XXII A.I.VE.LA Annual Meeting
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First prototype of a Lidar-Dial system for the automatic detection of harmful and polluting substances

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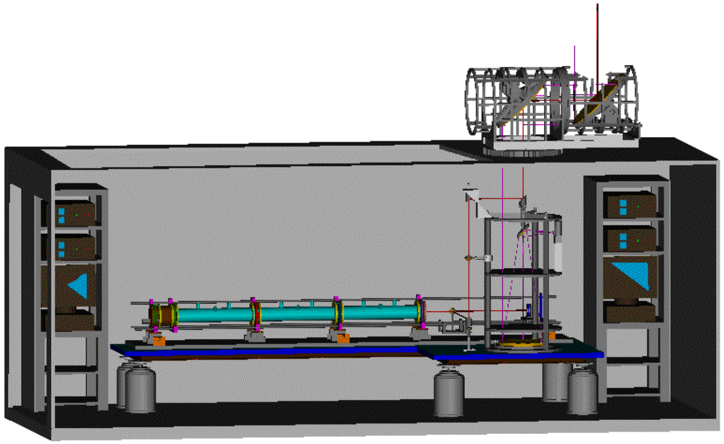
Lidar-Dial Techniques

The Lidar-Dial techniques are widely recognized as a cost-effective approach to monitor large portions of the atmosphere and, for example, they have been successful applied, by our group, to the early detection of forest fires.

At the University of Tor Vergata, a mobile Lidar/Dial station based on CO2 laser source has been designed and built .

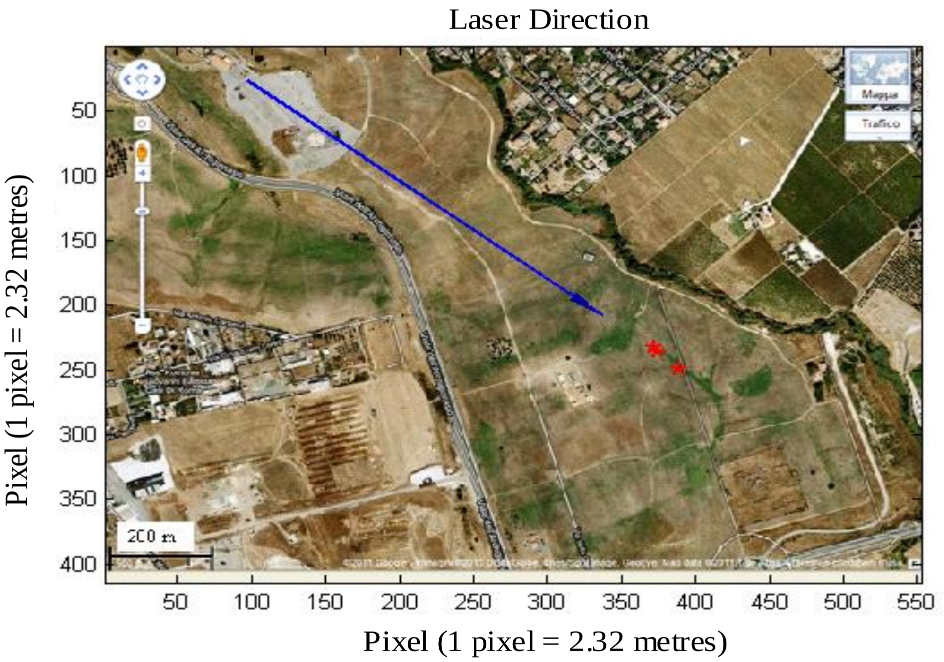


The aim of our work was to prove the effectiveness of a remote sensing system in both configurations, Lidar and Dial, for reducing false alarms in the detection of forest fires.

Lidar-Dial Techniques: Forest Fires

A Lidar measurement is performed first to evaluate the aerosol mass fraction dispersed in the atmosphere, using the non-absorption wavelength of the water molecule. If the returned signal reveals a backscattering peak, the presence of a fire is highly probable. A second measurement is then necessary to establish the concentration of water; this is achieved by emitting a secondary laser pulse at the wavelength corresponding to the absorption line of the same molecule.

