Remote control and telescope auto-alignment system for multiangle LIDAR under development at CEILAP, Argentina

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Abstract: At CEILAP (CITEDEF-CONICET), a multiangle LIDAR is under development to monitor aerosol extinction coefficients in the frame of the CTA (Cherenkov Telescope Array) Project. This is an initiative to build the next generation of ground-based instruments to collect very high energy gamma-ray radiation (>10 GeV). The atmospheric conditions are very important for CTA observations, and LIDARs play an important role in the measurement of the aerosol optical depth at any direction. The LIDAR being developed at CEILAP was conceived to operate in harsh environmental conditions during the shifts, and these working conditions may produce misalignments. To minimize these effects, the telescopes comprising the reception unit are controlled by a self-alignment system. This paper describes the self-alignment method and hardware automation.

Keywords: multiangle LIDAR, Raman, CTA observatory, aerosols

1 Introduction

The Cherenkov Telescope Array Consortium (CTA) [1] contemplates the design, construction and the operation of two observatories for the detection of gamma ray produced by extraterrestrial sources at energies ranging between $10^{10}$ eV and $10^{14}$ eV. These observatories will be deployed at each hemisphere for full sky-map coverage. Each Observatory will consist of a telescope array sensitive to the atmospheric generated Cherenkov radiation that will improve the performance of the actual detectors. The goals proposed for CTA will be attained using an array of multiple telescopes distributed over a surface of 1 and 10 km² in the northern and southern hemispheres, respectively located at sites with excellent optical and atmospheric conditions at a height of 1500 to 3800 m above the sea level. The comprehension of the atmospheric conditions during the measurements is extremely important for the CTA Observatory, and multiangle LIDARs plays a major role in monitoring of sky conditions, by both detecting the overall cloud coverage and measuring the atmospheric opacity due to aerosol and clouds. The multiangle Raman LIDAR being built at CEILAP uses six 40 cm diameter and 1 m focal length each. An optical fiber of 1 mm diameter is placed at its focal plane, producing a 1 mrad field-of-view (FOV).

Additionally, this LIDAR has special requirements regarding its operation:

- It has to be operated remotely and the operator may not have an a priori knowledge of LIDAR techniques.
- Telescopes, mechanics and electronics, will be exposed during night time to environmental conditions (wind bursts, temperature spans, etc.), which could produce mirror misalignments.

To minimize the signal loss due to misalignments, each of the six mirrors are mounted on a steerable frame, equipped with two stepper motors for tilting over two orthogonal axes (Figure 1). These movements are handled by a microcontroller that communicates with the LIDAR PC through a WiFi connection (a brief description of this system is provided in section 1.2). Since 2012, a shelter-dome was acquired to host the system. Based on the CLUE shelter concept, we have built this unit using a standard 20 ft shelter modified completely as shown in the Figure 2 CLUE shelters are also being used by other LIDAR groups in the CTA collaboration [4].

To open/close the shelter, hydraulic cylinders were installed and can be controlled from its control panel located at the shelter, and remotely via the control software being
developed at CEILAP. These are the main reasons to encourage the development of a fully automatic alignment system to keep the telescopes aligned during the acquisition period.

1.2 LIDAR Communication

The LIDAR system under development has to be operated remotely from the control center, with a high degree of automation, as the local observing crew may have no advanced LIDAR training. The PC control LIDAR communicates with the LIDAR system via WiFi link, with two routers with WDS features paired, creating a local LIDAR network under the TCP/IP protocol (see Figure 3 for a schematic layout of the system).

At the link endpoints, several processes communicate with each other to send/receive control and monitoring messages, as will be briefly described on the next section.

1.3 LIDAR Software

PC LIDAR control works under the Linux operating system and all the software was developed using C/C++. A socket-based IPC (Inter Process Communication) was programmed to communicate with the microcontroller at the LIDAR shelter. To increase their efficiency, each process is totally independent, and communicates to the others via control messages. The graphical user interfaces were developed using a set of ROOT libraries. A brief description of each process is described below:

**adq**: It is the main process, which controls the acquisition timing, communicates with the laser, triggers the Licel acquisition system, sends the acquired new file to the **plot** process, and, if necessary, to the alignment process.

