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PerspectUV- AN OPEN PATH AMBIENT GAS MONITOR FOR INDUSTRY

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ABSTRACT

PerspectUV is a unique instrument developed to perform ambient air monitoring in urban and industrial settings. It has been designed to be transportable with quick and simple set-up and operation that requires no specialist knowledge by the user. The instrument is fully weather-proof for operation in a wide range of environmental conditions and maintenance is minimal.

This paper describes the instrument's innovative and patented principle of operation and the measurement technology is compared with other commercially available open path monitoring technologies.

The device is an Open Path Gas Monitor which consists of an ultraviolet transmitter, a receiver containing up to four solid state interferometers (one per gas to be monitored) and software for configuration, alignment, data logging, diagnostics and graphical data display. The system can monitor over path lengths of up to 1000m between the transmitter and the receiver. Multiple receivers can be 'daisy-chained' via the integral RS485 data communications to a single computer serial port.

Due to the novel single beam solid state interferometric elements, this instrument has superior performance with respect to internal misalignment, vibration, shock, temperature fluctuations and scintillation effects in comparison to conventional dual beam interferometers. The modular multi-channel construction allows simultaneous monitoring of up to four gases per receiver.

Data is extracted in real time using a new gas measurement technique called Ultraviolet Correlation Interferometry (UVCI). This allows fast response times of less than two seconds with superior signal-to-noise performance, detection limits of around 1ppb are achievable. No spectral data libraries are needed and the receiver outputs Path Integrated Concentrations directly to the computer or data acquisition system that is running the *PerspectUV* software.

The PerspectUV is intended for measuring very low levels of atmospheric pollutants over long paths with a fast response time. Typical applications are 'fence-line' monitoring of industrial sites and air quality monitoring in urban environments. The gasses most commonly measured include Benzene, Toluene, Formaldehyde, Styrene, Nitric Oxide, Nitrogen Dioxide, Sulphur Dioxide and Ozone.

KEYWORDS

Interferometer, Birefringent, Molecular Spectroscopy, Gas Monitor, Open Path

INTRODUCTION

Open path monitoring is an efficient technique for ambient gas monitoring where a large area must be covered. There are two main advantages of open path monitors in comparison to point source monitors. Economically, an open path system can replace a number of point source monitors. Physically, open path data is a more representative measurement than point source data because it samples a line integral through the atmosphere.

An open path gas monitor is very similar in principle to a laboratory spectrophotometer. A spectrophotometer analyses a sample by looking at its light absorption signature to determine how much of a given chemical is present. An open path monitor operates in the same manner except that the "sample cell" is a section of atmosphere, usually between 10 m and 1000 m in length. A system may consist of a transmitter and receiver located a distance apart (bistatic configuration), or a combined transceiver with a remotely located retro-reflector (monostatic). The measured quantity is the path-integrated concentration, hence the long lengths of their paths make these instruments very sensitive to low average concentrations. Typical minimum detection limits (MDL's) are in the low part per billion (ppb) range for a 500 m path.

A detailed review of open path instrumentation is found elsewhere (Sigrist, 1994). This work focuses on the application of a different type of technology that is newly available in the market-place.

The technology used for spectral instrumentation is usually dependent on the observed region of the spectrum. Ultraviolet (UV) or visible instrumentation is predominantly dispersive, using an optical element such as a diffraction grating or prism to spatially separate the spectral information. In contrast to interferometric systems, the advantage of dispersive systems is that they are easy to construct and to keep aligned due to relaxed optical tolerances.

Infrared systems are typically Fourier transform Infrared (FTIR) spectrometers. FTIR spectrometers acquire data with an interferometer, and convert this data to a spectrum by using a Fourier transform. Because infrared detectors are governed by a thermal noise baseline, there is a great signal to noise advantage in performing interferometry as opposed to dispersing the light (Griffiths, 1986).

The *PerspectUV* ultraviolet interferometer system was created to circumvent the stability and internal alignment problems of conventional Michelson-type interferometers through the use of a solid state interferometric element. By using correlation interferometry, data is taken in real time with a large signal to noise advantage over Fourier transform spectroscopy. The result is a stable instrument with a fast response that is well suited to an industrial environment.

This paper describes the technology behind the design and operation of the *PerspectUV*. Ivanov (1996) discusses results of an intercomparison with point source monitors.