The combined detection of the two laser wavelengths, together with the choice of water, a characteristic emission during the first combustion stages, has allowed reducing significantly the occurrence of false alarms.



ALARM

Direction : 6° 18' 20" NORD

First peak = 1125 m

Second peak = 1184 m

Third peak = 1484 m

Figure – Visual output of the signal processing software for the case of a fire detected about 1.2 km from the mobile station in the north direction.

Lidar-Dial system for pollutants: main elements

- Specifications and Conceptual Design
- Lidar system
- Dial system
- Minimum detectable concentrations
- Conclusion

Specifications

Continuous monitoring of the area under surveillance

Identification of the released chemicals

A very compact system
with a range of
at least 600-700 m in urban area

Optical wavelengths in
an eye-safe range for humans

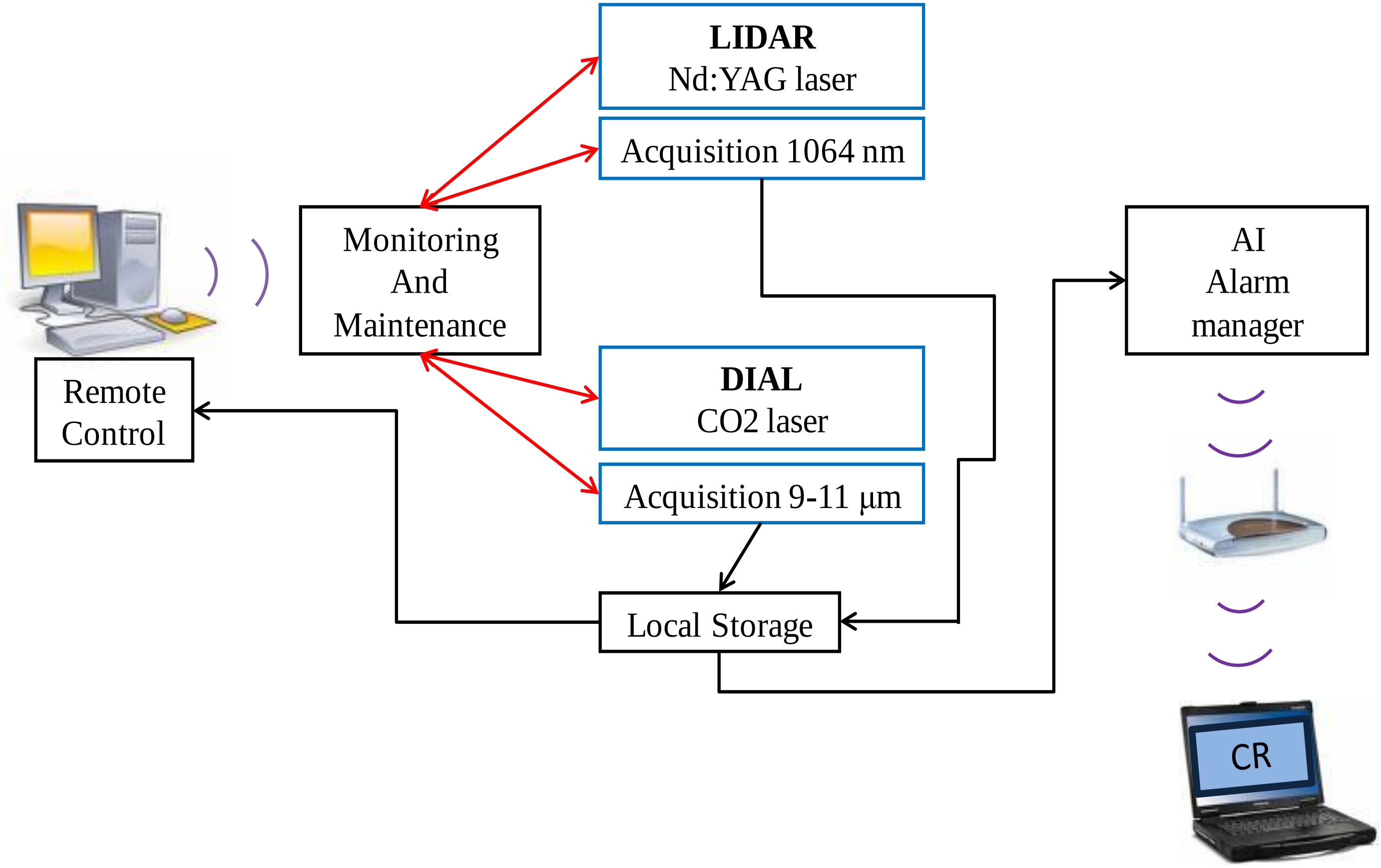
Low cost

Conceptual design

The proposed system consists of:

a) continuous monitoring the area to be surveyed with the Nd:YAG laser

b) after detection of variations in the aerosols, accurate concentration measurements with the CO_2 laser



LIDAR
Nd:YAG laser

