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# Environmental monitoring using optical techniques

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## ABSTRACT

An overview of optical techniques for environmental monitoring is presented. Range-resolved measurements of atmospheric pollutants can be performed using the differential absorption lidar technique. Fluorescence lidar allows assessment of vegetation status and also the conditions of the facades of historical buildings. Diode lasers provide particularly realistic schemes for atmospheric gas analysis, where certain wavelength ranges, which are not easily directly assessed, can be reached by sum- and difference frequency generation. Finally, the gas correlation principle can be used for real-time imaging of hydrocarbons. Several types of such optical environmental monitoring are illustrated with examples from research at the Lund Institute of Technology, Sweden.

**Keywords:** Lidar, laser-induced fluorescence, diode laser spectroscopy, gas correlation, air pollution, hydrocarbons

## 1. INTRODUCTION

Optical spectroscopy, and in particular laser spectroscopy, provide many possibilities for real-world applications. Powerful techniques have been developed for chemical analysis, combustion diagnostics, environmental monitoring and biomedical diagnostics (see, e.g., [1,2]). A comprehensive treatment, where a vast number of applications of atomic and molecular spectroscopy is related to the basic aspects of the field, is presented in [3].

We will here focus on environmental monitoring, and numerous examples from the research performed at the Lund Institute of Technology are given. Atmospheric monitoring includes the laser radar, the diode laser spectroscopy and the gas correlation imaging methods, while laser-induced fluorescence (LIF) is applied to hydrospheric pollution measurements, vegetation status assessment and building facade monitoring. Non-intrusive measurements in real time are provided, as is characteristic for remote sensing techniques.

## 2. ATMOSPHERIC LIDAR

The Lund group has been pursuing atmospheric laser radar monitoring for a long time, including industrial and geophysical measurements. A review of some of the activities is given in Ref. 4. A full integration between plume-transect, integrated-gas-content measurement and automatic wind assessment for total flux determinations at industries has been achieved [5,6]. Extensive work on the monitoring of mining areas, geothermal fields, and active volcanoes has been performed [7-13]. In particular, the total fluxes from the Italian volcanoes Etna, Stromboli and Vulcano have been measured in shipborne campaigns, where Differential Absorption Lidar (DIAL), Differential Optical Absorption Spectroscopy (DOAS) and Correlation Spectroscopy (COSPEC) were intercompared [14]. Present lidar group activities focus on hydrocarbon monitoring in the IR region. Hydrocarbons play a very important role in modern society, being primary fuels and also very important materials for the chemical and pharmaceutical industries. Monitoring and control of the outflow of gaseous hydrocarbons is important for preventing loss of valuable raw material, for avoiding explosion hazards as well as for environmental protection. The primary C-H stretch molecular vibration occurs in the 3.4  $\mu\text{m}$  region with small and characteristic shifts for different molecules. We use a optical parametric oscillator (OPO) and difference frequency generation in our lidar system to enable IR monitoring of hydrocarbons [15-18].

### 3. FLUORESCENCE LIDAR

The Lund group has performed extensive fluorescence lidar work regarding water quality, vegetation status, and historical building facades [19-24]. In particular, part of the Lund Cathedral was scanned with a fluorescence lidar system for assessment of algal and lichen growth [25]. Full fluorescence spectra were recorded in each image point and multi-variate analysis was employed for data presentation. A field campaign for similar measurements in Parma, Italy, was recently performed [26].

### 4. DIODE LASER SPECTROSCOPY

Diode lasers provide convenient means for certain types of spectroscopic diagnostics. Normally, only line-of-sight path-integrated data are obtained, similarly as in DOAS [27]. A particularly high sensitivity in diode laser absorption measurements can be obtained in frequency-modulation (FM) spectroscopy, of which two-tone FM spectroscopy is an especially convenient variety. We have focussed on a full characterisation of the absorption lineshape, which allows the technique to be used under varying gas temperature and pressure conditions. With the fast development of the semiconductor laser technology, new wavelength regions are becoming available. We recently demonstrated first single-mode diode laser spectroscopy in the violet spectral range, frequency-modulation spectroscopy with blue diodes, and also their usefulness in sum-frequency generation to the UV region, also accessing the mercury line at 254 nm [28-30]. We are also, like many other groups, performing diode laser spectroscopy in the IR range, accessible by difference-frequency generation or directly by quantum cascade lasers. Simultaneous monitoring of background atmospheric methane and the oxygen and water vapour concentrations, was recently performed by tuning two diode lasers to appropriate wavelengths [31].

An emerging new field of diode laser spectroscopy, GASMAS (GAs in Scattering Media Absorption Spectroscopy) relates to the study of free gas dispersed as bubbles or pore enclosures in scattering materials such as wood, fruits, ceramics, foams, and insulating materials. Thus, oxygen gas was extensively studied in many materials, with demonstrations also of the possibilities for pressure measurements and diffusion studies [32,33]. By combining CW measurements with pulsed photon propagation studies, which map out the different pathlengths through the scattering medium, it is possible to determine gas concentrations [34]. The new technique uses quite simple equipment, which still allows advanced studies in several novel fields to be performed also in developing countries [35].

### 5. GAS CORRELATION IMAGING

We have developed a powerful imaging technique for hydrocarbon monitoring. The gas correlation principle combined with passive thermal background illumination is employed for the visualization of gases absorbing in the IR region [36]. The technique was demonstrated at a full-scale polyethylene plant, where ethylene emissions from flares as well as pipes were detected. The method is expected to allow effective surveillance from the production, distribution to the end use phase for petroleum products.

### 6. CONCLUSIONS

Environmental monitoring using optical techniques has reached a mature state in certain aspects, while other areas of application are emerging. With the fast development of compact and tuneable lasers, sensitive detectors and computers, the techniques can be expected to play a major role in the future surveillance and management of the environment

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