MEASUREMENT TECHNIQUE

The ultraviolet absorption spectrum of most gasses shows a periodic structure. This structure is due to the spacing of the molecular vibrational levels for a given electronic transition. Correlation interferometry uses the periodicity of these spectral features as an identification criterion for gas measurement.

Interferometers are sensitive to periodicity. The position where maximum modulation occurs in an interferogram is dependent on the spacing of the periodic features in the input spectrum. To illustrate this point, consider the example of Sulphur Dioxide and Formaldehyde. These two gasses absorb in the same region of the spectrum but have a different periodicity. The absorption spectra of these gasses and the corresponding interferograms are shown in figures 1 and 2 respectively.

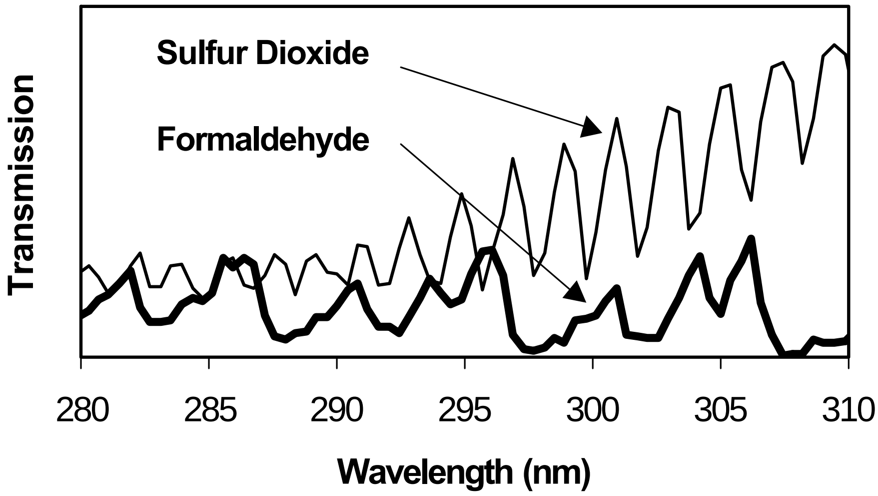

Fig. 1. Absorption spectra of two gasses in the same spectral region.

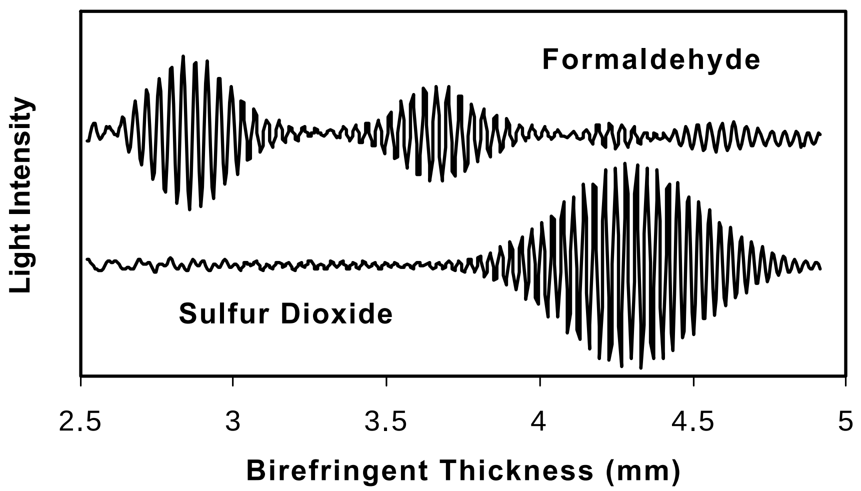

Fig. 2. Interferograms of the two gasses shown in the previous figure.

The path length difference (termed birefringent thickness in figure 2) required for maximum modulation of the interferogram is dependent on the periodicity of the gas absorption spectrum. Sulphur Dioxide has a spectral signature (figure 1) that is easily recognizable as periodic, and hence has one localized modulation envelope in the interferogram (figure 2). Although Formaldehyde does not exhibit such obvious spectral structure, figure 2 shows the interferometer is able to pick out two main superimposed periodic interferometric signatures.

