

Advanced research technology for art and archaeology – ART4ART mobile laboratory

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The paper presents a mobile laboratory that corroborates advanced photonic techniques for investigation-diagnosis-intervention on artworks, historical buildings and sites. Due to a flawless flexible structure design, It substantially improves the decision and work conditions. It allows complex intervention without risks and – very important – with many on site and in real-time controlling procedures and feedback. ART4ART's innovative laboratory based on the selection of the techniques that creates a new concept of art restoration with no sampling assay or preparation, and with real-time results delivery.

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1. Introduction

Although a large number of early experiments in conservation using lasers were carried out in the 1970's, the first major project involving laser cleaning practices began in the late 1980's. Since then, laser cleaning techniques have evolved rapidly - projects have been completed touching most important sites such as Notre Dame in Paris [1] and the Cathedral at Amiens [2], where large areas of stone (the portal of La Mère de Dieu at Amiens) have been restored using laser based cleaning.

Lasers have been proven to be a promising alternative to more conventional cleaning techniques for certain applications, but we must also consider their limitations. Particularly, in the case of stone exposed to environmental pollutants and past conservation treatments including binders/supports that often present a hard crust of dirt and grime - well adhered to the fragile stone surface and patina, laser cleaning outcomes have been more efficient than traditional techniques.

The success of these applications rises not only from the scientific publications which address some of the parameters of laser systems or ablation mechanisms, but also in the increased use and acceptance of these advanced laser based techniques in their conservation/restoration cultural communities, a clear indication of its potential and its growing acceptance in the conservation community at large.

Two of the most important cases of the firsts East European large surface laser based cleaning of immobile cultural heritage were:

The Lady's Church from Bucharest-Romania (2004) [3]. Because of the unhealthy policy of urbanism and of the high pollution generated especially by a very intense traffic, this historical and artistic site was deteriorated; the poor conservation condition of the stone did not allow application of traditional cleaning methods.

$\lambda = 1064 \text{ nm}$
 $f = 20 \text{ Hz}$
 pulse duration: 6-8 ns
 $E = 400 \text{ mJ}$
 $F = 1.4 \text{ J/cm}^2$
 $A_{\text{total}} = 44 \text{ m}^2$



Fig. 1. Laser cleaning at Lady's Church.

Stavropoleos Church from Bucharest (2005) [4], one of the most important architectural and historical monuments from Romania. It required a special attention because of the complex palette of materials that have been used to build it up. Very fragile decorations, affected by environmental degradation, addressed a challenge for stone restoration.

$\lambda = 1064 \text{ nm}$
 $f = 20 \text{ Hz}$
 pulse duration: 6-8 ns
 $E = 400 \text{ mJ}$
 $F = 1.4 \text{ J/cm}^2$
 $A_{\text{total}} = 48 \text{ m}^2$



Fig. 2. Laser cleaning at Stavropoleos Church.

The main goal of the team was to develop a proper cleaning solution that will offer the best protection for the original stone layer but with a complete removal of the dark encrustations from the surface, and also to have a

proper vision of cleaning inside the extended strategy of restoration, the later being a chain of complex and well determinate steps. The restorers and conservators involved in those 2 major East-European projects, confirmed the fact that the severely damaged stone layers - affected by high temperature gradients and environmental conditions, would have experienced losses using the traditional methods of sand blasting, chemical substance etc.

Thinking conservation as a complex multidisciplinary approach, the monument was restored following an all together vision of the architecture and decorations under a common strategy. In the same time, both applications were strictly supervised by authorities and a main challenge was to control and prove the quality and the harmless effect of the intervention. The necessity to bring on site various instruments and to correlate the results as control procedure generated the idea of creating mobile laboratory.

Like other mobile equipment, this laboratory offers a special service regarding complex conservation situation by investigation and diagnosis done onsite and without sample assay, mainly by non-contact and non-invasive methods. Last but not least, it offers services of restoration by laser cleaning for all sorts of materials due to the large available range of laser parameters. Cleaning of stone, ceramics, paper, parchment, textiles, and other materials can be performed with existing equipment on laboratory.

Even some mentioned materials are not specific for immovable artworks; this offered facility is very important for the case of precious, delicate and sensitive in case of transport, or when a high insurance and bureaucracy is involved.

