AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

SAND94-1206C
Conf-9404162--1

Optical Detection System for Multispectral UV Fluorescence Laser Remote Sensing Measurements.

Gary C. Tisone, Brian Clark, Colleen Wakefield-Reyes, Philip J. Hargis Jr.,
Bob Michie, Tom L. Downey, and Rick A. Mills
Sandia National Laboratories
Albuquerque NM 87185

Abstract

A mobile laser remote sensing system is being developed for multispectral UV fluorescence detection of vapor, liquid, and solid effluents. The system uses laser wavelengths between 250 and 400 nm to excite UV fluorescence spectra that can be used to detect and identify species in multicomponent chemical mixtures. With a scanning mirror assembly, the system is designed to map chemical concentrations with a range resolution of ~ 5 m. In this paper we describe the optical detection system (scanning mirror assembly, 76 cm diameter collection telescope, relay optics, spectrometers, and detectors) associated data acquisition and control electronics. We also describe unique diagnostic software that is used for instrument setup and control.

Introduction

A mobile laser remote sensing system operating at ranges between 50 m and 10 km with a resolution of about 5 m is required for multispectral UV fluorescence measurements. Detection of the fluorescence species at the longer ranges with current laser technology requires as large a telescope aperture as possible. The laser for the multispectral detection technique needs to operate between the wavelengths of 250 to 400 nm with laser energies of 10 to 30 mJ at 10 to 30 Hz. The optical detection system is required to detect and analyze the elastic and Raman returns, along with the fluorescence from any effluents excited by laser beam. The wavelength range of the fluorescence detection system is 250 to 700 nm and multivariate analysis requires a set of fluorescence spectra from as many as 40 laser wavelengths. Large sets of data acquired during a measurement need to be stored and then transported to other computer systems for analysis.

A schematic diagram of the optical system is shown in Figure 1. The system centers around a vertically mounted telescope shown in the Figure, where the laser is transmitted coaxial with the telescope. Scanning the optical system near the horizon (50° to -10° from the horizon, 360° in azimuth) is accomplished with the large, flat turning mirror shown in Figure 1. Light collected by the telescope is focused by the primary and secondary mirrors and then reflected into the optical analysis and detection subsystem. The optical subsystem, shown in Figure 1, uses an imaging spectrometer with a linear intensified array, variable filters with appropriate detectors to record time dependent returns from the elastic, Raman and fluorescence returns. In order to have a detection scheme that will cover the light intensities anticipated over the range of the system we wanted the capability of digitizing the analog return signals and the capability of photon counting at longer ranges. Also in order to eliminate early laser scattering and to increase the dynamic range of the system we have designed the system to gate the photomultiplier tubes on for the time or range of interest. Finally, the data acquisition and control, including the laser and telescope will be under the control of a computer system. For the early experiments the major part of the data analysis will be done on a separate multiprocessor workstation. This requires rapid transfer of data between computer systems. The eventual goal is to integrate the data acquisition system, control and analysis into one computer system that will be capable of control, data acquisition and analysis with the multivariate algorithms on a near real time basis.

Telescope design and specifications.

The telescope system needs to collect as much of the scattered light and fluorescence light from the excitation volume as possible. A 76 cm primary mirror that was within the constraints of trailer size, time scale of the project, and availability of mirror blanks was procured to build the telescope. The telescope was designed scan near the horizon with an elevation of 50° to -10° with an rotation in azimuth of 360°. An important feature to maximize the telescope aperture was mounting the telescope vertically and pointing the system with a flat that extends above the roof of the trailer. Pointing of the system is accomplished with the flat and the whole telescope system does not have to move for tracking. The working range of the telescope is from 50 m to beyond 3 km. With this large focal range, and requirements to admit the full laser beam image diameter, there is no unique optimum design for the telescope. A compromise design focal distance of 250 meters gives an image quality that is the same at 100m and 3 km.

The telescope design is similar to a Cassegrain two mirror telescope which has a concave primary mirror with a convex secondary that forms an image through a hole on the axis of the telescope. This design allows the telescope length to be about one fifth that of a single mirror design Newtonian with the same optical aberrations. In this design the light is reflected onto the table eliminating the usual hole in the primary mirror. A design, known as Dall-Kirkham, was chosen which uses an aspherical primary and a spherical secondary. This design reduces construction costs, reduces alignment difficulties and allows the working F number of the system to be changed by changing the lower cost spherical secondary. The mirror surface is coated with an enhanced Al coating that reflects greater than 90% in the wavelength range from 250 to 600 nm. The mirror surfaces are specified to have a surface flatness less than 10 waves flatness. While this is 20 x worse than the requirements for a normal astronomical telescope, the blurring due to the surface flatness is much less than the image size of the laser beam image.

