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LIDAR REMOTE SENSING OF THE PARMA CATHEDRAL AND BAPTISTERY

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ABSTRACT

Fluorescence lidar is a well known instrument that is mainly employed for the remote sensing of the Earth's surface. In recent years, IROE, in collaboration with other Italian and foreign institutions, carried out the first experiments on remote sensing of historical buildings using fluorescence lidar. The main part of these experiments deals with the remote monitoring of biodeteriogens and the lithological characteristics of the building materials. This paper describes the results of the field experiment carried out at the Parma Cathedral and Baptistery in September 2000.

Two systems, the tripled Nd-YAG lidar of the Lund Institute of Technology and the XeCl lidar of the CNR-IROE, operated for one week, in order to test the possible applications of both fluorescence point measurement and fluorescence thematic imaging in the remote non-destructive monitoring of buildings.

Apart from confirming the possibility of detecting biodeteriogens, for the first time in our knowledge the processing of the fluorescence data made possible the detection of restorations and the distinction between pigments having the same color.

Keywords: fluorescence lidar, cultural heritage, biodeteriogen, stone buildings

1. INTRODUCTION

The use of laser-induced fluorescence (LIF) for the remote sensing of the stone cultural heritage was introduced in 1995¹, and has been developed in subsequent years. The investigation covered different aspects, such as the identification of stones of the same type, but coming from different quarries², the identification and characterization of biodeteriogens^{3,4}, and the detection of surface treatments^{5,6}. Particular attention was devoted to the possibility of preparing thematic images of the building surface by means of a scanning fluorescence lidar^{7,8}.

A field experiment was planned by the authors in order to make a thorough investigation of the potential of fluorescence lidar in the remote sensing of historical buildings. The experiment was based on two fluorescence lidars with different characteristics: the first one belongs to the Lund Institute of Technology (LTH), and the second one, to the IROE-CNR "Nello Carrara".

The test was performed in Parma, Northern Italy, from September 10th to 19th. The targets were the Cathedral and the Baptistery of the town, both located in the Cathedral square. These monuments were selected for the following reasons:

- 1) Their history is well known also as far as the building materials involved are concerned;
- 2) the two buildings show biodeteriogen colonization, and in the past were cleaned and partially protected with the use of chemical treatments. Consequently they offer the opportunity of testing the lidar technique on different types of targets;

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- 3) the LIF signature of the stones (*Ammonitico Rosso Veronese*,) which compose the external part of the baptistery and some decorative parts of the cathedral is well known, since it has been thoroughly analyzed in Firenze⁹ and Lund¹⁰;
- 4) the Cathedral square lies within a pedestrian area, and is therefore not disturbed by the traffic. It is also sufficiently large enough to host the two lidar vans without limiting in their operations.

This paper describes the experiment and its first results.

2. THE CATHEDRAL SQUARE OF PARMA

The cathedral square of Parma houses two of the most interesting medieval buildings in northern Italy, the Cathedral and the baptistery (Figure 1).



Figure 1 - Medieval monuments of the Cathedral Square in Parma, Italy. The Cathedral (left up) and the Baptistery (right) viewed from the Square.

The cathedral is one of the most complex and structured religious buildings belonging to the Romanesque stile. The church was built before 1046 AD, and was then rebuilt after the earthquake of 1117 AD. The reconstruction ended around 1284 AD with the erection of the bell tower. The facade is composed of ashlar of different stones, which are mainly whitish or yellowish. The facade lower part shows three doorways. The central doorway is covered by a marble porch (*protiro*) decorated with carved figures. The upper part of the facade is embellished with three orders of small arches. Some parts of the façade, particularly in the right side, are colonized by biodeteriogens or show bleak crusts. It is known that the marble porch was submitted in the past to protective treatments of an unknown chemical composition. The baptistery is considered to be the most beautiful building of the transition period between Romanesque and Gothic stile. The construction started in 1196 AD and ended in 1260 AD after a long stop pause due to political conflicts. The decoration of the upper part was completed in 1307 AD. It is an octagonal structure with four superposed orders of open arches and a fifth order of blind arches.. The baptistery is completely covered with slabs of *Ammonitico Rosso Veronese*, a calcareous stone widely employed as decorative material, for its color and typical texture. The lower part has three carved doorways. Must of the decorations were carved by the famous artist Benedetto Antelami. The baptistery was completely cleaned and submitted to protecting treatments about ten years ago.

