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PERFORMANCE CHARACTERISTICS OF COMPACT MOBILE LIFS (LASER-INDUCED FLUORESCENCE SPECTRUM) LIDAR

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ABSTRACT

We developed a compact but versatile laser-induced fluorescence spectrum (LIFS) lidar that has potential use for material or aerosol identification outside experimental rooms. The compactness and mobility of the LIFS lidar means observations can be more freely conducted at any place and any time. Its performance characteristics were validated by three-dimensional fluorescence imaging of targets and remote detection of quasi bio/organic aerosols.

1. INTRODUCTION

Because of their unique characteristics, lidars have been widely using in environmental monitoring. Most lidars are best suited to experimental rooms. If lidars could move around a field freely at the time needed, their usefulness would expand. Field observations are important because the need might be sudden. Sudden events include thunder storms, volcano eruptions, and other natural events, and human-related activities/accidents such as chemical factory fires, dispersion of agricultural chemicals, gas leakages of buried pipe, and so on. The outbreaks of these events are hard to predict. Sometimes the events are so localized that we have to approach the area as closely as possible and yet avoid danger.

Using a mobile lidar is one of the best solutions for that purpose. Mobile lidars have already been developed, but most of them require a vehicle that is exclusively manufactured for the lidar. In addition, the size of the vehicles tends to be large because conventional laser systems and measurement instruments are big. Moreover, the power consumption is also large. Traditional mobile lidars were mainly based on Mie scattering and/or an absorption process with filter detection. Recent technologies such as microelectromechanical systems (MEMS) are capable of downsizing laser systems and spectroscopic instruments and decreasing the power consumption, while still maintaining the performance. So, lidars can be smaller even if we use a complicated spectroscopic instrument in addition to filter detection. Then, compact but versatile mobile lidars will be available for the abovementioned outbreaks and events. In other words, just-in-time lidar observation will be possible.

The Shinshu University lidar group has been interested in several phenomena occurring in the “livingsphere”, where strong relations exist between human life and the natural environment [1]. Of many various materials in the livingsphere, we focused on biological and organic materials because they affect human health and life most directly. A quick response to such accidents with these materials is important.

In this paper, we describe a compact but versatile mobile laser-induced fluorescence spectrum (LIFS) lidar that is applicable to multi-observation.

2. METHODOLOGY

With the abovementioned events taken into account, a new lidar was designed to have multipurpose use and mobility.

2. 1 Laser-induced fluorescence spectroscopy

To detect biological and organic materials in the livingsphere, we introduced laser-induced fluorescence (LIF) spectroscopy through lidar signal detection. Since almost all materials exhibit their own unique auto-fluorescence spectrum, it is possible to judge the types of material by comparing lidar observation data and the LIF spectrum database. We can easily find materials such as pollens, yellow-sands, minerals, detergents, and agricultural chemicals. Both natural materials and artificial products exist everywhere in our livingsphere.

If we set up the spectrometer used for fluorescence detection to match a specific observation target, LIFS lidar can be easily transformed for many uses, for example, Raman lidar and high-resolution Mie-Rayleigh lidar.

2.2 Compact vehicles

One simple idea behind lidar mobility is that lidar can be loaded into a vehicle. Another idea is the intended space of observation is limited. However, the actual roadways to approach the target space may be narrow and winding, and so the vehicles must be compact and commercially available. Fortunately, we can easily find such vehicles in our daily life. Figure 1 shows an example. The standard carrier space that can transport the lidar is about 1725 mm (L) x 1240 mm (W) x 1200 mm (H) [2].

3. Development of LIFS lidar

Figure 1 shows the LIFS lidar that we developed. Our lidar consists of a THG YAG-laser (Quantel, Ultra100-355-20), the energy of which at 355 nm is 20 mJ, a cassegrainian telescope with a diameter of 254 mm (Meade, LX200-25), and a photonic multichannel analyzer with spectral sensitivity of 200–900 nm (Hamamatsu, PMA-12). The analyzer is optically connected to the telescope with an optical bandle fiber. Synchronized detection of the fluorescence with laser oscillation [3] was achieved by changing the gate opening time of the charged-coupled device (CCD) of the analyzer by using a digital delay/pulse generator with a delay resolution of 5 ps (Stanford Research Systems, RG535). A laptop computer (Fujitsu, FMV-BIBLO) controlled the whole lidar operation.