Acquisition 1064 nm

Monitoring
And
Maintenance

DIAL
CO2 laser

Acquisition 9-11 μm

Local Storage

Remote
Control

AI
Alarm
manager

Lidar system

Transmitter	
Laser	
Active medium	Nd:YAG
Emission type	Pulsed (Q-Switched)
Wavelengths	1064 nm, 532 nm, 355 nm
Pulse repetition rate	10 Hz
Beam divergence	1.5 mrad
Beam waist diameter	7 mm
Pulse duration	8 ns @ 1064 nm
Pulse energy	330 mJ @ 1064 nm,
Power supply	100/240 V, 10 A, 50/60 Hz
Receiver	
Telescope	
Focal length	1030 mm
Primary mirror diameter	210 mm
Primary-secondary mirrors distance	820 mm
APD (model 1647 – New Focus)	
Spectral response	800 nm ÷ 1650 nm
3-db bandwidth	15 kHz – 1GHz
Peak response	0.6 A/W
NEP	1.6 pW/√Hz
Output impedance	50 Ω
Power supply	+/- 15 V
Active area	0.8 mm^2

The Lidar system, for the continuous monitoring of the area to be surveyed, is based on a Nd;YAG laser and a an Avalanche PhotoDiode (APD). The choice of these components is mainly dictated by the need of developing a compact system, robust enough to guarantee continuous (24/7) operation in hostile environments.

For the transmitter, a CFR (Compact Folded Resonator) laser has been chosen, due to, mainly, its reliability.