3. THE LIDAR SYSTEMS

Two lidar systems were used in this experiment, both of which installed in mobile laboratories. The two vans were

placed in the cathedral square, one just in front of the Bishop Palace and the other one at the center of the square (Figure 3).



Figure 3 - The IROE-FLIDAR (foreground) and the LTH lidar (in the back) in the Cathedral Square.

3.1 - The LTH lidar

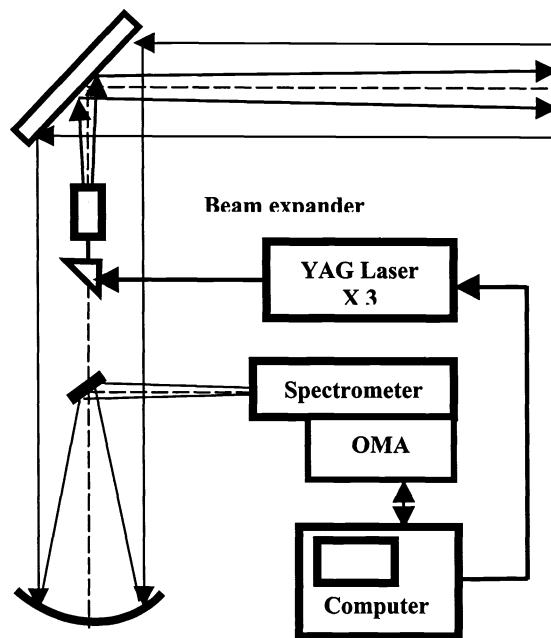


Figure. 4 - Layout of the LTH fluorescence imaging lidar.

The lidar system used for the measurements was designed and built at LTH for environmental monitoring^{11,2}. In this experiment, it was operated in the point remote monitoring mode: the laser beam was directly sent onto the target, and the induced fluorescence light is collected by the telescope.

During this experiment, the target was scanned sequentially in two dimensions, and the detection was accomplished by means of an Optical Multichannel Analyser. In this way, the final data were fluorescence spectra which were stored with the corresponding beam-positioning (x,y) co-ordinates. A basic layout of this system arrangement is shown in Fig. 4. The excitation consisted of a tripled Nd:YAG laser beam ($\lambda = 355$ nm, 20 Hz) expanded by a Galileian lens telescope, so that the footprint at the target distance had a diameter from 2 cm to 8 cm. The target was scanned with a

computer-controlled first-surface flat mirror, which collected also the fluorescence and directed it into a 40 cm diameter Newtonian telescope. Finally, the signal was sent to the detection system described above.

3.2 - The FLIDAR3

The FLIDAR3 is a high spectral resolution fluorosensor which was specially developed at IROE-CNR for the monitoring of the sea and vegetation¹². It consists of by three main modules (Figure 5): the optical one, which comprehends the actual optical sensor; the electronic module, which includes the detection and acquisition systems, and the gas-handling module, for refilling the laser cavity. The optical module consists of two excitation sources, an excimer laser (308 nm) and a dye laser (480 nm), as well as a 25 cm-Newtonian telescope. The optical module is connected by means of optical fibers to the electronic module, which includes a 275 mm-focal-length spectrometer, a gateable, intensified diode array detector (512 channels), and dedicated electronics for the acquisition and storing of the spectra. The sensor is battery-powered, while the electronics can be also powered by a motor generator. The main technical design criteria which have directed the development of the sensor were compactness, low-weight, and limited consumption. The fulfilment of these requirements, together with autonomy in regard to the power supply, facilitates the operation of the system in the field. All the equipment is installed in a small van (*FIAT Ducato*).

