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STAND-OFF BIOLOGICAL DETECTION BY LIF (LASER INDUCED FLUORESCENCE) LIDAR

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ABSTRACT

Laser active technology, based on lidar principle, is one of the most promising technology for biological cloud detection and classification. CILAS is leading French active stand-off in biological detection since 2000. Demonstrators have been realised through French MOD and European Commission program and are exposed in this paper. The development is based on the LIF (Laser Induced Fluorescence) principle. An UV laser is used for fluorescence generation of specific molecules of biological materials. Then, the analysis of the fluorescence spectrum gives a signature of the cloud. The classification methods remain a challenging point.

Keywords: UV laser, stand-off detection, laser induced fluorescence, biological threat.

1. INTRODUCTION

Biological attack is an increasing threat. Having the capability to warn people before infected by a disseminated biological cloud will provide a high advantage, in term of countermeasure (area evacuation, individual protection deployment, …).
Up to now, local or point detectors have raised standards of safety, but operational needs require the more challenging biological stand-off detection. Biological stand-off detection will provide early warning system, indicating an imminent arrival. Laser active technology, based on lidar principle, is one of the most promising technology. The European Commission program has funded the BODE (Biological Optical Detection Experiment) project to prepare Europe capability to face such biological threat. This project supported operational use of such equipment, scenario definition and the development of a demonstrator which was testing in relevant environment. CILAS was the project leader, with the contribution of 8 partners (BIRAL-UK, DLR-Ger, FOI-Sweden, Galileo-Italy, LDI-Estonia, CEB-Fr, SDIS-Fr, EADS-Fr). The French MOD also has contracted to CILAS to upgrade the current Biological Lidar belonging to DGA/CEB for increasing its performances, in the frame of the PERSEIDES R&T program for the development of new technologies against RBC (Radiological Biological Chemical) threat. Both are based on the LIF (Laser Induced Fluorescence) analysis : UV laser beams are used for fluorescence generation of potential biological aerosols. Backscattered channel allows cloud detection, whereas the fluorescence channels first detect if the cloud is transmitting fluorescence, then analyse the fluorescence spectrum, and classify the cloud nature (biological agents or interferents). The Figure 1 illustrated the principle exposed, and the schematic lay out.

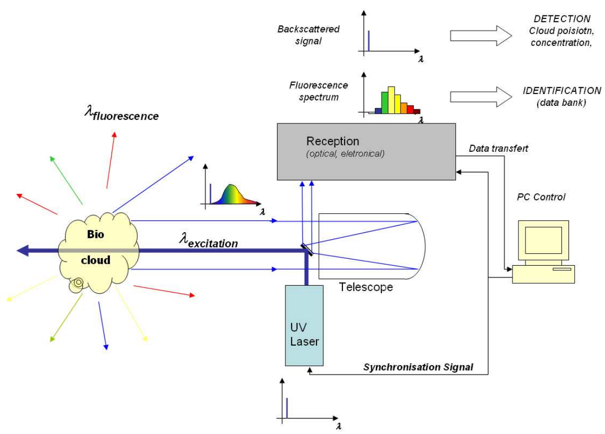

Figure 1 : LIF Lidar principle

The principle and technology have been initially developed for military purposes, but the current potential risks identified for biological dissemination (terrorist attack) push to continue investigations in order to provide qualify products for civilian end-users, like firemen, police, security societies, …. Typical scenarios of attacks have been already identified and defined [1], helping to specify the mission products.

2. OVERVIEW OF CURRENT DEVELOPMENTS

The NATO report [2] gives a good overview of all current projects of biological lidar stand-off detection. The Table 1 summarizes the main characteristics of the developed prototypes from different countries : the UV laser used and the type of receiver sensor are précised if available.

	UV Emission	Reception
Canada	UV excimer laser 120-170 mJ/pulse @ 351 nm – rate = 125 Hz	Backscatter signal using photomultipliers Fluorescence signal using Intensified CCD + spectrometer
Germany	UV Solid State Laser 266 nm 355 nm	Information not released
Norway	UV Solid State Laser 150 mJ/pulse 355 nm – rate = 10 Hz	Backscatter signal using photomultipliers Fluorescence signal using Intensified CCD + spectrometer
UK	UV Solid State Laser 40 mJ/pulse 266 nm – rate = 10 Hz	Backscatter signal using photomultipliers Fluorescence signal using photomultipliers + spectrometer
USA	UV Solid State Laser 355 nm (at least)	Information not released

Table 1: LIF Lidar development

We can see that all the systems use in general only one UV excitation wavelength, associated with a quite resolved spectrometer and a high sensitive sensor (Intensified CCD or Photomultipliers). Some other developments, like the BODE demonstrator, explore the capability of dual UV excitation wavelengths in order to record two types of different fluorescence spectrums, allowing to reduce the resolution of the receiver spectrometer resolution, and therefore the channel number.