Lidar system: Signal-to-noise Ratio

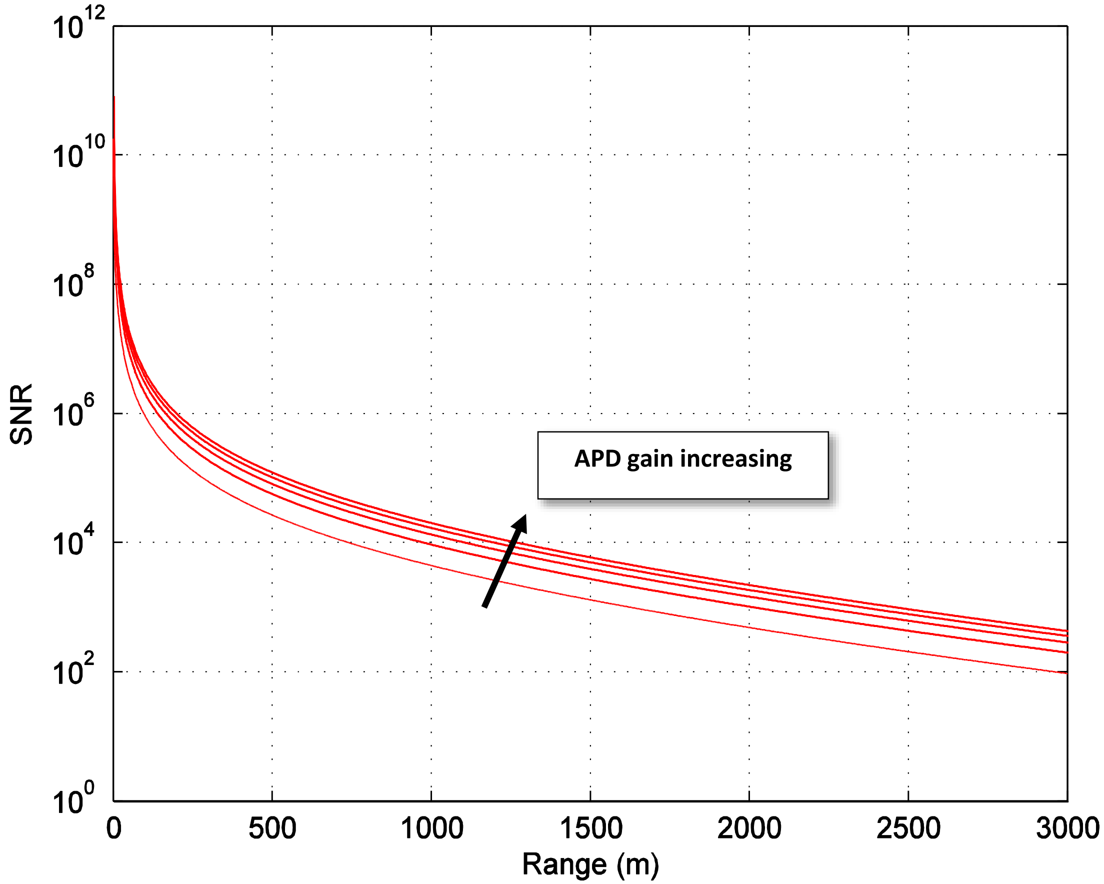
The SNR is mostly determined by the optical detector and the signal power incident on the detector element. According to Keiser (1983) the SNR for an avalanche photodiode is given by:

$$SNR = \frac{(1/2 \cdot R \cdot m^2 \cdot P_r)^2}{2 \cdot q \cdot (R_o . (P_r + P_B) + I_D) \cdot F(M) \cdot B \cdot \frac{4 \cdot k_B \cdot T \cdot B}{R_{eq} \cdot M^2} \cdot F_{amp}}$$

P_r is the received optical power
P_B is the received optical power of background signal
m is the modulation index
M is the avalanche gain
I_D is the primary bulk dark current
$F(M)$ is the excess photodiode noise factor $=M^x$ with $0 < x \leq 1$
B is the effective noise bandwidth
k_B is the Boltzmann's constant
T is the absolute temperature
R_{eq} is the equivalent resistance of photodetector and amplifier load
F_{AMPL} is the noise figure of the amplifier
and R is the responsivity calculated as: $R=M^*(\eta^* q)/(h^* v)$

with η the quantum efficiency, q the electron charge, h the Planck's constant and v the frequency of a photon.

Lidar system: SNR calculation



SNR simulation for the Nd:YAG system, varying the APD gain between 2 to 10.

Dial system

The design of the Dial system, for the accurate measurement of the pollutant concentrations, is based on the physical parameters of a working ground-based Lidar-Dial station which has been built and continuously upgraded at the University of Calabria. A similar set-up has been improved and mounted on a mobile station at the University of Rome – "Tor Vergata".

Transmitter TEA CO_2 laser		
	Output power	10^9 W
	Beam divergence	0.77 mrad
	Spectral range	$9 \div 11\,\mu m$
Receiver		
	Primary ROC	2400 mm
	Primary diameter	400 mm
	ZnSe lens focal length	50 mm
	Total Focal length	576.6 mm
	F.O.V.	0.88 mrad
	Detector type	HgCdTe
	Detector sensitivity D^*	$3.38 \cdot 10^{10}$ cmHz$^{1/2}$/W
	Detector size	1 mm^2