Table I

Telescope specifications

Nominal Primary Diameter	76 cm
Minimum usable diameter	74 cm
Primary f number	F/2
Over all telescope f number	F/11
Focal range	50 m to infinity
Optimized focal range	250 m
Mirror coating	Enhanced Al, 250 to 700 nm
Surface quality	< 10 waves

The specifications for the turning mirror are similar to those for the focusing optics and are shown in Table 2. In addition to the mirror specifications, telescope pointing specifications are given in Table 2. A pointing accuracy of 0.5 mRad gives a resolution of 0.5 m at 1 km. The stability of the system should be within 0.5 mRad accuracy.

Table 2

Specifications for the turning flat and pointing system.

Nominal dimensions	76 x 108 cm
Mirror coatings	Enhanced Al, 250 to 700 nm
Azmituthal pointing	± 180°
Elevation	50° to - 10°
Rotation velocity	> 0.2 °/sec
Acceleration	0. 2 °/sec^2
Pointing accuracy	0.5 mRad
Pointing stability (30 mph wind)	0.5mRad

The telescope and a 4 x 10 ft optical table are mounted to a common support frame. The support frame is designed to maintain the relative alignment of the laser and the optical instruments with the telescope.

Optical Analysis and Detection Instrumentation

The return signal is divided on the optical table into several different channels for analysis. Included are a channel for the elastic return from the transmitted laser, a channel for the Raman shifted return from N_2, a broad band fluorescence channel and a channel for an imaging spectrometer with an intensified linear array that detects the dispersed fluorescence return. A schematic diagram of the optical detection instrumentation is shown in Figure 2. In addition to splitting the light into four different channels, the light out of the spectrometers can again be split into more than one photomultiplier in order change the photomultiplier gain which effectively increases the dynamic range. We have two different detection system designs. The first design uses optical relay lenses, optical flats and beam splitters to transport and divide the light from the telescope into the spectrometers. There are several advantages using this system. First a high transmission through the system is expected. Second, an aperture at the telescope system focus can be made to be the defining aperture of the monochromators and spectrometer. Under this condition all of the instruments will see the same part of the image of the laser beam. Finally the lens design can correct for chromatic aberrations in the lenses. This system, which requires careful design and construction in order to maintain alignment of the system has been designed and is being constructed.

A simpler approach, based on fiber optic bundles, has been designed, constructed and is being characterized. While this design might have a lower efficiency, it has the advantage of being easier to align. However. the alignment of the fiber coupled optics between the telescope and the entrance to the fiber bundle is critical. A schematic diagram of the fiber coupled elements is shown in Figure 3. The light from the focus of the telescope is focused onto the end of a fiber bundle constructed from 50 micron UV quartz fibers with an over all diameter of about 1 mm. The nominal acceptance angle of the fiber is equivalent to about F/2 compared to the F/11 telescope output. With the fiber bundles there is a loss of 40 to 50 % at the entrance of the bundle due to the fiber packing fraction and reflections. The total area of the fiber is determined by matching the area of the slit images of the monochromators and spectrometer to the area of the output fibers. The output of the collection fiber bundle is divided into 4 equal bundles for distribution to the instruments. If the total area of the fibers is not illuminated it becomes important that the fibers be randomized with respect to the output bundles. At the output end of the fiber pig tails the fibers are transformed into a rectangular array whose dimensions are imaged and matched to the dimensions of the entrance slits of the monochromators and spectrometer. The coupling optics are designed to match the F/2 fibers to the F/4 acceptance of the monochromators and spectrometer. The light exiting the monochromators is collected by fiber bundles and transported to the photomultipliers. The light exiting the elastic channel is divided into three channels for three photomultipliers that can have the gain adjusted to give a larger dynamic range for recording the signal. Two photomultipliers, a 10 stage GaS cathode, and a 14 stage, bialkali cathode, with gated bases are being evaluated for use in the system. The final system will most likely use a combination of these two tubes.