In fact, we assumed two approach types in term of fluorescence signal acquisition :

1. only one UV wavelength is transmitted, and there is a need of fine resolution spectrometer for the fluorescence analysis, because some interferents, like diesel, pollens, foliage debris are fluorescing, and can have similar fluorescence signature as real biological agent. So high resolution is needed to increase the classification capability and reduce the false alarm rate
2. if two UV wavelengths are transmitted (like 266 and 355 nm), you highly decrease the probability that the signature of one biological agent and the signature of one interferent remains the same for both wavelengths. That allow you to reduce the spectrometer resolution, giving the following advantages :
    a. higher fluorescence signal collected per channel
    b. lower data numbers to be analysed
    c. cost reduction
    d. possible design reduction

Study for evaluating the minimum number of channels for biological lidar [3] gives a range value of [10-20] for an excitation at 355 nm.

Also the Table 1 do not mentioned “auxiliary” wavelengths (mainly 1,06 µm) used for cloud detection (backscatter signal), or mapping if associated with a scanner head.

3. INITIAL CILAS ACTIVITIES (1980-2000)

CILAS activities on stand-off detection historically began in the 80’s, under DGA program for chemical detection. First national R&D program have been initiated, for a short range demonstrator. Then, in the beginning of the 90’s, cooperation with USA Army (ERDEC) converged to the MIRELA demonstrator (Figure 2), a high range demonstrator. It was based on DIAL and DISC methods with tunable CO_2 laser. The performances were quite honourable, with detection and classification capability up to 5 km.

Figure 2 : MIRELA Chemical Lidar (courtesy DGA/CEB)

On the same time passive, multispectral imager technology succeeds to overcome active technology, but remains not useable for biological detection.

At the end of the 90’s started the research in the biological stand-off detection. Still under DGA program, a first version of a LIF lidar demonstrator has been developed and evaluated (Figure 3). The system demonstrated the principle and the feasibility to detect biological simulant agents.

Figure 3 : Biological lidar demonstrator (courtesy DGA/CEB)

The system is transportable for field test and has some hundred meters of detection range. The system completed two trials campaigns.

4. Recent activity (2008 – 2009)

Two projects drive active biological stand-off activity. First, the BODE project. The BODE study was carried out for the PASR FP7 program between 1st January 2007 and 31st March 2009 to prepare Europe capability to face Biological threat with a LIDAR stand-off detector. The system was designed for short range detection (100-300 m).

The main subsystems of the BODE LIDAR system are:

- the emission with non linear crystals: a specific OPO (Optical Parametric Oscillator) setup has been built in order to produce the most effective UV wavelengths for fluorescence generation. In order to improve the classification capability the laser source has been designed through a dual UV excitation scheme: the laser alternatively fires 2 specific UV wavelengths

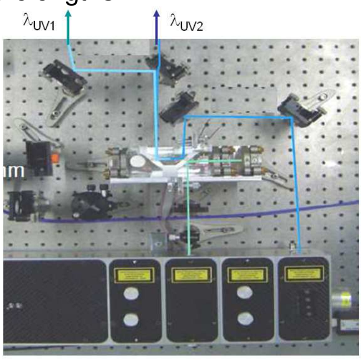

Figure 4 : Dual UV laser source (courtesy DLR)

- the optoelectronic reception (see figure 5): a telescope forms the basis of the receiving optics with the emissions from fluorescent particles within the acceptance angle of the telescope directed to a multichannels photomultiplier array via a series of dichroic filters.

Figure 5 : Lidar Receiver (courtesy BIRAL)

- the Man Machine Interface (MMI) and data processing. A preliminary version of an operational MMI was developed, containing the principal information : the camera display, knowing where the system is pointing, the cloud position and the level of the alarm (no alarm, bio alarm, threat alarm).

