LIF and SFS Techniques for Early Detection of Biofilms Harmful for Cultural Heritage

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Abstract—Specific LIF (laser induced fluorescence) and SFS (spectral fluorescence signature) sensors have been developed for detecting biofilms colonizing the surface of cultural heritage artefacts. The sensors contribute to a large-scale monitoring and decision supporting system, which is being deployed for historical monument protection within the framework of the European project STORM.

Keywords—fluorescence; biological materials, environmental monitoring; spectroscopy; sensor fusion

I. INTRODUCTION

This research reports the first results of the development and implementation of the Portuguese cluster of a large-scale monitoring and decision supporting system, which has been deploying since 2016 in Europe and Turkey within the framework of the European project STORM (Safeguarding Cultural Heritage through Technical and Organisational Resources Management). The cluster is hosted at the Early Christian Basilica of Tróia (District of Setúbal, Portugal) and comprises subsystems for fluorescence and weather data.

II. MONITORING SUBSYSTEMS

The fluorescence monitoring subsystem includes two sensors. The first one is based on LIF technology and is involved in assessing how much external weather conditions favor biological colonization, using as targets two samples (isolated fragments of plaster of no cultural significance) strategically placed outdoors near the Basilica, affected by sufficiently stable biofilms. The LIF emission of the sample was excited by 9 ns, 5 mJ radiation pulses generated by a frequency-doubled Q-switched Nd:YAG solid-state laser (excitation wavelength 532 nm). The emission was collected using a standard Thorlabs collimator F8105MA-635, passed through a longpass optical filter FEL0550 with the cutoff wavelength of 550 nm, introduced into an optical fiber and analyzed/recorded by a USB4000 spectrometer from Ocean Optics.

The other sensor detects spectral fluorescence signatures using the wide spectrum of a lamp radiation, which permits to scan the excitation wavelength by means of a computer-controlled monochromator. This turns the fluorescence spectra graphs $F_{\text{lif}} = F(\lambda_{\text{ex}})$ into surfaces $F_{\text{sfs}} = F(\lambda_{\text{ex}}, \lambda_{\text{em}})$, in which the detected spectral density of the fluorescence emission $F_{\text{sfs}}$ is a function of both the excitation and emission wavelengths $\lambda_{\text{ex}}$ and $\lambda_{\text{em}}$. The relatively less intense radiation of the lamp allowed using the SFS sensor for the assessment of biological infestation of very fragile Basilica wall paintings.

The weather and environmental data monitoring subsystem is presently represented by an off-the-shelf weather station Oregon Scientific WMR-300 integrated with open source software.

The preprocessed data from both subsystems are directed to the local server, where the information is collected, fused and analyzed in order to provide permanent assessment of various climate-related hazards to the project stakeholders.

III. PRELIMINARY RESULTS

Both LIF and SFS sensors are capable of detecting very thin chlorophyll-containing biofilms, hardly visible or even invisible to the naked eye. Depending on the ecosystem composition and biofilm density, the chlorophyll fluorescence manifests itself a) in the LIF spectra, as one or two peaks in the spectral range of 650-750 nm; and b) in the SFS, as a distinct maximum ("hill" of a characteristic shape) in the area approximately centered at $\lambda_{\text{ex}} = 500$ nm, $\lambda_{\text{em}} = 670$ nm. The fluorescence measurements were able to attribute numerous suspicious green spots at the wall paintings to some non-chlorophyll dye, seemingly not related to biological infestation — due to their SFSs that drastically differ from any in vivo chlorophyll signature recorded.

The SFS technique has demonstrated an additional ability of early detection of some non-chlorophyll biofilms composed by bacteria or fungi, that radiate sufficiently strong emission in the vicinity of the point $\lambda_{\text{ex}} = 300$ nm, $\lambda_{\text{em}} = 400$ nm.

The fluorescence data demonstrated good global correlation with the measured local environmental parameters.

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