The monochromators for the fluorescence and Raman channels are 110 mm focal length, F3.9, Ebert monochromators that can be controlled from the system computer using RS232 links. With a 1200 line/mm grating the dispersion of these monochromators is 6.7 nm/mm. The fiber bundles were designed to match an input slit of 0.6 mm giving a band pass of about 2 nm for the system. Higher resolution can be attained with narrower slits and a loss of efficiency of the system. The relative response of the single monochromator system with two different photomultiplier tubes is shown in Figure 4. The response was measured using a calibrated D_2 light source from 200 nm to 400 nm and a calibrated tungsten light source for the spectral range from 400 nm to 600 nm. The principle wavelength region of interest is from 250 to 400 nm. The difference in the relative response for two different photomultipliers is due to the different gains of the 10 stage 943-02 tube and the 14 stage 9813QB tubes. In order to separate the much weaker Raman signal from other components of the backscattered signal, the Raman channel has a double monochromator of the same design as the other channels. This will increase the stray light rejection from 10^{-5} to 10^{-10}. Finally the channel to disperse and record the fluorescence spectra at each laser wavelength uses a F/3 imaging spectrometer. With the 1 inch, 1024 element, intensified array that we will use to record the spectra, this spectrometer will cover the spectral range of 200 nm to 800 nm with a resolution of 3 nm.

Control and data acquisition hardware and software

The instrumentation was chosen using the constraints listed in the introduction along with the requirement that the control of the system be under one computer system. Also the time scale for putting the system on line precluded any development of custom hardware. These constraints required the use of commercially available instrumentation that could interface with an IEEE-488 buss using commercially available software. The data acquisition and instrument control was developed using LabView$_{TM}$. The first implementation of the software, referred to as the diagnostic software, will use a PC platform for control, data acquisition and the data transfer.

The data will be transported to a multiprocessor work station for analysis. The diagnostic software will eventually be transported to the workstation platform in order to acquire and analyze data on a near real time basis. Instrumentation, such as the monochromators and telescope pointing, that require the serial RS232 control can still be controlled using this software. In order to achieve 5 m resolution over the full range of the return signal, a digitizing rate of 200 Mhz (a point every 5 ns) or a multichannel scaler with a minimum bin width of 5 ns is required. Also digitizing or counting for up to 10,000 data points to record data for the full range is necessary for each instrument. A schematic diagram of the instrumentation with IEEE 488 connections is shown in Figure 5. Diagnostic software using $\text{LabView}_{\text{TM}}$ required the development of virtual instruments (VI's) for each of the instruments and subsystems under control. In addition an integrated control panel for setting and confirmation of the settings for data acquisition and timing and an integrated control panel for saving or recalling the instruments have been developed.

The multispectral UV fluorescence technique requires recording , transporting and analysis of large amounts of data. Raw signals that are expected from the laser return for each laser wavelength are shown in Figure 6. A data set for one laser wavelength, accumulated every 1 sec to 1 min, could contain up to 50,000 data points. The complete set of data for multispectral analysis can contain data from up to 40 different laser wavelengths. A schematic of the complete data set is shown in Figure 7. A complete set of data for one point in space could contain up to 2 M data points, accumulated at rates up to once every 40 sec. This data is transported to the workstation platform for storage and analysis. The diagnostic software has developed an autosequence control program for automating instrument acquisition, creating data directories, and creating files. It also includes transferring of the data directory to other computers via Ethernet. In order to verify the data acquisition, a decode program for automatically scanning through the data files, printing the data block headers and measurement headers, and for providing scaled data plots has been developed.

Summary

An optical detection system for multispectral UV fluorescence laser remote sensing measurements has been developed and constructed. The detectors and data acquisition hardware have been assembled and software for the first experiments has been developed. The system is currently being characterized and is being installed in the trailer for the first ground tests.

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000.