Overall these correlated techniques are managed to deliver information on monitoring-investigation-diagnosis and intervention for particular cases. It must be underlined that the assembly of real-time experimental data is part of the most advanced approach in the field.

2. Motivation

The processes of conservation involve two main activities: rectifying past deterioration and preventing further deterioration. It is important to understand that the result of both activities depend on an understanding of the characteristics of the objects themselves, therefore the laser techniques approached three main complementary directions that were developed along the road: investigation, diagnosis and intervention.

The motivation behind the development of the new laser techniques, complementary to the large number of existing standard investigation/ diagnosis/ intervention methods, comes from the need of high precision, non invasive, non- or micro-destructive means to remove even smaller (sub-micron) particles from substrates, to avoid the use of solvent techniques (= environmentally hazardous waste products/unwanted residues on small area substrates) and to reduce the risks of our cultural heritage preservation. However, for many materials the processes of decay are complicated and are still far from clear. In this manner a lot of studies and investigations have been

done in order to achieve the best analysis and diagnosis solutions. All the techniques were tested in laboratory, and now the domain has reached its maturity, cases were validated, and the time has come to take all these one step further: the new achievement ART4ART – a mobile laboratory that incorporates all the latest techniques, all in service of the cultural heritage.

3. Techniques

This new laboratory is a complex new “tool” for Cultural Heritage Preservation/ Conservation area that introduces the ability to perform in situ and without sample assay advanced analysis/diagnosis/cleaning-conservation by photonic techniques, in a time when most high precision techniques are often limited by the impossibility of working outside of laboratory.

The selected methods and instruments - perfected mostly in the last decade - address a wide range of materials and are extremely versatile. Although most of the components of the mobile laboratory are correlated one to another, we can disaggregate the techniques following the three major directions developed in the last few years at the European Level:

Intervention:

- *Large surfaces laser cleaning on organic and inorganic materials (stone, frescoes, metal, wood etc):*
 - Q-switched Nd:YAG laser with two articulated arms;
 - wavelengths: 1064, 532, 355 and 266 nm;
 - related energy for each wavelength: 600, 280, 100, 70 mJ
 - pulse frequency: $2 \div 20$ Hz
- *Small and delicate surfaces high-precision Nd:YAG laser cleaning* by instruments with high optical magnification, and high flexibility for paintings/documents/textiles and small and medium 3D objects:
 - Micro-laser xy and Micro-laser xyz- systems with adjustable laser fluencies;
 - with energy of 40 mJ for monopulse mode (fluence up to 325MW/mm²);
 - with energy of 110 mJ for double pulse mode (fluence up to 1.12 GW/mm²).

Monitoring and documentation

- *3D laser scanning* - for fast and accurate digital reconstruction of complex surfaces
 - hemispherical scanning with 360° × 270° field of view
 - range (optimal effective) **1.5m to 22m**
 - scan rate (points/second) 190,000
 - laser spot size at 10 meters 5 mm
 - laser spot size at 20 meters 10 mm
 - min. vertical resolution (points/degree) 20
 - min. horizontal resolution (points/degree) 10
 - max vertical resolution (points/degree) 250
 - max horizontal resolution (points/degree) 140

- *Ground Penetrating Radar for architecture, archaeology and large wood object, operating*

Antenna Frequency (MHz)	Suitable Target Size (m)	App.Depth Range (m)	App. MAX Penetration Depth (m)
25	1.0	5 - 30	35 - 60
50	0.5	5 - 20	20 - 30
100	0.1 - 1.0	2 - 15	15 - 25
200 - 250	0.05 - 0.50	1 - 10	5 - 15
500	0.04	1 - 5	3 - 10
800	0.02	0.4 - 2	1 - 6
1000	1cm	0.05 - 2	0.5 - 4
1600	1cm	0.2 - 1	0.5 - 2

- *Air quality control and microclimate monitoring by radio data transmission*
 - Temperature sensors, temperature range: - 40 + 800C
 - Relative Humidity, RH range 0-95%
 - Air Quality sensors: SO_x, NO_x, CO₂, CO.
- *Databases that comprise complex documentation on specific case studies, as well as assurance data for the investigation/diagnosis, monitoring and intervention procedures.*