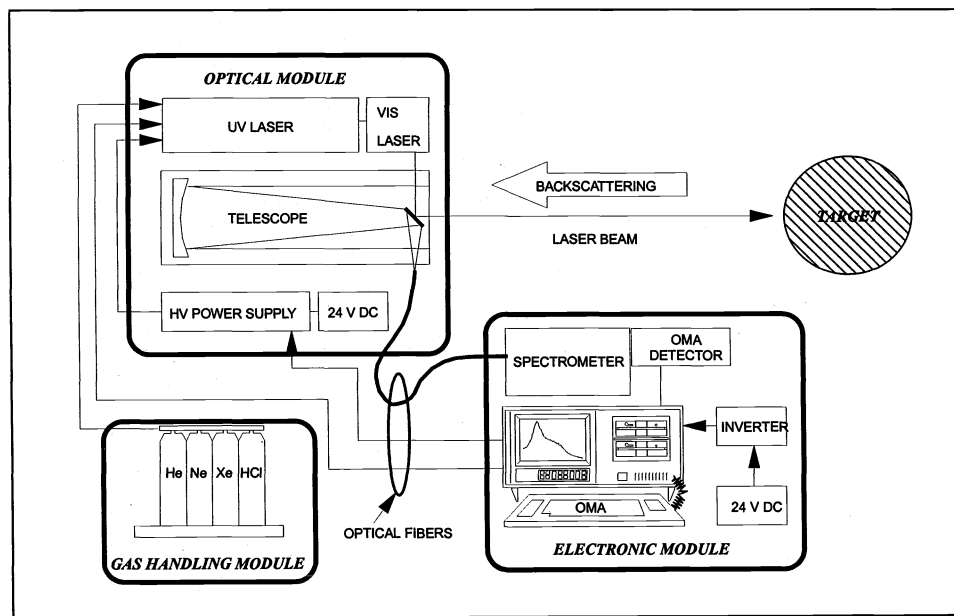


Figure 5. FLIDAR3 block diagram.

4. EXPERIMENT AND RESULTS

In the first part of the experiment, fluorescence spectra were detected on selected points with both lidars in order to obtain the signatures of the different litotypes. About 300 points were controlled on the cathedral and 200 on the Baptistery. While the stones of the Baptistery were only of *Ammonitico Rosso Veronese*, the stones of the Cathedral facade were of different litotypes such as *Ammonitico Rosso Veronese*, *Istria* stone, etc. Stones belonging to the same litotype showed a similar spectral behavior (Figure 6), as it had also been observed previously⁹. Important differences between the spectra detected by the FLIDAR and those detected by the LTH lidar are shown in figure 6. The differences can be attributed to the difference in excitation wavelength between the two lidars. Figure 7 shows the spectra taken at three different levels on the marble (*bardiglio*) side of the Cathedral's main doorway. This part of the façade was submitted to a conservative treatment some year ago. The presence of the treatment is indicated by the sharp peak at about 400 nm in the LTH lidar signal and at 375 nm in the FLIDAR one. The peak is more evident in the signals related

to the upper part of the marble ashlar, and decreases rapidly in the lower part which is more subject to meteorological washing.

The second part of the experiment was devoted to detecting fluorescence images of some sections of the two buildings. Only the LTH lidar was employed for this application.