A small power generator with output power of 900 VA (Yanmar, G900is) was prepared for observation at the aimed areas, where no power lines existed.

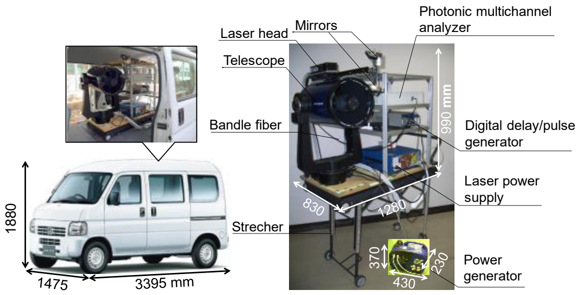

Fig. 1. Photograph of developed LIFS lidar and the lidar loaded inside a compact vehicle.

The LIFS lidar was set on a stretcher so that we could easily carry it from our laboratory and load it inside a car.

4. RESULTS

4.1 Database of LIF spectrum

We prepared powdered materials for the data collection experiment to make the LIF spectrum database. Some materials were made from solids that are candidates for aerosols. They were crushed by a cryogenic sample crusher (Japan Analytical Industry Co., Ltd., JFC-300) in the following procedure. First, materials that had dropped on the ground were frozen by liquid nitrogen. Then the frozen materials were crashed by shaking them with a stainless ball inside a stainless container. LIF spectra of the powdered materials were measured with the same instruments used for the LIFS lidar.

Because each of the LIF spectra of the powdered materials has a different shape (see Fig. 2 & 4), the LIF spectra can be used to classify aerosol species. We have collected LIF spectra of over 20 different materials so far. Some of the materials are fallen leaves, dried insects, bird feathers, and pieces of a road sign block. They are classified into vegetation, animal matter, and artificial materials.

4.2 Performance characteristics of LIFS lidar

1) Three-dimensional LIF spectrum imaging

In this paper, the targets were a plant and a wooden board. They were arranged side by side, at 15 m and 20 m away from the lidar, respectively. The laser beam scanned the target

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area by rotating the telescope on which the laser was set, and at the same time the telescope collected the LIF spectrum from each target. This experiment was conducted under natural light conditions inside a gymnasium.

LIF spectra from the plant leaf and the wooden board are shown in Fig. 2. A LIF spectrum of the plant leaf has three peaks; a large 425 nm peak with a small swell around 500 nm, and two peaks around 685 nm and 740 nm of chlorophyll. It is well known that chlorophyll is one of the most important biomolecules for plants. Thus, the LIFS lidar has the potential to provide the physiological status of a plant non-destructively and remotely. For example, the relative intensities of the two chlorophyll LIF spectra had a strong relation to the chlorophyll concentration, which varied depending on the month and season [4].

A LIF spectrum from the wooden board has only a smooth curve with a peak around 425 nm. The result confirmed that plants and wooden boards can be distinguished by comparing their spectra.

The laser scan made a fluorescence image. Depth information was also obtained by changing the detection time of the photonic multichannel analyzer because the actual gate opening time of the CCD detector was increased by steps of 10 ns.

Figure 3 is a three-dimensional image of the chlorophyll LIF spectra, in which a wavelength region from 730 nm to 740 nm was extracted from the whole spectrum shown in Fig. 2. In Fig. 3, the 730–740 nm fluorescence image appears at the position of the plant and disappears where the plant is not present. Also, the image can be found

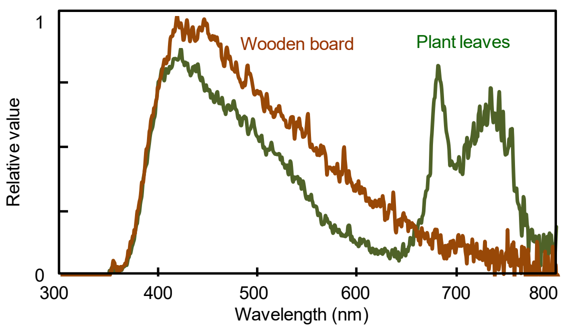

Fig. 2. LIF spectra obtained from a plant leaf and a wooden board by the LIFS lidar.