Dial system

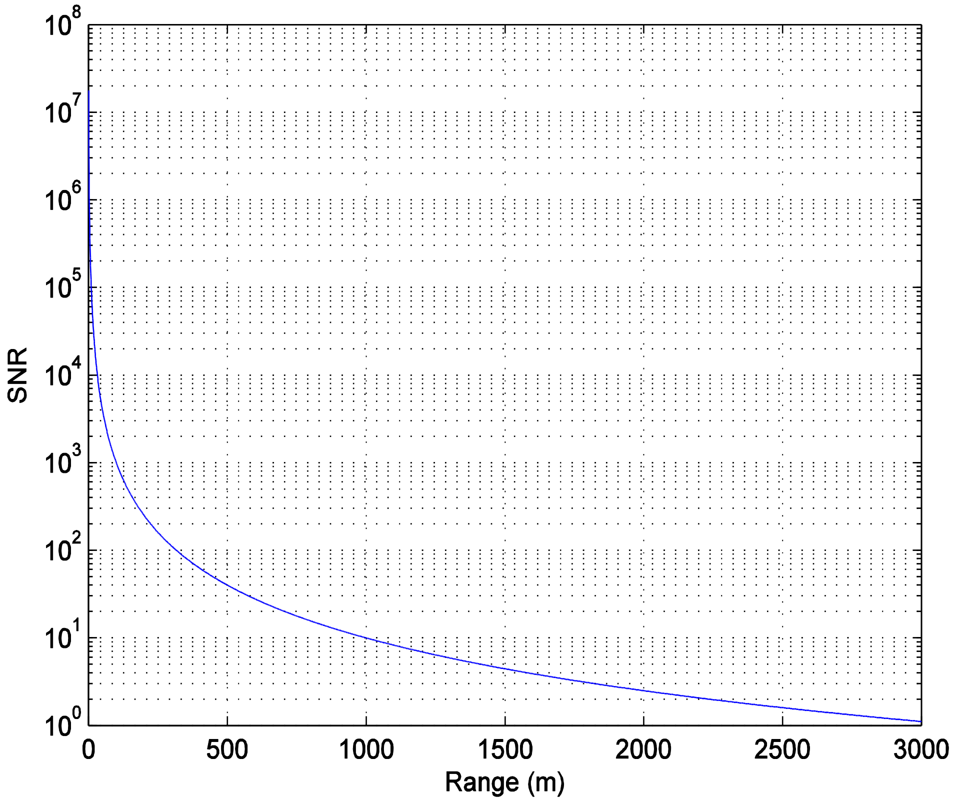
This set-up allows rapid tuning of the two lines (on and off) and keeps the misalignment within a range of 0.1 mrad , moderately below the beam divergence.

The values used to evaluate the SNR, and later the average minimum concentrations, which can be revealed by our mobile Dial system, are reported in the following table .

Parameter	Symbol	Value
Active surface	A	1260 cm^2
Noise eq. power	NEP	$2.35*10^{-8}$
Reflectivity target	ρ	0.1
Receiver efficiency	k	0.1
Constant term	$\Delta P_r/P_r$	0.01

Dial system: SNR simulation

In this case the SNR remains above 4 over the distance range of 1.5 km.



SNR simulation for the CO2 system. Wavelength: 9P14 (λ_{ON} Ammonia molecule)