The instrument uses correlation interferometry to determine the gas concentrations continuously. This technique scans one small region of interest in this interferogram to determine the amplitude of this modulation. The interferometric region is chosen so that the gas of interest produces a modulation maxima, and other gasses that absorb in the same spectral region produce modulation minima. For instance if we scanned the interferograms in figure 2 near 4.3 mm, we would get a strong signal from Sulphur Dioxide, but only a weak signal from Formaldehyde. When the absorption is small, the amplitude of this interferogram is proportional to the integrated concentration of the gas present. To increase selectivity, the interferometer is optically filtered so that only light from the spectral region of interest is observed. Thus this technique filters both in the spectral domain and in the interferometric domain to achieve maximum selectivity. Because numerical data analysis is not required data is quickly output to the user (normally at 2-second intervals).

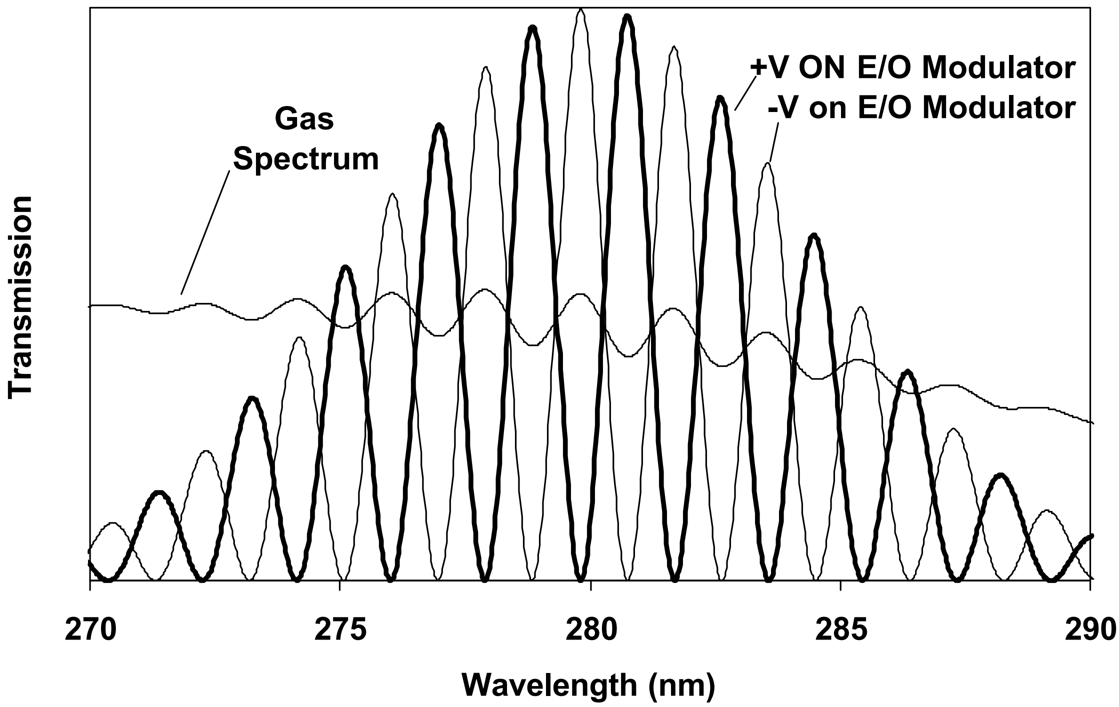

Fig. 3. Transmission spectra for gas and instrument with different E/O modulator polarities.

Another way to understand correlation interferometry is to visualize it entirely in the spectral domain. Figure 3 illustrates the transmission function of an interferometer with a bandpass optical filter. This appears as the product of a Gaussian function (bandpass component) with the square of a sine function (interferometer component). Also shown is the periodic transmission of a hypothetical gas. When the interferometer is tuned so it is in phase with the gas spectrum, a maximum intensity will be transmitted; when it is tuned to be 180° out of phase with the spectrum a minimum intensity will be transmitted. The PerpectUV interferometer is tuned to positions that correspond to the maxima and minima points in the modulation envelope of the interferogram.