Investigation/Diagnosis

- *Optical Microscopy investigation or surface morphology control:*
 - standard non-reflective objectives: 30×, 50×, 100×
 - high resolution: 200×, 500×, 1000×
 - 25÷200× zoom lens
 - approx. 12 mm working distance
 - xyz stand

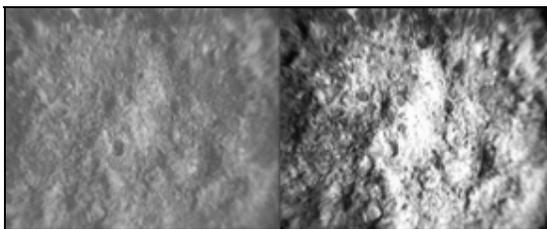


Fig. 3. Surface morphology control during laser cleaning process.

- *LIBS (Laser Induced Breakdown Spectroscopy) and LIF (Laser Induced Fluorescence) - straightforward and simple analytical techniques, which provide results practically instantaneously after the analysis; both applicable in situ.*

The results are presented as atomic/ionic and fluorescence spectra for surface chemical composition and stratigraphy;
 - spectral range: 350-920 nm

i.e.: LIBS analysis made on a textile piece- 1 pulse, 0.5 mm² diameter (see Fig. 4).

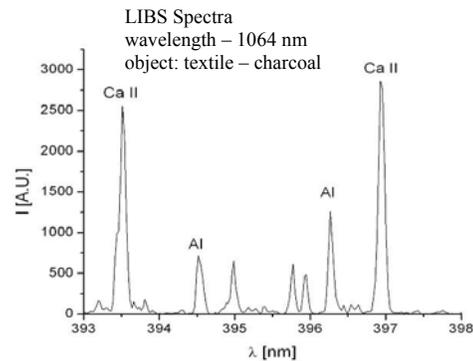


Fig. 4. LIBS spectra of a textile object.

i.e.: Stratigraphic investigations on the same textile piece, using 5 laser pulses (see Fig. 5).

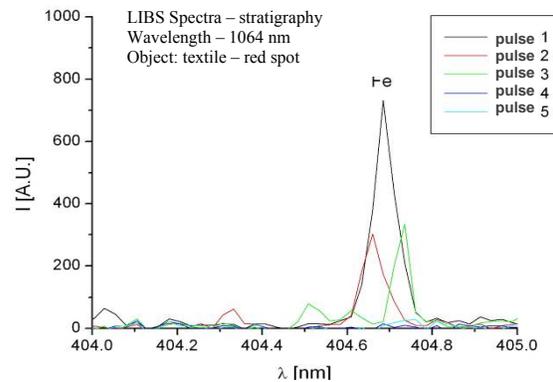


Fig. 5. Stratigraphy investigations using LIBS technique.

- *Mass Spectrometry: transmission and reflection spectra, colorimetry – for chromatic stability of studied elements;*
 - color spaces: CIE 94, CIE LCH, CIELAB, CMC, FMC-II, Lab, XYZ, xy
 - observers 2 degrees, 10 degrees
 - repeatability (white tile) - (typical) 0.04 RMS ΔE CIELAB
 - (maximum) 0.10 RMS ΔE CIELAB
 - measurement cycle time: 1 second
 - spectral range: 360 nm to 750 nm
 - wavelength interval 10 nm
 - photometric resolution 0.01%
 - apertures (illuminated/measured): regular area of view 10 mm/5 mm circular diameter; small area of view: 5 mm/2 mm circular diameter
- *Thermography and emissivity determinations; surface temperature monitoring, infiltration paths determination, incipient defects and detachments*
- *Multispectral analysis for multilayer structure investigation*

- UV reflectance and fluorescence, VIS, NIR and false color IR image modes
- wavelength range: 350-1150 nm
- 2 illumination sources: - halogen lamp for VIS-NIR & UV lamp at 365 nm for UV range

The system is designed considering the object itself and its environment because the object is continuously affected by external changes such as RH and temperature variations

All the methods and techniques have been already used independently in major conservation/restoration projects that envisaged highly important cultural and historical monuments.

4. Conclusions

The investigation/diagnosis/restoration and monitoring/control results have been published and accredited. As a major step forward, the mobile laboratory for onsite interventions was designed and developed by INOE, incorporating all previous techniques in stands and mobile setups on board.

Aknowledgements

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