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Details of a face from the Porta del Paradiso by Lorenzo Ghiberti before and after cleaning. Courtesy of S. Siano

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Dear participants at the Cost Action G7 –seminar “Artwork Conservation by Laser”

It is an honour for the city of Vantaa to have your meeting and workshop here in the modern and youthful city of Vantaa.

Culture and art are becoming more and more a strategic instrument for the policy of cities in Europe. The challenges posed by globalisation, the multiculturality of our societies and technological trends of our economies must all be addressed in order to manage the city.

Vantaa is known for its active business policy in such fields as logistics, environmental know-how and electronics, and its aim is to build up centres of excellence. In order to reach this Vantaa also promotes the networking of businesses, polytechnics, universities, and research establishments.

The vision of Vantaa is to be an international centre for business operations, logistics and knowledge, a good place to live for people of all ages. The international contacts of our institutions, especially the wide variety of international actitivites of EVTEK Institute of Art and Design, are very highly appreciated and play a crucial role in the strategy of the city,

The EVTEK Institute of Art and Design is an institute, which offers very highly appreciated educational training. Education in arts and design and the interest in the arts are strong in Vantaa. Vantaa is also well aware of the importance of education, which bases on the modern high technology. The city pays special attention to the demands of the information society and to life-long learning.

Welcome to Vantaa and good luck to your international cooperation! I hope your seminar will be a success.

Erkki Rantala,

The Mayor of The City of Vantaa

COST European Cooperation in The Field of Scientific and Technical Research

Introduction to COST Mission

COST – co-ordination through co-operation

COST is a pan-European intergovernmental framework for international co-operation between nationally funded research projects. It enables broad European Research & Development co-operation supporting scientific networks and allowing scientists to collaborate in a wide spectrum of Science & Technology activities. Based on national needs and resources, COST aims at promoting and co-ordinating pre-competitive basic and applied research or activities of public utility in areas of interest to research institutes, universities and industries throughout Europe.

Established in 1971 by 19 European States, COST comprises today 34 member states in Europe and Israel as a co-operating state. It also welcomes the participation of interested institutions from non-COST states and Non-Governmental Organisations without any geographical restrictions thus extending international collaboration far beyond the borders of Europe.

Successful co-operation in COST Actions

Co-operation in COST takes the form of concerted research Actions. These are broad networks of co-ordinated national research projects bringing together different national and industrial research efforts in focussed Actions addressing specific themes and solving scientific and technical problems by joining forces.

The basic underlying principles behind the COST co-operation are:

- *A bottom-up approach; researchers from any COST country can propose COST Actions based on national or local needs.*
- *Openness; COST is open to all scientific domains and open to participation of all member states. Also participants outside member states are welcome, based on mutual benefit.*
- *Flexibility; participation in COST Actions is voluntary associating only interested countries*
- *Research to be co-ordinated is funded nationally. Only co-ordination costs, like travel expenses to the COST meetings, are funded through the EU Framework Programme.*

The success of COST is based on the above features and its built-in flexible mechanism.

COST offers an easy access to the state-of-the-art information produced in Europe's leading research institutes. It has turned out to provide a valuable forum for the exchange of ideas and results, helping scientists to develop new partnerships and allowing them to make their research known in the international arena. Not only does COST facilitate the bringing-together of old or previously unknown partners, but it can build networks and collaboration for future participation in the Framework Programme.

Covering all scientific disciplines COST

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complements the national and Community research programmes. It has often been used for testing and exploring emerging topics and indeed, it has succeeded in generating themes of the future, thus paving the way for Community activities.

COST in the ERA

Over the years COST has experienced a vast expansion developing into one of the largest frameworks for European research co-operation. Today there are nearly 200 ongoing COST Actions involving 25.000 - 30.000 scientists from 34 member countries and from Israel, over 70 institutions from 11 non-member states, like Russia, the USA, Canada and Japan, as well as from Non-Governmental Organisations.

With this huge amount of scientific interaction and being able to mobilise large networks of national research activities, COST will make a substantial contribution to the development of the European Research Area.

This is a time of big changes for COST; necessary improvements of administrative procedures and rearrangement of the scientific secretariat are under way. COST has provided an innovative, cost-effective and flexible frame for S&T developments, training and dissemination in Europe for over 30 years. It has proved to be very adaptable, dynamic and responsive to the demands of the scientific community. And so it will remain in the future.