In Fourier transform (FT) spectroscopy, the entire interferogram is taken, from the zero point to a predetermined path length difference. A spectrum is calculated by apodizing this data, taking a Fourier transform, and dividing by the instrument sensitivity. The resolution of this spectrum is determined by the maximum path length difference measured. Only a small fraction of the time is spent in the modulation envelope produced by the target gas, so the signal to noise ratio of a gas measurement using FT spectroscopy is worse than that of correlation interferometry. Most information that is gathered in FT spectroscopy determines the spectrum in superfluous regions. Once the spectrum is obtained, either by FT spectroscopy or by differential optical absorption spectroscopy (DOAS), the spectrum is numerically fit to the data to determine gas concentrations. Because of the integration time required to produce a spectrum and the time required to perform numerical fits, the data is not available in real time.

INSTRUMENT DESIGN

System

The gas analyzer is a bistatic open path instrument. The transmitter consists of a 75 watt Xenon arc lamp (with power supply) and an f 3.3 mirror to collimate the light. This transmitter produces a beam of light that has about a 1 m divergence over a range of 500 m and a smooth ultraviolet spectrum from 200 nm to 400 nm.

The receiver consists of an f 4 receiving telescope and from one to four channels, each tuned to provide continuous measurement of a single gas. A computer for setup, display, storage, and alarm triggering collects data accumulated from a number of receivers.

Optical

In order for a dual beam interferometer to work effectively, it must have both beams recombine with wave-fronts that are flat to within a fraction of the wavelength of the observed light. For a conventional Michelson interferometer used in FTIR work, the construction and alignment of the optical components must have a total error due to misalignment and flatness of 1×10^{-6} cm for $\lambda/20$ optics at 200 nm. It is difficult and costly to produce optical components with these tolerances, and to maintain alignment of these components to within this specification usually limits the practicality of such instruments to the laboratory. On the other hand by employing a polarization interference filter (Yariv, 1983) as an interferometric element, these tolerances are relaxed by a factor of 100, making the components easy to manufacture and keep aligned, even in an industrial environment.

A schematic diagram of a polarization interference filter (PIF) is shown in figure 4. Polarized light from the sample is incident upon a birefringent crystal. A birefringent medium is a crystal with two indices of refraction. Which index affects the light is dependent on its orientation and polarization with respect to the crystalline axes. The crystal is oriented so that light polarized in the plane of the paper is slower (extraordinary ray) than light polarized perpendicular to the plane of the paper (ordinary ray).

Both the polarizer and analyzer are oriented 45° with respect to these two axes. Polarized light traveling through the crystal is effectively "split" between these two axes, and "recombined" at the analyzer. In a two-beam interferometer, retardation is achieved by having two different path lengths with the same index of refraction. With a PIF the same effect is achieved in one path, but with two different indices of refraction. Thus the polarizers are analogous to the beam splitters in a conventional two-beam interferometer. The interferometer is coarsely tuned by adjusting the length of the birefringent crystal, and it is scanned over a small interferometric range with a variable birefringence electro-optical modulator. After passing through the PIF, the light is filtered with an optical bandpass filter to limit the observed interference to a small spectral range, and then directed to the detector.