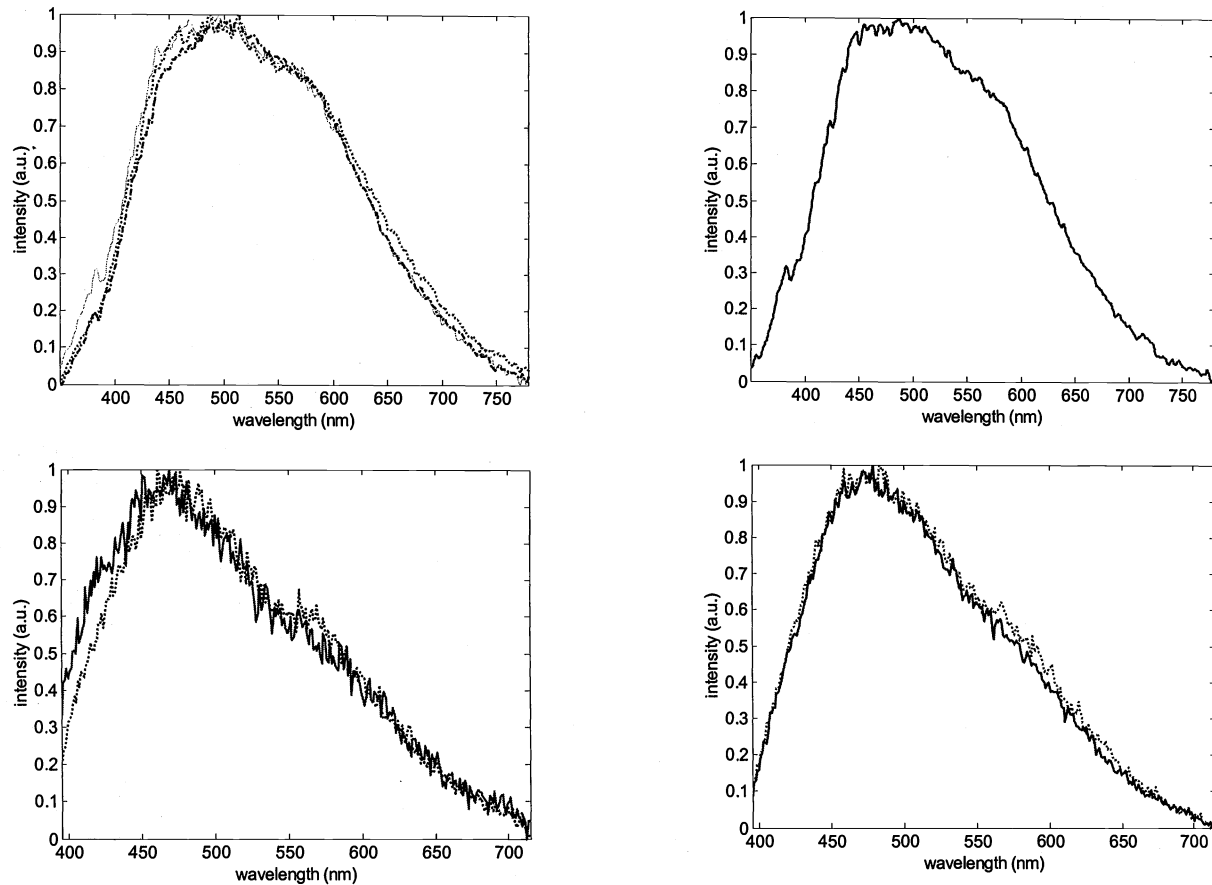


Figure 6. Normalized fluorescence spectra of *Ammonitico Rosso Veronese* in different points of the Cathedral facade as detected with the FLIDAR3 (up) and the LTH lidar (down). On the left three points on the left side column of the porch; on the right: stone 61 of the porch.

A complete spectrum of 512 spectral points was detected in each pixel. Consequently the full data set consists of 512 images, each of which corresponds to a specific wavelength. The detection speed was faster than 30min/m^2 , depending on the pixel dimension.

The images can be processed in different ways depending on the parameter being investigated. The ratio between the images at two properly-selected wavelengths often provides interesting information; however for some parameters the use of more complex procedures, such as the Principal Component Analysis, is needed (Figure 9).

5. CONCLUSION AND FUTURE TRENDS

The Parma experiment demonstrated that the use of a fluorescence lidar makes possible rapid monitoring of a building façade, and confirmed the previous results regarding the possibility of a remote mapping of biodeteriogens and litotypes. For the first time in our knowledge, the presence of protective treatments was detected by means of a fluorescence lidar to confirm the laboratory results.

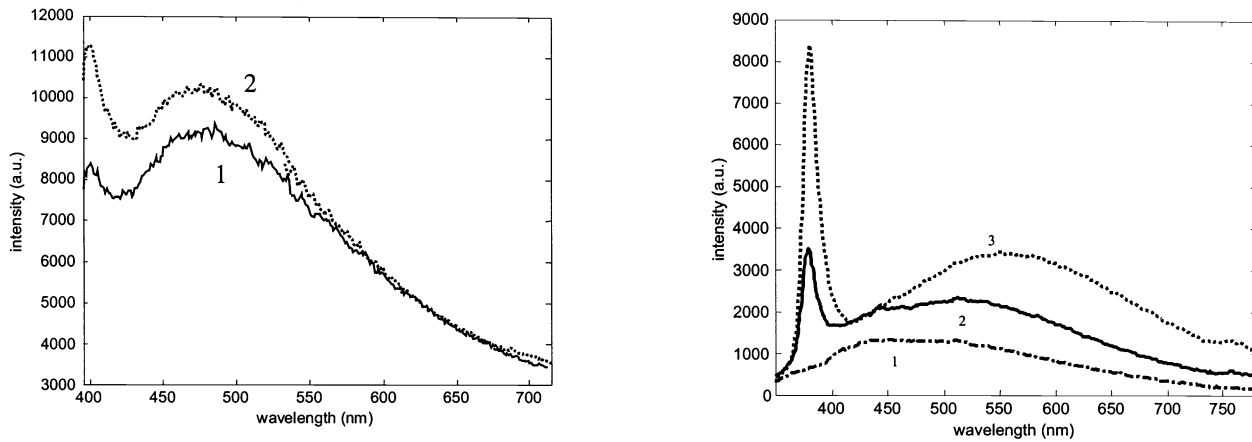


Figure 7. Fluorescence spectra of the marble (*bardiglio*) left side of the cathedral's main doorway. Left: LTH lidar. Right: FLIDAR. The spectra were taken at different distances from the ground, the distance increases with the number.

