RI.S.T.A. (Consortium for Research on Advanced Remote Sensing Systems) is leading a research project funded by MURST (Italian Ministry of Research and Technology), with Quanta System and Kayser Italia as partners, to realize a lidar system for monitoring of particulates in atmosphere. The main goal of the project (named LAPMI) is to get a compact, inexpensive, user-friendly lidar system. The LAPMI project is part of the European research program EUREKA, where INOE 2000 (National Istitute of Research and Development for Optoelettronics, ROMANIA), CEPIEM (Institute for Employment Protection, Health and Ergonomics, ROMANIA), Prefecture of Bucarest, and Italian CO.RI.S.T.A. are working together to develop techniques to monitor particulates in atmosphere by means of lidar systems.

This paper reports on the realisation of a portable lidar prototype for *in situ* measurements of aereosols. The lidar system realised by CO.RI.S.T.A. and its partners is provided with an optical apparatus of emission/reception in bistatic configuration composed by a Nd:YAG laser, a Cassegrain telescope and a beam-steerer, and two acquisition channels at two different wavelengths. The prototype can perform 3D measurements by scanning the atmosphere along the azimuth and the zenith angles, by means of two stepping motors Thanks to its limited size (height 1m, width 1m) and light weight (less than 50 Kg), the system can be easily moved for *in situ* measurements. Both the telescope and the acquisition channels have been modelled and deeply analysed with Zemax (Zemax,1999), a 3D simulation program which allows to design optical system and to investigate their performance. Intercalibration measurements of the prototype with the more complex lidar of the INFM (National Istitute for the Physics of the Matter) will be presented.

2 THE PROTOTYPE

A lidar is essentially composed of a transmitter (laser) and a receiver (telescope). Its principle of operation is illustrated in Figure 1: the backscatterers (molecules, aerosols) at the distance R from the system send back part of the laser pulse toward A, active surface of the telescope. Consequently, the analysis of the detected signal as a function of t, time interval between emission and detection, allows one to study the optical properties of the atmosphere along the beam, since the simple relation between t and R is given by:

$$R = \frac{ct}{2} \quad (2)$$

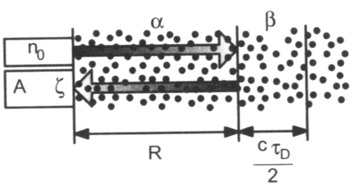

Figure 1. Lidar principle of operation. The points represent generic atmospheric scatterers (molecules, aerosols)

The photons detected within τ_D, detector response time, are backscattered from the layer delimited by the distances R and $R+c\tau_D/2$. Their number n is proportional to the thickness $c\tau_D/2$ and to the backscattering coefficient β of the involved air volume. Furthermore, in its round trip, the original pulse consisting of n_0 photons is attenuated by the atmosphere. This phenomenon is quantified by the extinction coefficient α. Moreover, n is proportional to the solid angle A/R^2 and the efficiency ζ of the detection system. So the lidar equation can be finally written (Measures R.M. 1992),

$$n(R,\lambda) = n_0(\lambda)\zeta(\lambda)\frac{A}{R^2}\beta(R,\lambda)\frac{c\tau_D}{2}\exp\left[-2\int_0^R \alpha(R',\lambda)dR'\right] \quad (1)$$

Basically the functional scheme of our lidar system is the following: the laser signal, sent into the atmosphere by an hand-operated beam steerer, is collected by the telescope, passes through a diaphragm and then is collimated on a narrow-band interference filter. Then the radiation is detected by a photomultiplier and is acquired by a multichannel board. The two wavelengths can be remotely selected in order to automatically switch from a 355 nm measurement to a 532 nm measurement. In figs 2 and 3 a layout and a picture of the prototype are shown respectively.

In order to maintain high efficiency and compactness of the system, a diode pumped Nd-Yag laser source was realised by Quanta System (Quanta System 2002) The laser source can be operated in second and third harmonic with an energy per laser pulse of 500 μJ and 300 μJ respectively, and a repetition rate of 1 kHz. The pulse lenghts are about 50 ns for both wavelenghts, leading a spatial lidar resolution of 7.5 m

In table 1 the laser source characteristics are summarised.

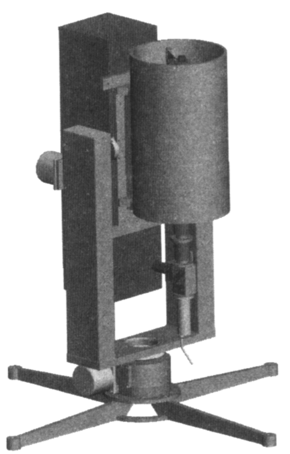

Figure 2. Lidar prototype layout

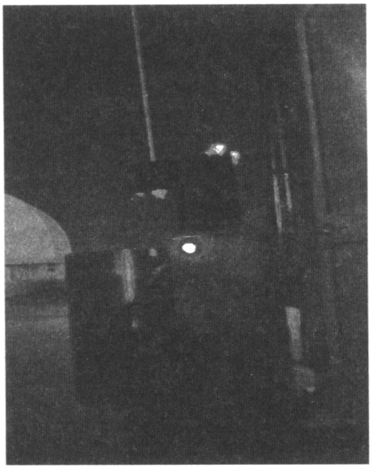

Figure 3. A Lidar prototype picture

Table 1. Characteristics of the laser source for Lapmi project

Wave-length	Energy per pulse	Beam polari-sation	Pointing stability	Beam diver-gency	Repe-tition rate	Pulse length
532 nm	500 μJ	TEM_{00}	≤100 μrad	1 mrad	1kHz	50 ns
355 nm	300 μJ	TEM_{00}	≤100 μrad	1 mrad	1kHz	50 ns