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Paradigm of an Integrated Multinational and Multidisciplinary Field of Research on The Conservation of European Cultural Heritage

Objectives

The investigation and preservation of Cultural Heritage are topics of continuous European concern and, besides the scientific interest; they have social, political and economic implications. Various *Natural Sciences* including *Conservation* are disciplines covering the area, and although their integration would seem crucial, it is usually lacking. Recently, a multidisciplinary approach of study and preservation aspects of Cultural Heritage has created the new Interdisciplinary field of *Artwork Conservation by Laser*. By combining the advances of laser technology - science and applications – with the modern conservation science, the field aims at scientific and technological benefits. COST Action G7 has been initiated for addressing challenges in three main directions: Laser and Optical systems in Analysis and Diagnostics; Real-time Optical equipment for Monitoring both Artworks and Environment, therefore uncovering their complex relations; Laser-assisted Divestment applications.

Description of the work

COST Action G7 "Artwork Conservation by Laser" started mid 1999 and includes delegates from 20 countries. The main goal is to maintain an active Scientific Network amongst the different disciplines – laser scientists, engineers, physicists, chemists, conservators and art historians – and the different European countries sensitized in the field. For management reasons it has been divided in three working groups with evident or latent interlinks. These working groups are: (1) Laser Systems for Cleaning applications, (2) Laser & Optical Systems in Analysis and Diagnostics and (3) Real-time Optical Systems for Environmental aspects and the Response of Artworks. The first working group embraces research, training aspects and other activities related to laser cleaning, the most widely known application in the field. The second working group includes research activities associated to the use of laser as an analytical or diagnostic tool in studying an artwork. Well-known examples are the Holographic Interferometric techniques for structural diagnostics of an object or the Laser Induced Breakdown spectroscopy (LIBS) for the *in situ* layer-by-layer elemental analysis of the surface. Finally, the third working group covers the existing gaps in research on environmental aspects (e.g. continuous monitoring of pollution and/or light levels) in relation to their specific effects on the art pieces. The significance of the action lies on the unique multidisciplinary approach towards the common goal of the preservation of Cultural heritage. Therefore, it can be used as a successful paradigm for other actions where different disciplines must cooperate.

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Results

The results of COST Action G7 could be summarized as follows:

a) Maintenance and further advancement of excellence in Europe.

b) Pointing the needs and Promoting the research in the field producing novel results in a world-class level.

c) To enhance and link methodologies in order to obtain accuracy and explore new techniques in studying and preserving monuments and works of art.

d) To create Databases in the three working groups.

e) To contribute towards the creation of norms.

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Laser Techniques in Conservation and End-Users

The Seminar "*Conservators and the use of laser techniques in conservation*" organised by the Conservation Department of EVTEK Institute of Art and Design is part of the 6th COST Action G7 Committee Meeting hosted by our institute. This seminar is not only dedicated to conservators who want to know the last improvements in such techniques but also to our conservation students who will be soon professionals themselves. During the seminar both of them will have the chance to get the up-to-date knowledge on the subject and to discuss with specialists.

The objective of this seminar is to give the state of the art on laser applications in conservation focusing more on cleaning applications. We considered as very important for the participants to get some feedback from end-users. Attention has then been paid on the choice of speakers. Most of them are conservators or are scientists working closely with conservators.

We are very happy to have among the speakers some of the best specialists in the field who have gained a large experience with time and who can talk freely of the advantages and disadvantages of laser techniques. As you will see laser cleaning is like all the other cleaning treatments in conservation. This technique gives good or very good results in some specific cases. In others traditional techniques are still the best but often laser cleaning can successfully be used in complement.

At the end of the seminar application of laser techniques in diagnosis will be introduced. It is a very promising field that is still under development in conservation due to the knowledge and equipment required. Some interesting results will be given to you.

I hope that this seminar will convince you of the possibilities of laser techniques in conservation and why not offer a starting point for some projects that might be initiated in Finland.

