CSIR NLC– SOUTH AFRICA – MOBILE LIDAR – SYSTEM DESCRIPTION

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ABSTRACT

A mobile LIDAR system is being developed at the Council for Scientific and Industrial Research (CSIR) National Laser Centre (NLC), Pretoria (25°5′ S; 28°2′ E), South Africa. The system is primarily designed for measuring trace gases/pollutants in the troposphere region of the atmosphere. At this moment, the system has been developed for atmospheric backscatter measurements. The complete detailed system description is presented in this paper.

1. INTRODUCTION

The laser radar, more popularly known as LIDAR (LIght Detection And Ranging), is becoming one of the most powerful techniques for active remote sensing of the earth's atmosphere. Lasers offer great advantages over conventional light sources in terms of peak power, narrow spectral width as well as narrow beam width. Laser systems were deployed for atmospheric studies immediately after the discovery of the laser in 1960. Fiocco and Smullin [1] were the first to use a laser for atmospheric studies. In 1963, using a 0.5 J Ruby laser, they obtained Rayleigh scattered signals from the atmosphere up to an altitude of 50 km and further detected dust layers in the atmosphere. Ligda in 1963 made the first LIDAR measurements of cloud heights in the troposphere height region [2]. Leonard detected Raman scattering of O_2 and N_2 using Nitrogen laser [3]. A year after, Cooney made range-resolved nitrogen measurements up to an altitude of 3 km with a ruby laser [4], and in 1970, Inaba and Kobayasi [5] and Kobayasi and Inaba [6][7], with the same laser, performed spectral analysis of nitrogen, oxygen and several pollutants. Since these pioneering attempts, laser remote sensing of the atmosphere has come a long way. With the discovery of different laser sources, improvements in detector technology and improved data collection and analysis techniques, LIDAR has become a reliable and effective tool for atmosphere research.

Using advanced techniques and instrumentation, a mobile LIDAR system is designed and being developed at National Laser Centre (NLC), Pretoria (25°45′ S; 28°17′ E). The system is designed primarily to focus on pollutant measurements. At present, the system has been developed for atmospheric backscatter measurements. Future plans include qualitative industrial pollutant measurements, 3-D measurements using an XY scanner, a two channel LIDAR system, water-vapour measurements, the implementation of DIfferential Absorption LIDAR (DIAL) and ozone measurements.

2. LIDAR SYSTEM DESCRIPTION

The LIDAR system comprises a laser transmitter, optical receiver and a data acquisition system. It uses a Nd:YAG laser for transmission which is presently employed at the second harmonic at 532 nm. The second and third harmonic generation of the laser provides output of the laser source at 1064 nm with maximum power of about 400 mJ at 10 Hz. The laser optical properties are specified as 0.6 mRad for divergence and 1 cm^{-1} for line-width and 8 mm for beam diameter. The major specification of the LIDAR system is listed in Table 1. The complete LIDAR system is custom fitted into a van using a shock absorber frame (See Figure 1). Hydraulic stabilizer feet have been added to the vehicle suspension to ensure stability during measurements.

The system block diagram showing all the components is given in Figure 2. The respective three blocks, transmission, receiver and data acquisition sections are subsequently explained.

Table 1. Specifications of the LIDAR system.

Parameters	Specifications
Transmitter	
Laser Source	Nd: YAG - Continuum
Operating Wavelength	532 nm
Average pulse energy	196 mJ (at 532 nm)
Beam Expander	3 x (optional)
Pulse width	7 ns
Pulse repetition rate	10 Hz
Beam Divergence	0.2 mRad
Receiver	
Telescope type	Newtonian
Diameter	404 mm
Field of View	1 mRad
PMT	Hamamatsu® R7400-U20
Optical fiber	Multimode, 600 µm core