Dial system: minimum detectable concentrations

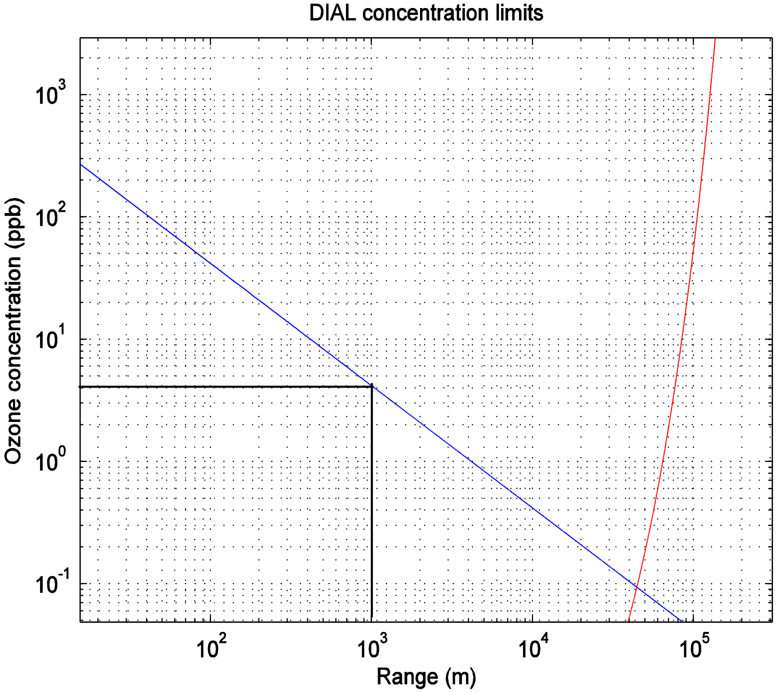
For the greater distances the minimum concentration can be evaluated setting the difference in the backscattered return at two frequencies equal to the noise of the detector (NEP):

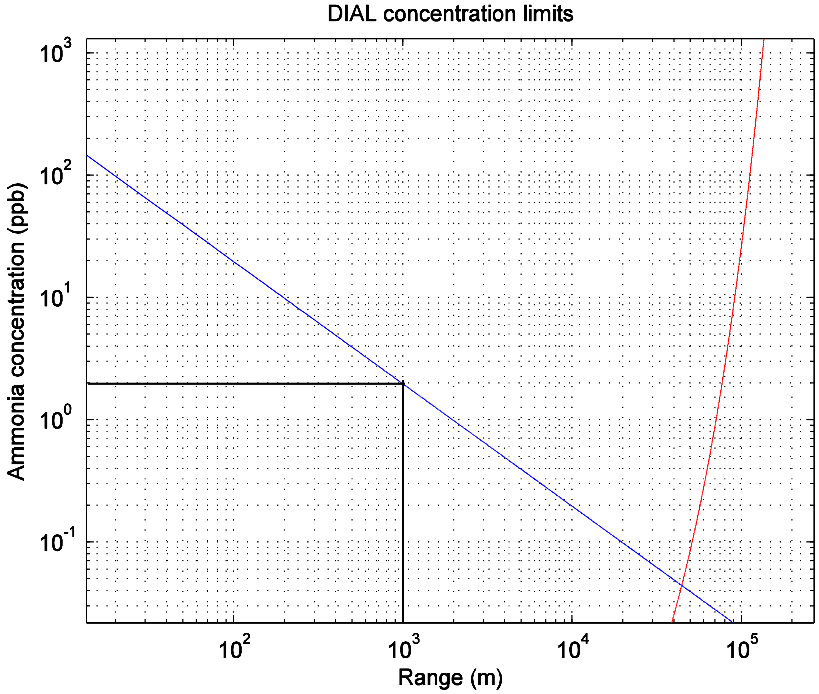
$$n_{\min} = \frac{(NEP)\pi R}{2\zeta \cdot \rho \cdot A \cdot P_0 \left(\Delta\sigma\right) \exp\left(-2\alpha R\right)}$$

At shorter ranges a more restrictive limitation may occur due to the inability of the measurement system to distinguish between the fractional change in the Lidar signal due to real variations of the species concentration and random fluctuations caused by atmospheric turbulence:

$$n_{\min} = \frac{5 \cdot 10^3 \cdot (\Delta P_r / P_r)}{\left(\Delta\sigma\right) \cdot R}$$

Dial system: minimum detectable concentrations





Ammonia minimum detectable concentration.
About 2 ppb @ 1 Km

Ozone minimum detectable concentration.
About 4 ppb @ 1Km

Conclusions

- The simulations reported in the previous sections indicate that both lasers can provide measurements with a more than acceptable SNR over the whole distance range required by the specifications.

- The sensitivity of the measurements seems also to be adequate to the application of pollutant detection.

- The positive results of the calculations therefore motivate the full design and the procurement of the system.

- We are also considering the application of the same approach to automatically recognize and identify substances used in chemical weapons

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