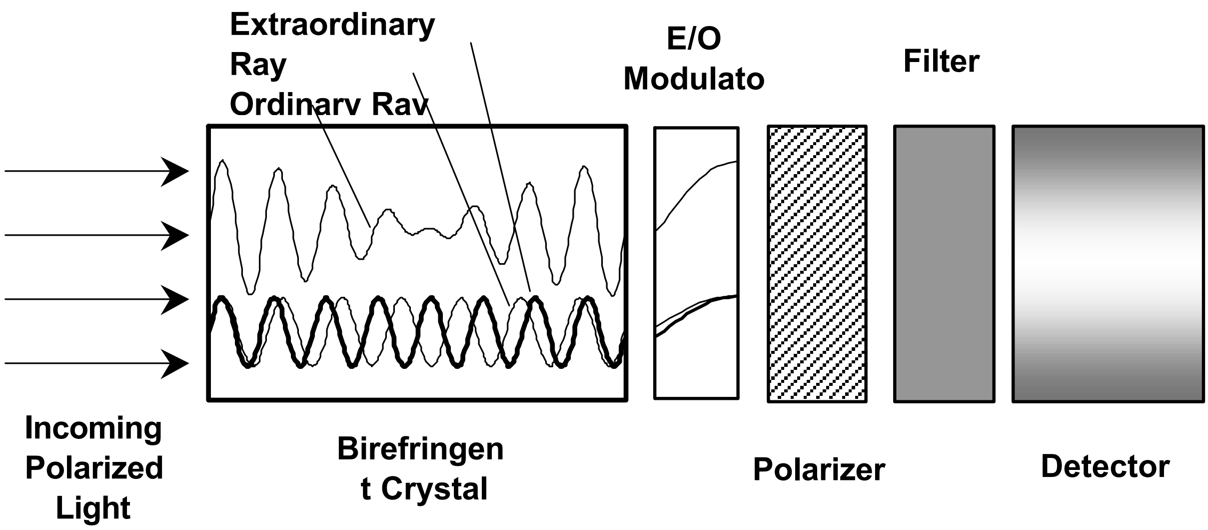

Fig. 4. Schematic diagram of a Polarizing Interference Filter (PIF).

Utilization of birefringent technology has three main advantages over typical dual beam interferometers. The first advantage is ease of manufacture. The effective path length difference of a PIF is the length of birefringent crystal multiplied by the difference in the indices of refraction of the fast and slow axes. Because this difference is only about 1% of the index of refraction, the interferometric pattern is "magnified" by a factor of 100. This is why the flatness / alignment tolerance is relaxed.
The second advantage is stability. Because the interference pattern is effectively "frozen" within the crystal, it is more difficult to internally misalign such a system. This also makes the interferometer insensitive to vibration. The third advantage is the purity of the signal. Scintillation caused by differing convective effects in the two beams normally reduces the quality of data in conventional interferometers. The shared solid state interferometric beam paths in this instrument make it impervious to scintillation problems.

Electronic

An automatic gain control (AGC) circuit holds the average current from the detector constant. Effectively, this normalizes the signal so that the amplitude of the modulation is approximately proportional to the integrated gas concentration regardless of the light intensity in the instrument. The signal from the detector is filtered with an electronic bandpass filter that is centered at the frequency of the electro-optic modulator. This removes the DC offset of the signal. The AC signal is then synchronously rectified.

Synchronous rectification is achieved by taking the product of the signal and the clock pulse controlling the electro-optic modulator. The clock pulse is a square wave that is symmetric about zero, so the product of these two signals will be positive in the case where no noise is present. Although this is similar to rectification, there is one important difference.
While rectification takes the absolute value of the signal, synchronous rectification may produce negative values. Synchronous rectification is necessary for the proper treatment of noise when the signal is summed. With a modulation frequency of about 32 kHz, and an integration time on the order of seconds, the correct treatment of noise is critical to the accurate observation of gasses at ambient levels.

An analog-to-digital converter then converts the synchronously rectified signal to a digital value every second. It is this digital signal that is output to the software.

This method of detection has a dynamic range advantage over both DOAS and FTIR instrumentation. DOAS and FTIR must discern a signal that is typically $\sim 10^{-4}$ of the measured intensity for ambient concentrations. With correlation interferometry this dynamic range problem is avoided because the signal is proportional to the amount of gas measured. This measurement method is robust with respect to AGC stability and detector non-linearities.

Software

The digital values from the interferometric channels are temperature compensated and converted into path integrated gas concentrations by the firmware within the receiver and placed into an output buffer whichis updated every 2 seconds. Each receiver has a unique communication address and includes comprehensive diagnostic and self-checking functions.

Up to 4 receivers can be connected via the RS 485 data link and a RS 485 / RS 232 converter to the serial port of any Windows 95, 98 or NT Personal Computer. Data is communicated as simple ASCII text files.

The 32-bit Windows ® PerspectUV software occupies only 4 MB of hard disk space and is supplied on two self-extrcating diskettes. The software displays the gas readings graphically in real time and can determine time-weighted averages of the data over user-specified intervals, and whether these exceed user-specified alarm thresholds.

The software performs periodic system checks of the instrument and logs the results. Historical data can be recalled, graphically displayed and exported whilst operating on-line.

CONCLUSION

Solid state ultraviolet interferometry is a viable technology for open path gas monitoring. The instrument described is unique with respect to commercial instrumentation presently available in the market-place.

The inherent stability of the solid state interferometer allows ultraviolet interferometric measurements to be made even in harsh industrial settings and inhospitable environmental conditions. The utilization of correlation techniques enables the extraction of continuous, stable, real time data, with high sensitivity, with a fast response time.

The compact nature of the solid state interferometer makes it possible to mount up to four modules in one receiver, for simultaneous measurement of up to four gasses.

ACKNOWLEDGMENTS

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