Filter FWHM	0.7 nm
Signal and Data Processing	
PC based photon counting system operating under LICEL real-time transient recorder	
Model	TR15-40
A/D Conversion	12 bit, 15 MHz
A/D Range	0 – 500 mV
Discriminator	64 level, 250 MHz
Memory Depth	4096
Bin width	0.2 – 2 µsec (30 – 300 m)
Integration time	50 - 1000 sec
Maximum Range	40.94 km
Spatial Resolution	11.25 m
PC	
TR15-40 Interface	Ethernet
Processor	Intel® Core2Duo 2.6GHz
Operating system	Windows® XP Pro

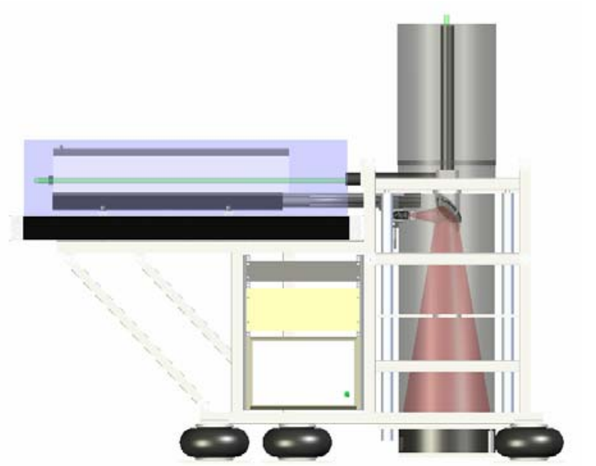

Figure 1. LIDAR system design setup in a mobile van.

2.1 Transmission Section

The transmitter employs a Q-Switched, flash lamp pumped Nd:YAG laser (Continuum®, PL8000). Nd:YAG lasers operate at a fixed wavelength of 1064 nm. Second and third harmonic conversions are accomplished by means non-linear crystals such as Potassium (K) Di-hydrogen Phosphate (KDP). The laser beam diameter is approximately 8 mm. The laser Q-Switch delay is set to 144 µsec for the optimized maximum output power. The visible green laser beam (532 nm) is passes through a beam expander (expansion of 3 times), before being sent into the atmosphere. Hence, the transmit beam divergence is reduced from 0.6 mRad to less than 0.2 mRad. The resultant expanded beam of 24 mm diameter is then reflected upward using a flat, 45 degree turning mirror. The mirror has a diameter of 75 mm and a thickness of 8 mm. The mirror coating is specified for 532 nm and has a more than adequate damage threshold of 1 GW/cm^2.

The laser power supply unit controls and monitors the operation of the laser. It allows the user to setup important parameters such as the flash lamp voltage, Q-Switch delay and the laser repetition rate. It also monitors system diagnostics such as the flow and temperature interlocks. General user operation and control is also available via a remote control interface. The power supply also incorporates a water to water heat exchanger which regulates the temperature and quality of water used to cool the flash lamps and laser rods. An additional and external water cooler (MTA, M10 R407C air-cooled chiller) is employed to remove heat from the heat exchanger.

2.2 Receiver Section

The receiver system employs a Newtonian telescope configuration with a 16 inch primary mirror. The backscattered signal is subjected to fall on the primary mirror of the telescope. The signal is then focused toward to a plane mirror kept at an angle 45 deg. It is detected by the Photo-Multiplier Tube (PMT) and the PMT output is transmitted to the transient digitizer and PC for analysis and archival.

The primary reflecting mirror has the radius of curvature of 2.4 m and the aperture radius is 0.41 m. The primary reflecting mirror is coated with an enhanced aluminum substrate. We have also employed a motorized 3-Dimensional translation stage in order to accurately align the fiber. Presently, alignment is manually accomplished with plans in the forth-coming year to automate the procedure using PC control. By the automation, the fiber will be aligned quickly and efficiently. The beam transition and reception optics is well shielded which further reduces back-ground noise.