DISCLAIMER

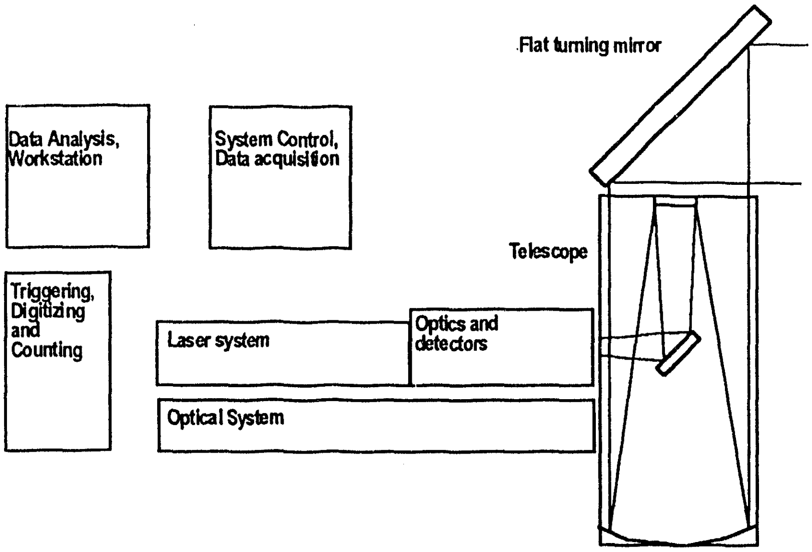

Figure 1. Schematic diagram of the UV multispectral remote sensing system. The optical table and telescope are rigidly coupled together.

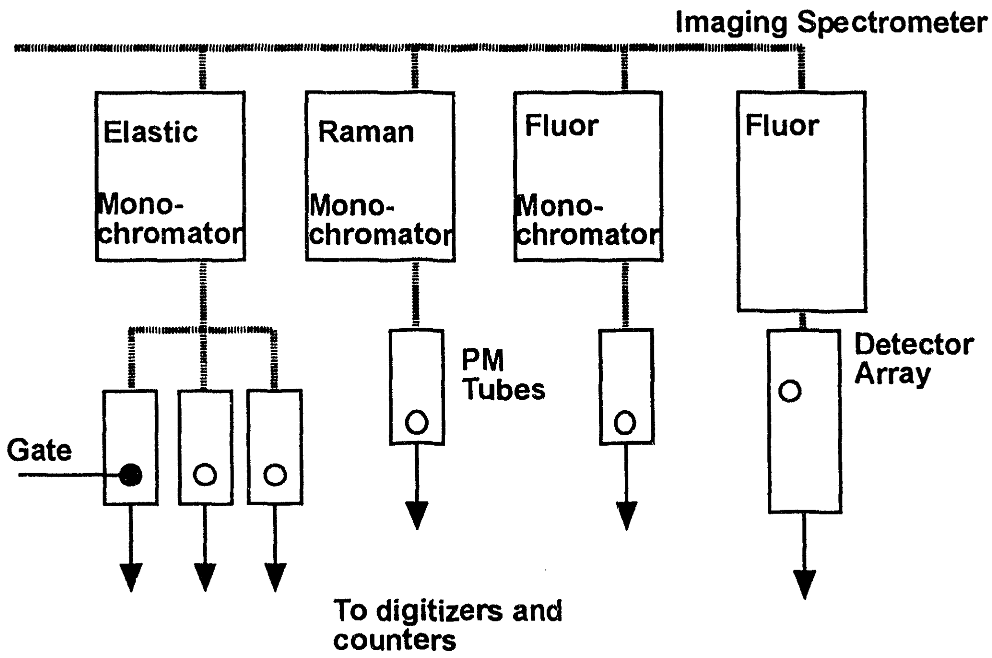

Figure 2. Schematic diagram of the optical detection and analysis system.