This prototype has been projected in a bistatic configuration with a telescope-beam laser distance of 27 cm, leading to a minimum observable range of 170 m and 150 m with diaphragm of 3mm and 4 mm respectively. To send the laser radiation into the atmosphere a hand-operating beam steerer has been designed made up by two plane mirrors, with coating for both 532nm and 355nm, mounted at 45^0 on two hand-operating gimbal mirror, as shown in Figure 4.

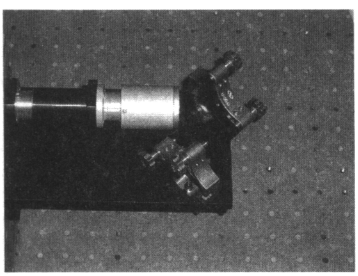

Figure 4. A beam steerer view

The telescope has a Cassegrain configuration with a spherical primary mirror and an elliptical secondary mirror (see fig 5). To achieve this configuration we performed simulations with Zemax software, looking for the best compromise between compactness, low cost, a good aberration correction and a good backscattered radiation retrieval. The primary mirror has a diameter of 20 cm with a central aperture of 3cm, while the secondary mirror has a diameter of 6 cm. A 17 cm buffle has also been realised to avoid the detection of the light that enters the tube without being reflected by the mirror (H. Rutten, 1999). The effective telescope focal length is 140 cm; diaphragms of different diameters (2,3, 4 mm) can be used in order to see different atmosphere ranges, starting form 140 m, 170 m, 210 m , respectively, up to 5 km, having in the mean time the telescope field always greater than laser beam divergence.

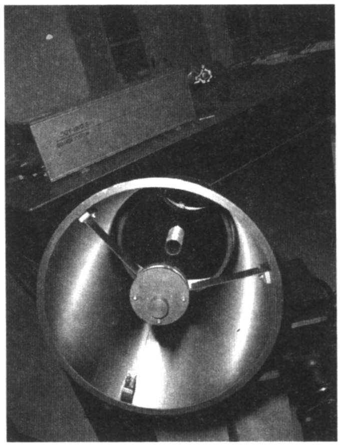

Figure 5. A view of the lidar Cassegrain telescope

Spectral selection is made by two narrow band interference filters, with (0.5 ± 0.1) nm FWHM, center wavelength of (532 ± 0.075) nm and (355 ± 0.075) nm respectively, transmittance > 35%, and a blocking of 10*e^-6 out of band. The backscattered laser radiation coming from different atmosphere ranges focuses in different position on the optic telescope axis. By performing simulations we calculated the beam divergence θ due to this field depth, and the wavelength shift Δλ on the interference filters due to the beam divergence and to the effective refractive index of the filters (Colavitto T,2001)., as follows:

$$\Delta\lambda = (\lambda_s - \lambda_0) = \frac{\lambda_0 (n_{eff}^2 - sin^2\theta)^{1/2}}{n_{eff}} - \lambda_0 \quad (3)$$

with

$$\begin{cases} n_{eff}(\lambda = 355nm) = 2.124 \\ n_{eff}(\lambda = 532nm) = 1.841 \end{cases} \quad (4)$$

In table 2 and in table 3 we report divergence angles and Δλ calculated for different atmosphere range and with a 3 mm diaphragm for the two wavelengths.

Table 2. Divergence angles and Δλ for different atmosphere heights at 355 nm

Atmosphere height (Meter)	Δλ (nm)	θ (mrad)
170 (min observable height)	-0.017	4.6
467 (full overlap height)	-0.025	18
100000	-0.009	15

Table 3. Divergence angles and Δλ for different atmosphere heights at 532 nm

Atmosphere height (Meter)	Δλ (nm)	θ (mrad)
170 (min observable height)	-0.015	14
467 (full overlap height)	-0.03	18
100000	-0.03	18

The wavelength shift introduced by the beam divergence and the effective refractive index of the filters is always smaller than the filter bandwidth for both the 532nm and 355 nm

To detect the backscattered radiation two acquisition channels was designed. The digital detector is an Hamamatsu photomultiplier H6180 with a discriminator and a preamplifier stage, while the analog detector is an Hamamatsu photomultiplier H6780. The analogue and digital signals are acquired by means of a multichannel board with a 12 Bit A/D resolution and a DC-20 MHz bandwidth, for the analog acquisition and a 250 MHz maximum count rate and a 10 MHz - 250 MHz bandwidth for the digital acquisition respectively