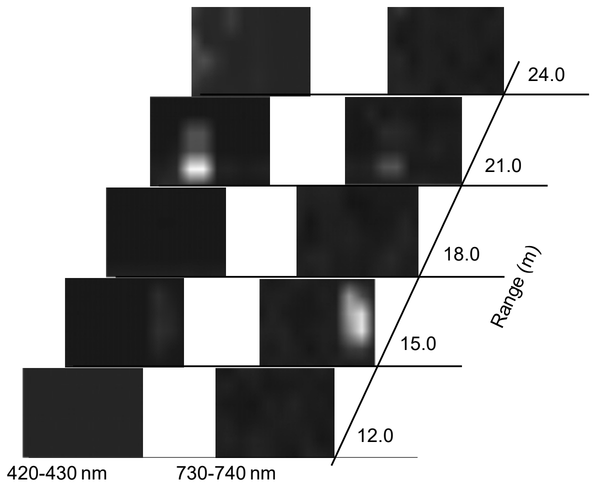

Fig. 3. Three-dimensional images of the 730–740 nm and the 420–430 nm LIF lidar spectrum.

at the position where the wooden board is placed, because the board has a very little fluorescence at the 730–740 nm range. It has been reported that ultraviolet-induced fluorescence of leaves provides us with information, for example, on photosynthesis, primary photochemical reactions, the presence and accumulation of the product [5]. This shows that the distribution of the plant living status can be remotely monitored by the LIFS lidar.

Figure 3 also shows an image having a wavelength region extracted from 420 nm to 430 nm, which are the peaks of both targets. At 15.0 m only the plant image appears but it is a quite weak fluorescence image, at 21.0 m an image of the wooden board appears clearly. The image appearing at 24.0 m is the back wall of the gym, which cannot be seen in the 730-740 nm image.

2) Remote detection of LIF spectrum of quasi bio/organic aerosols in daytime

Powdered materials were prepared as quasi aerosols. The powder was held by two non-fluorescence quartz plates located 20 m away from the lidar. An experiment of LIFS lidar fluorescence detection was made outside in the daytime. The whole system could be operated by the power generator.

Figure 4 is a spectrum of the powdered frass of fall webworm larvae. The frass is easily crushed by stepping on it and is subsequently blown into the air by the wind, becoming a bioaerosol. The surface of the frass itself looked brown, but the LIF spectrum of the powdered one resembled that of the plant leaf shown in Fig. 2. This is because pieces of leaves that the larva ate were included in the frass. The difference between the surface color and the powdered LIF spectrum is interesting because it helps to understand the process of the degradation of material.

A LIF spectrum of the powdered road corn/pylons which were wasted on the construction ground is also shown in Fig. 4. Plastic is one of the materials that becomes artificial aerosol (i.e., human made and human activity related), for example, by being crushed by a passing car. Artificial aerosols do not easily decompose in nature, so the LIF spectrum will be the same for a long time. The crushed or powdered material is carried everywhere through human activities or by natural means. As most plastics show a stronger fluorescence characteristic than do natural materials, they are a good marker to track anthropogenic activities for a very long time, as Corcorn et al. reported [6]. The LIFS lidar observation can give provide more information.

Fluorescence monitoring is usually made under dark conditions because (auto-)fluorescence intensity is very weak. In our case, the synchronous detection during a very short period of 10 ns (CCD gate width) could reduce the background sunlight noise effectively. This success offers daytime information that is fundamental and indispensable data for understanding the dynamical phenomena driven by solar energy.

5. CONCLUSIONS

Mobile laser-induced fluorescence spectrum lidar, LIFS lidar, was developed. The versatile functions made possible by the lidar mobility were confirmed by field observations. The results showed the possibility of three-dimensional monitoring of biological and organic aerosols, plant health status, the degradation process of materials, and long-time tracking of anthropogenic activities.

The compact and mobile LIFS lidar is confirmed to make field observations easier.

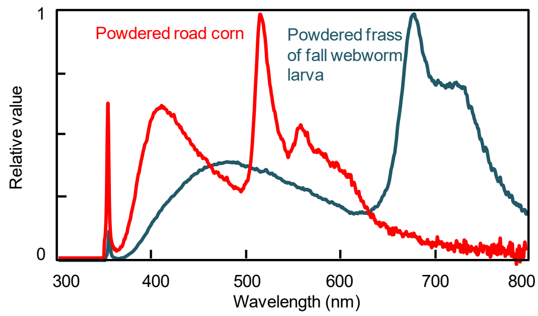

Fig. 4. Remote detection of LIF specta of powdered frass of fall webworm larvae and powdered road corn by the LIFS lidar.

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