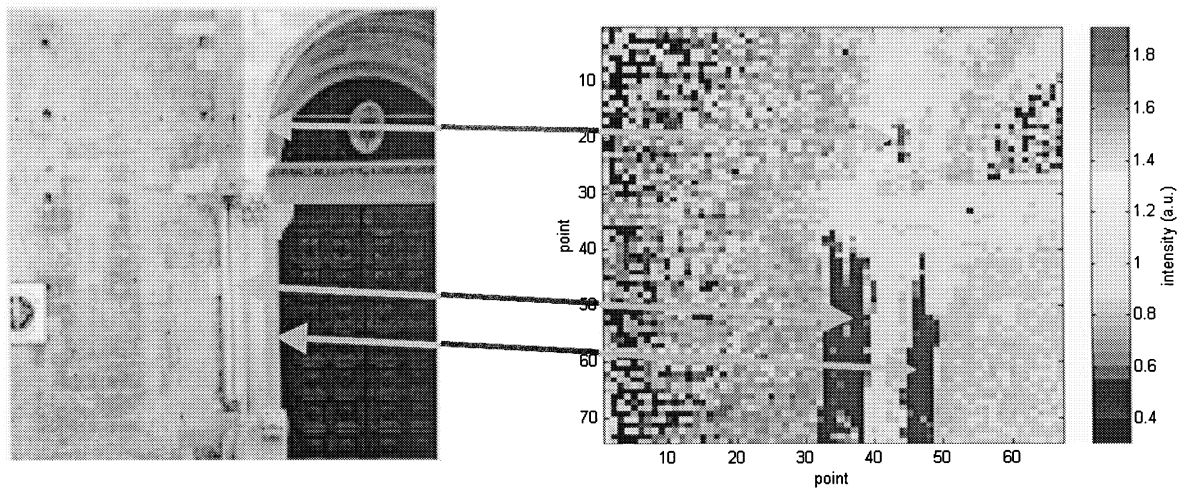


Figure 8. Detection of a protective treatment over the left side of the Cathedral's main doorway. On the right ratio between the images at two selected fluorescence wavelengths. Target distance: 60 m.

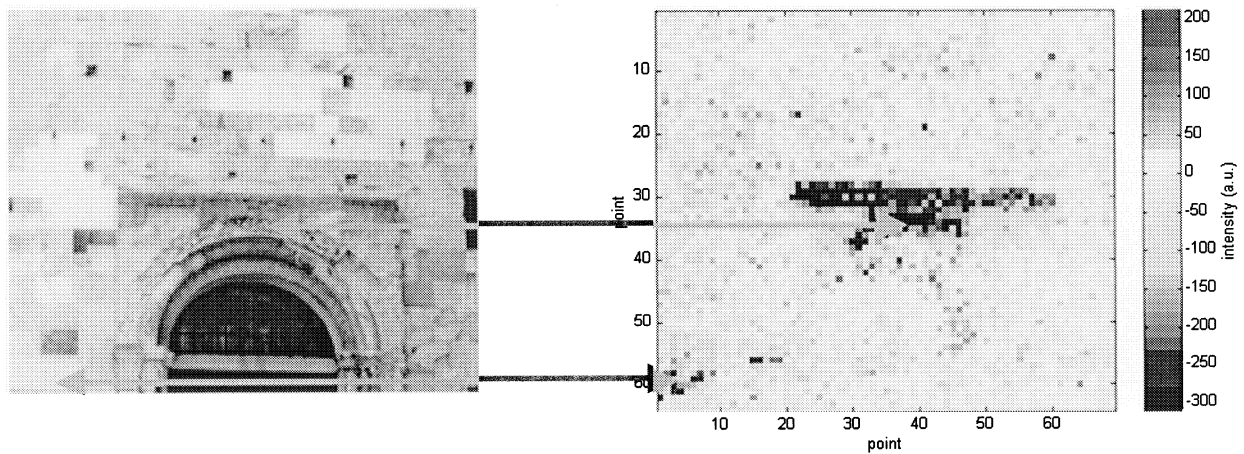


Figure 9. Biodeteriogen colonization near the right doorway of the Cathedral. Detection by PCA. Target distance 80 m.

The processing of the data is still in progress, and more complete results and conclusions will be provided in the near future.

It has to be pointed out that the lidar systems used in the Parma experiment, and in previous experiments, were designed and built for applications other than the remote sensing of historical buildings. Considering the first results of the experiment, the development of a fluorescence lidar specifically designed for this purpose would be highly appropriate.

6. ACKNOWLEDGEMENTS

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