Figure 6 : Preliminary MMI (CILAS)

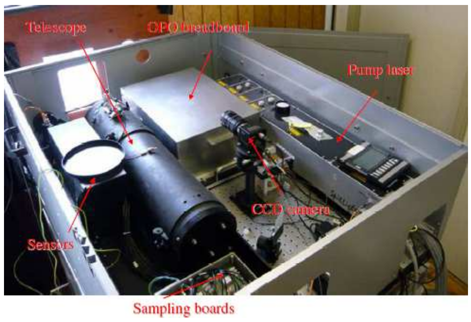

Figure 7 : BODE breadboard

The demonstrator has been tested and evaluated at the FOI facility located in Umeå (Sweden). Trials did go through chamber test, for a first calibration phase and data bank realisation. Then tests were performed to artificial outdoor cloud dissemination (Figure 7).

Figure 8 : Umeå test (courtesy FOI)

After the completion of the tests, the raw data were processed in delayed time to define and adapt the numerical processes (for instance identify the most suitable numerical filtration) and furthermore to analyse the results. The ROC analysis (*Receiver Operational Characteristic*, a statistical approach) which is a useful tool to analyse the performances of a system in terms of sensitivity was used. A specific analysis software was developed by CEB for that (see figure 9).

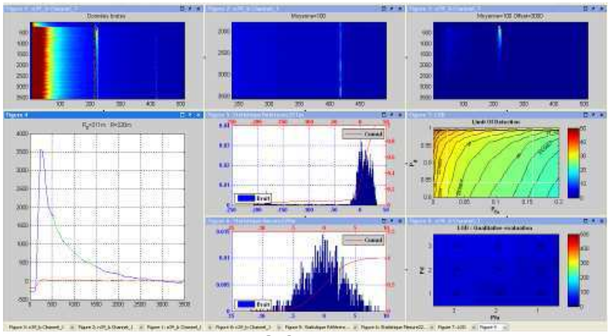

Figure 9 : Data ROC processing (courtesy DGA/CEB)

Then, FOI uses the Principal Component Analysis ("PCA" analysis) for selectivity measurement and demonstrated good classification capabilities. The figure 10 shows one output result : three clusters clouds represent the three types of biological threat.

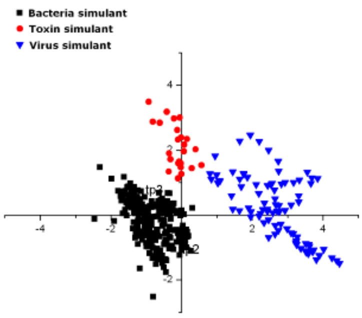

Figure 10 : Cloud classification processing (courtesy FOI)

The main conclusion of the BODE project are :

- a complete evaluation of a biological lidar, helping to compare real results and numerical models
- the classification of using PCA methods seems promising. With some technical improvements to the system, it is expected that the BODE type LIDAR should have the ability to classify aerosols as biological agents or interferents
- dual UV excitation can help to the discrimination, because the recorded spectrum of the simulant agents are different for each excitation wavelength

French ongoing activity is now focalized one a second project : the performances enhancement of the French biological lidar. The new version will have higher sensitivity, higher range working and new classification algorithms based on the state of the art of data processing.

5. PERSPECTIVES

The principle of LIF for biological cloud detection and classification has been demonstrated through the current projects investigation. The use of several excitation wavelengths can improve the classification capability, but further additional information from a cloud can be retrieved by analysing the following parameters :

- the depolarisation ratio : using a polarized UV wavelength or additional wavelength (532/1064 nm) can provide information about the aerosol shape
- the wavelength ratio : by using several wavelengths for mapping the cloud (UV/532/1064 nm), the ratio of the backscattered echo for the cloud between those wavelengths can provide information about the size range of the aerosol

But improvements remain to be focused also on size and weight reduction, mainly dominate by the laser size, first, and then, by the receiver aperture.
The classification algorithms also have to be deeper investigated : their optimisation should privilege low false alarm at the cost of real positive alarm (non detection).

6. CONCLUSION

Biological stand-off detection is a research field with high motivation : having early warning system can highly improves the reduction casualty in biological attack. Excepted USA, all developments are on the status of demonstrator. Mainly all current developments are based on LIF lidars, with UV wavelengths based on tripled or quadrupled YAG wavelengths. The fluorescence spectrum is analysed with high resolved spectrometer, and the signal processing and data analysis remain a challenge to push this technology on operational concept. This gap should be highly reduced on short term, and let hoping fully operational stand-off biological availability in Europe in the field of 5 years.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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