**plot**: Waits for messages from the **adq** process, and plot the signals on the display.

**alignment**: This process receives the path to the acquired file from **adq** and processes this signal to obtain the alignment parameters to determine the telescope position. A brief description of this algorithm is described in section 1.5.

As can be seen in next figure, both **adq** and **plot** processes are totally independent. **alignment** does not require a graphical user interface.

1.4 Microcontroller-Controlled Telescopes

This is a cooperative procedure between the **adq** and the **alignment** process, both running on the LIDAR PC, and the firmware inside the Rabbit microcontroller. The tilt angle of the telescopes is driven by a set of stepper motors, handled by a RCM2200 Rabbit System microcontroller. This is a Z80 family-based high-performance 8 bit microcontroller. It has a built-in Ethernet interface with an integrated TCP/IP stack, making it a good choice for interconnectivity. This interface is used to link the microcontroller with the LIDAR PC. The instruction set is based on the original Z80 microprocessor, with some additional instructions. The aims of the Rabbit microcontroller algorithm are to decode

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the information received from the LIDAR PC process (adq and alignment), and to handle signals to the stepper motor drivers. Therefore, the firmware of the Rabbit microcontroller is a dummy terminal that only receives message and drives the control signal to the selected motor/relay. After that, it sends an acknowledge message back to the alignment process.

1.5 Telescope auto-alignment procedure

The auto-alignment system procedure being applied in this work is based on methods reported in [7] [8], where the overlap between the emission beam and the receiving telescopes is quantified by averaging the LIDAR signal level at certain range. In this work, the procedure is slightly different to the cited papers, due to the specific features of the multiangle LIDAR being developed. This algorithm sweeps each FOV’s mirror over 2 orthogonal axes (see Figure 5 for a layout of the coordinate system used).

1.6 Telescope auto-alignment simulation

Simulation of the alignment process was made over North-South and West-East axis, to show what results from the self-alignment process. The next plots shows different overlap values at 10 km, as a function of scan angle. This altitude has taken based to guarantee good quality signal over most of the troposphere. Taking into account that the laser beam is homogeneous, and the static atmospheric conditions, we can obtain a trapezoidal shaped plot, as shown in Figures 7 and 8 for West-East and North-South span respectively.

An overlap function simulation was done, following the system specifications listed in Table 1, and using a laser beam parallel to the reference axis of Figure 6. It can be seen that a full overlap is achieved at 5.445 km approximately, without losses at higher ranges.

| Parameter          | Value     |
|--------------------|-----------|
| Mirror Diameter    | 40 cm     |
| Mirror FOV         | 1 mrad    |
| Distance Mirror-Laser | 50 cm  |
| Laser Initial Diameter | 6 mm   |

Table 1: LIDAR features used for the overlap factor calculation.

For the East-West scanning, the telescope must be set to the angle corresponding to west-side point (-0.14 mrad) of the platform in the trapezoidal plot. This point will assure a full overlap at 10 km, and a extended useful range at lower altitudes.

For scanning over North-South direction (Figure 8), the telescope must be set to the middle point of the platform in the trapezoidal form. As can be seen, a symmetric scan is obtained due to the symmetry over West-East axis. This kind of plot allows not only to center the beam inside of the FOV of the telescope, but also to measure the laser divergence and the telescope FOV. From last two figures, it can be readily demonstrated that the width of the rise (or fall) of the trapezoidal plot is equal to the laser divergence, and the full width at half-maximum (FWHM) is the telescope FOV.
Figure 8: Simulated overlap value at 10 km as a function of North-South axis.

2 Conclusions

The construction of the presented multiwavelength scanning Raman LIDAR will be able to provide spectrally-resolved aerosol extinction profiles to characterize the atmospheric transmission at any required line of sight and in a short period of time. The need for a fully automated system was reported, and this is a work-in-progress. The communication and the acquisition systems of the LIDAR are fully operative. First measurements, made at fixed zenith angle, indicate that it is possible to achieve the expected auto-optimization goals during the scanning procedure. The modularity of the telescope system will permit system maintenance and optimization during operation reducing non-operational times. The collaboration of CEILAP, IFAE/UAB and LUPM to improve their LIDAR systems will permit to attain the requested goals in terms of system construction, LIDAR testing, instrumentation control and LIDAR signal processing. Actually, a new azimuth-zenithal scanning bench is under development by Mechanical Department of CITEDEF.

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