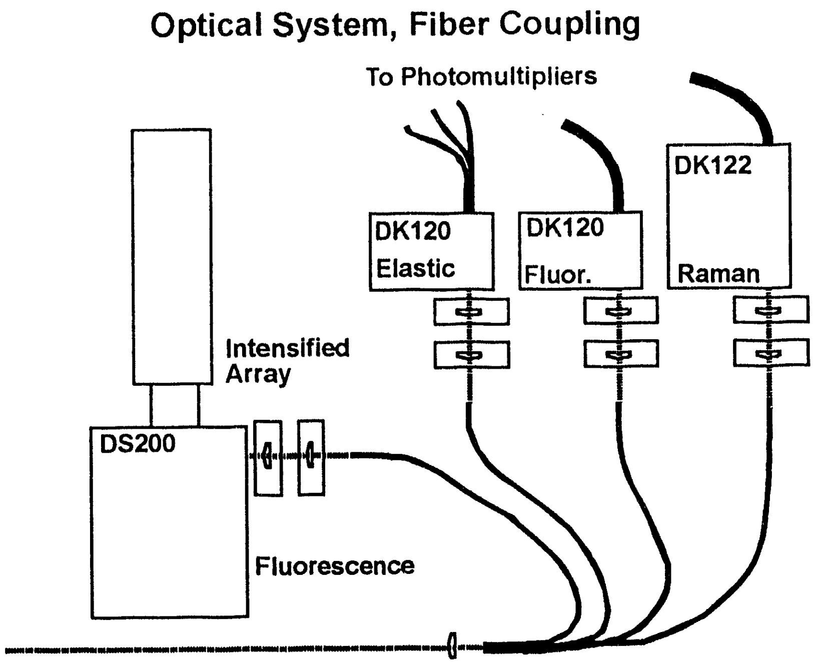

Figure 3. Schematic diagram of the UV multispectral remote optical detection system. The system in this figure is coupled with optical fiber bundles.

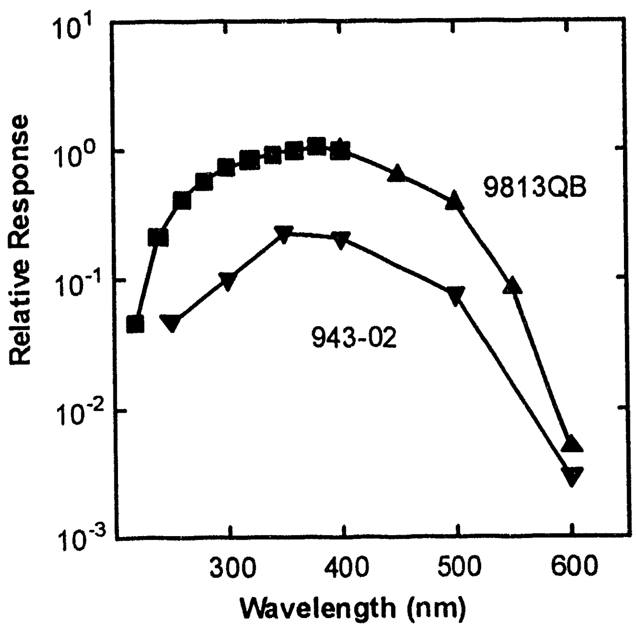

Figure 4. Relative response of fiber coupled detection system for two different detectors. The system efficiency at 400 nm is about 1%.

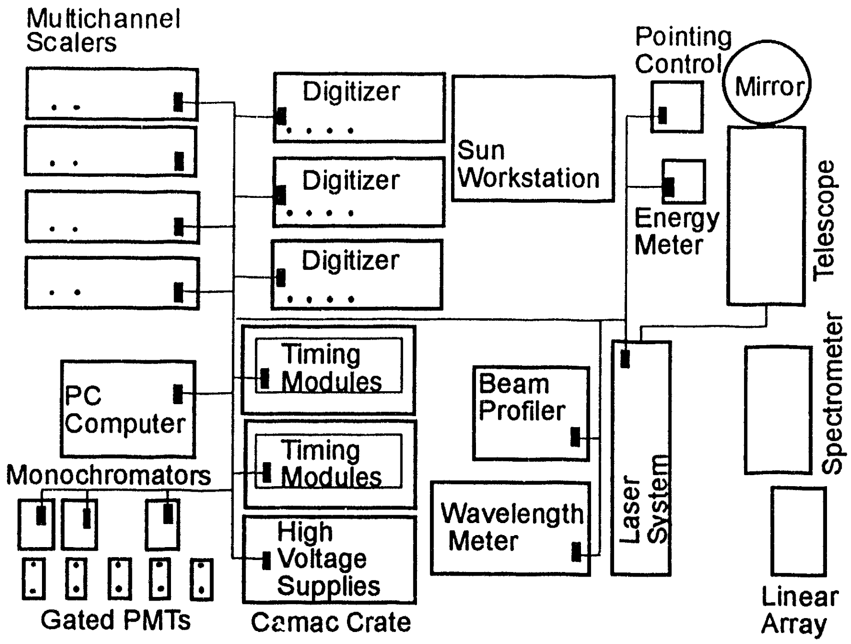

Figure 5. Schematic diagram of the unstrumentation for the UV multispectral remote sensing system showing the instrumentation and the IEEE control.