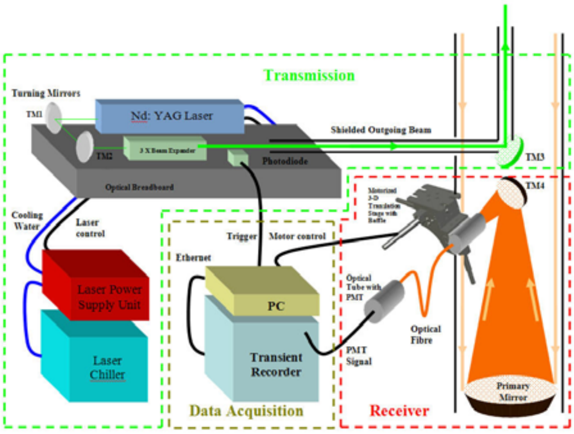

Figure 2. A simplified block diagram of the LIDAR system.

2.2.1 Optical Fiber

A multimode, premium-grade optical fiber is used to couple the received backscatter optical signal from the telescope to the PMT. The one end of the fiber is connected to an optical baffle which receives the return signal from the telescope. The other end is connected to an optical tube, with collimation optics, which couples the signal to the PMT. The fiber has a numerical aperture of 0.22, providing an acceptance angle of 25.42 degrees. The acceptance angle is sufficient and comparable with the solid angle provided by the curvature of the primary mirror used in the telescope. The fiber core is composed of pure silica with a high OH content which is optimized for the 300 nm – 1100 nm spectrum. The fibers are protected by a stainless steel jacket which provides flexibility and mechanical protection. The fiber also has the advantage that it can be used for optical alignment of the fiber tip to the telescope. This can be accomplished by coupling an alignment laser source into the 'PMT' end of the fiber and directing the light exiting from the 'telescope' end of the fiber into the telescope. The sharpness of the focused image obtained at an extended distance away can be observed to identify the optimal position of the fiber.

2.2.2 3-D Translation Stage and Optical baffle

As mentioned above, one end of the fiber is located, to collect the backscatter signal from the telescope. To accomplish this, accurate alignment of the fiber tip is required and for this purpose a motorized 3-D translation stage is used. The optical fiber is connected to an optical baffle which is positioned by the stage. The baffle is a mechanical system, basically consisting of an optical tube and vanes along the inner wall of the tube. Its function is to shield the light coming from outside the field of view of the fiber. Therefore any light which originates outside the field of view of the fiber is allowed to make multiple reflections along the surfaces of the vanes, reducing the intensity and minimizing the effect of any stray light on the signal reaching the detector.

The stages are motorized and are controlled by three DC servo motors. The motors each have a travel of 12.7 mm (0.5 inch) and are packaged with Hall Effect encoders and limit switches. They operate at a voltage of 12 V and consume a maximum of 80 mA each. The encoders are specified at 12288 counts per revolution resulting in a linear resolution of 40 nm. The limit switches are mechanical and allow the software to perform a homing function. The motors are powered and controlled by independent servo drivers. The drivers communicate with the PC, via USB connections, using the supplied software. The supplied software interface provides all the necessary functionality such as homing, movement to a specific desired position and a jogging function which provides incremental movement in the specified direction.

2.2.3 The PMT Optical tube

A photo-multiplier tube is used as the detector which converts the optical backscatter signal to an electronic signal which can be transferred to a PC for storage and analysis. The PMT is installed in an optical tube which incorporates a collimation lens and a narrow band pass filter. The tube is thermally stabilized with the use of TEC cooling.

A lenstube SMA adaptor is used for fiber coupling followed by a visible achromat, which is used for collimation and also to reduce spherical aberration. The lens has a focal length of 10 mm and a back focal length of 6.7 mm. The surfaces are coated for the 400 nm – 700 nm wavelength region. Using the lens' specifications, it was calculated that a single lens would be sufficient to collimate the optical signal exiting the fiber (NA of 0.22) into a beam with a 6mm diameter, which is the requirement for the PMT.

The collimated beam is then passed through a narrow band filter. The filter is a custom band pass optical filter with a center wavelength of 532.19 nm. The Full Width Half Maximum (FWHM) is 0.7 nm with a maximum transmission of 64 %.