3 INTERCALIBRATION MEASUREMENT

The prototype was calibrated by performing simultaneous backscattering measurements with a fixed lidar of the INFM laboratory of Naples at 355 nm . This lidar system is based on a XeF Excimer laser (λ=351nm) working at a repetition rate of 50 Hz with a pulse energy of 50 mJ. The backscattered radiation is collected by a Newtonian telescope, in monostatic configuration, with a primary mirror of 30 cm diameter and focal length of 120cm (Amodeo A. 2000). The detection and data analysis system includes two acquisition channels corresponding to the elastic backscattered radiation and to the Raman shifted echoes from N_2 molecules. Data acquisition will be performed through a composite system, which includes both analog digitizing and photon counting techniques simultaneously to extend the sounded range from 100 meters to 20 Km. In Figure 6 and in Figure 7 two typical analogue and digital intercalibration measurement are sketched. These measurements have been performed with 3 mm diaphragm, an energy laser of 300 μJ. Measurement has been obtained by acquiring lidar signals averaged over 4000 laser shots for 30 minutes. The raw data were binned over 8 points leading to a 60 m spatial resolution. The so obtained profiles show a good agreement from 500m up to 7 Km. The slightly data departures at height lower than 500 m are due to the fact that effective area correction (Velotta R., 1998) has not been take in account for our data. (so that our lidar signals are always undervalued until all the backscattered lidar signal is completely in the telescope field of view). Moreover, a measurement at 532 nm has been compared with a simultaneous measurement performed with INFM lidar at 351 nm showing a consistent lidar data behaviour.

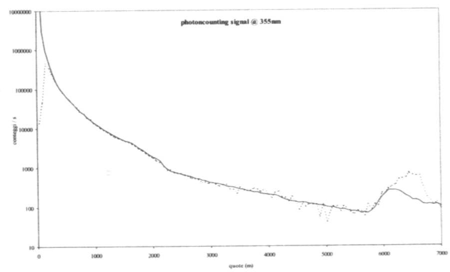

Figure 6. Photoncounting intercalibration measurement. The signal of the fixed lidar is the continuos line and the portable lidar signal is the dashed line

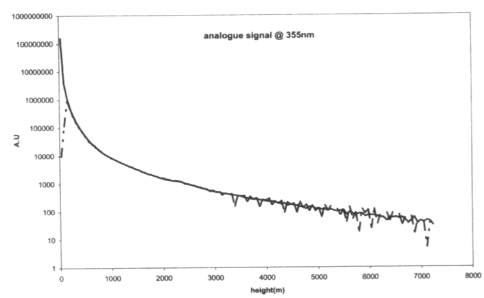

Figure 7. Analog signal intercalibration measurement. The signal from fixed lidar is the continuos line and the portable lidar signal is the dashed line

4 CONCLUSION

A new prototype of portable lidar for aerosols measurements has been realised. The prototype is provided with an optical apparatus of emission/ reception in bistatic configuration composed of a Cassegrain telescope and a beam-steerer, a Nd:YAG laser and two acquisition channels. The prototype can perform 3D measurements by scanning the atmosphere along the azimuth and the zenith angles. Thanks to its limited size (height 1m, width 1m) and short weight (less than 50 Kg), the system can be easily moved for *in situ* measurements. Intercalibration measurements with a fixed lidar have been performed showing very reliable performance of the prototype.

REFERENCES

Ambrico, P.F., Amodeo, A., Amoruso, A., Armenante, M., Boselli, A., Pandolfi, M.,Pappalardo, G., Spinelli, N., Velotta, R. *"Monitoring if an industrial area in southern Italy by using multi wavelenght lidar "* Optica Applicata **29,** 427, (2000).

Amodeo, A., Boselli, A., Fiorani, L., Passeggio, G., Velotta, R., *Innovative telescope for £-D lidar measurements,* Journal of Optoelectronic and advanced material, **2**, N1, 73-81, 2000.

Colavitto, T.*" Caratterizzazione lidar della dinamica degli aerosol nello strato limite planetario",* laurea thesis, Univ. Degli Studi di Napoli Federico II, a.a. 2000-2001.

Collis, R.T.H., Russel, P.B., In laser monitoring of the atmosphere, Ed. E.D. Hinkley,Springer-Verlag (1976).

John, R. Henderson, Arno, G. Ledebuhr, et al "*First Flight of the Cloud Detection Lidar Instrument Package*" Proceedings of the Sixth Annual ARM Program Science Team Meeting, March, 1996 UCRL-JC-123534.

Measures, R.M., Laser Remote Sensing, Krieger Publishing, Malabar, 1992.

Quanta System technical report for Italian Ministery for University research (2002).

Rutten, H. and vann Venroiij, M., *Telescope Optics* (Willman-Bell, Richmond, Va.,1989).

Spinhirne, J.D, Rall, J.A.R., and Scott, V.S., *"Compact Eye Safe Lidar System"* Rev. Laser Eng., 23, 112-118, 1995.

Velotta, R., Bartoli, B., Capobianco, R., Fiorani, L. and Spinelli, N., *"Analysis of the receiver response in lidar measurements",* Appl. Opt., **37**, 6999 (1998).

Zemax, Optical design program User Guide 8.0, 1999.