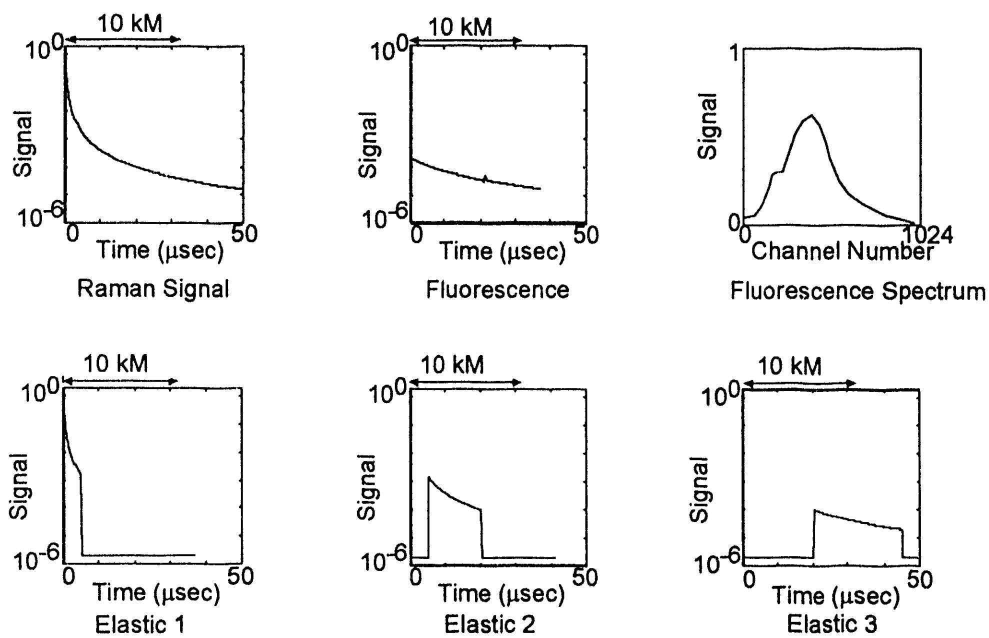

Figure 6. The unprocessed signals from the instrumentation at one laser excitation wavelength.

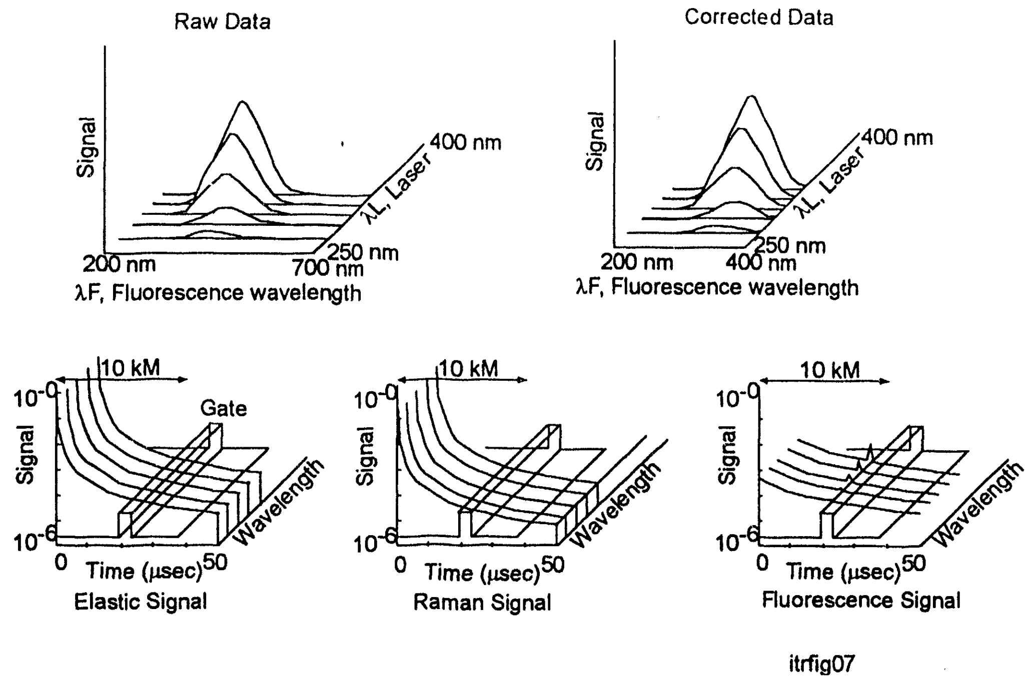

Figure 7. Schematic of a complete data set from multiple laser wavelengths from the UV multispectral remote sensing data acquisition system.