The filter transmission is sensitive to temperature fluctuations and therefore thermo-electric cooling was incorporated into the design with the use of a Peltier element. The Peltier is able to transfer heat from one side to the other by modulating the electrical current passing though it. It is used to maintain the filter at a temperature of approximately 23 degC, which is specified to be the temperature for maximum transmission.

The filtered signal then enters the PMT, which is encased in a 1 inch diameter metal package to couple into the optical tube. The photomultiplier tube used is a Hamamatsu® R7400-U20. It is a subminiature PMT, which operates in the 300 nm to 900 nm wavelength range and has a fast rise time response of 0.78 ns. This specific detector was selected by request for maximum sensitivity and is specified with a anode dark current of 0.37 nA. Typical anode dark currents for these devices range from 2 nA – 20 nA.

2.3 Data Acquisition and Archival

The data acquisition is performed by a transient recorder which communicates with a host computer for storage and offline processing of data. A Licel® transient digitizer was procured for this purpose. This unit is data acquisition system optimized for fast repetitive photomultiplier LIDAR signals in the analog voltage range of 0 - 500 mV. The system is favored due to its capability of both analog and photon counting detection, which makes it highly suited to LIDAR applications by providing high dynamic range.

The TR15-40 is the model that was procured. The digitizer comprises two simultaneous detection channels each with its own pre-amplifiers. The analog channel's amplifier is optimized for high linearity, while the photon count channel's amplifier is optimized for maximum speed and gain. An anti-aliasing filter selects the lower frequency range of the received signal below 7.5 MHz before it is digitized by a 12 bit A/D converter with a fast memory of 4 Kb. The data is stored in a First-In-First-Out (FIFO) memory buffer, before being accumulated in the respective Random Access Memory (RAM) bank.

The photon count channel uses a high pass filter to select the high frequency component (>10MHz) of the amplified PMT signal. The filtered component is then passed through a fast discriminator (250 MHz) and a counter which is able to detect single photons. The counts are buffered in the FIFO buffer, before being recorded to RAM. The application-specific integrated circuit (ASIC) allows for fast summation of the signals from the FIFO buffer.

The recorder incorporates two triggers and two RAM banks. Depending on which trigger input is used, the buffered signal is added to the respective RAM bank. This allows the acquisition of two repetitive channels if the signals can be measured sequentially. In DIAL applications, for example, this will be advantageous, since the backscatter of both the 'On' and 'Off' wavelengths can be acquired sequentially.

A software interface is included with the LICEL system which allows the user to acquire signals without the need for immediate programming. The LabVIEW® software development environment will be used, since this is also compatible with the 3-D translation control software as well. Communication with the PC is accomplished via Ethernet. This interface is convenient since it eliminates the need for extra interfacing hardware. Communication speed is 200kB/s and the Ethernet control module incorporates a Push mode which reduces the PC burden for control of the transient recorders and also reduces data transfer.

The results are stored in an ASCII-binary data file. The first three lines provide a header which describe the measurement situation and included information such as the location, start/stop times, number of laser shots, laser repetition rate and the number of included datasets. The Header is followed by a Dataset description, which includes information such as whether it is a Analog or photon count dataset, the PMT voltage, the laser wavelength and polarization and the analog voltage range and photon count discriminator level. The Dataset description is followed by the raw data, which is stored as 32 bit integer values separated by the ASCII equivalent of CLRF. These markers are used to determine data file integrity.

3. SUMMARY AND PERSPECTIVES

A mobile LIDAR system for remote sensing the atmosphere is designed at CSIR-National Laser Centre and currently the system is aimed at backscatter measurements for the height region from ground to 40 km. Our goal for the following year is to optimize the LIDAR in field campaign mode and measurements over different places around South Africa. Over three years, a two channel LIDAR system (implementation of water-vapour) and DiAL system (ozone measurements) are planned to be implemented.

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