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An Introduction to Laser Cleaning in Conservation

Laser-based cleaning techniques provide the conservator with an extremely controllable and precise method for removing unsightly and potentially damaging layers from museum artefacts. Lasers provide a unique source of energy: an intense, highly directional, pure form of light that is able to deliver energy to a surface in a very controllable manner. There exist many different types of laser, but currently the most commonly used laser for cleaning applications in conservation provides short pulses (typically 10 ns duration) of light at a wavelength of 1.06 μm, i.e. in the near infrared part of the spectrum. Careful control of the cleaning parameters (energy density, beam size and pulse rate) allows the conservator to sensitively remove any unwanted surface accretions without overcleaning the valuable surface of the artefact. In many cases, the high degree of selectivity and non-contact nature of the process mean that extremely fragile surfaces are cleaned without loss of material, patina and fine surface detail are preserved and old coatings remain intact. The laser often provides the conservator with a tool that allows the gradual layer-by-layer removal of material, allowing decisions regarding other aspects of the conservation process to be made at an early stage.

Within conservation, laser cleaning is presently used most widely in the field of sculpture. This is where most of the research work has concentrated since the pioneering work of John Asmus and colleagues during the 1970s and use of the laser is now well established in many conservation studios across Europe, sitting happily alongside more traditional methods of cleaning. Laser cleaning offers exciting opportunities in other areas of conservation, including paintings, paper, parchment, textiles and glass. In these areas, use of the laser is not so advanced, but research is underway to carefully evaluate the potential of different types of laser.

Laser cleaning of the frame from an old stone relief

This paper aims to give an introduction to laser cleaning as used in the sculpture conservation department of a national museum. The nature of laser radiation, the mechanisms involved in the cleaning process and safety issues will be briefly discussed and, finally, a series of case studies will be used to illustrate the advantages and disadvantages of the technique.

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Laser Cleaning of Stone

The Conservator Approach

In Austria the use of laser for stone cleaning in the field of conservation was introduced in 1995. During the last 6 years a lot of different stone monuments and historical facades have been cleaned by laser technique (e.g. Romanesque and Gothic parts from St. Stephens cathedral, marble sculptures from the parliament, Gothic outdoor sculptures and facades from many other churches). Modified Nd-YAG-Lasers produced by at least three companies have been used.

Some parameters and standards of these laser tools are different. Common parameters of Nd-YAG-lasers are: wavelength: 1064 and 532 nm, energy: 250 – 1000 mJ, impulses frequency: 5 – 20 Hz, duration of the impulse: 6ns, beam diameter: 2 – 20 mm, different lenses, beam transmission: mirrors or cables made in glass fibre.

In the field of conservation (= cleaning) the most important parameters defining the conditions are the stone type and the nature of its surfaces as well as the presence of historical layers above them. The characteristics of the layers (e.g. black crusts, dust, soot, salts) to be removed with the laser device are also important especially because of the effect and speed of the cleaning process. In principle every cleaning has to respect the signs of history and time because they are documenting the periods between creation and today. The task of laser cleaning is also connected with the "value of age" and other aesthetic values *(table 1, Annex)*.

Sandstone, calcareous sandstone, marble, red limestone as well as other bright stone types have shown very successful results after laser treatment. The risk of undesirable cleaning effects has been reduced through foregoing appropriate cleaning samples and permanent lab controlling. For special cleaning problems e.g. white marble surfaces with sandy scaling the laser tool can preserve even delicate surface details, which are often identified as the last preserved original stone surfaces. A big advantage can also be the possibility to clean without pre-consolidation (e.g. ethylsilicate, acrylicresins, siliconresins and other mixtures). In this case laser cleaning can often be faster than other cleaning techniques.

On an economical point of view the comparison between traditional and high tech cleaning systems is important. Often the best cleaning result can be achieved by combining three or more techniques, including also laser treatment for special purposes *(table 2, Annex)*. However, if there are monochrome or polychrome layers present, cleaning with Nd-YAG lasers is possible only in rare cases.

It is very important for the conservator-restorer to know everything about the laser tool and of the substance and surface which have to be cleaned. In addition safety regulations have to be followed thoroughly. Protection with special glasses for the eye, gas-mask for the breathing, correct cloths for the skin and a right isolation with a sign for danger of the working place (studio, scaffolding, workshop,) where the laser is used are always required.

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Laser Cleaning of Plaster

The Conservator Approach

As far as it is known it was in year 2001 that laser cleaning was used for the first time in Finland for conservation purposes when a private conservation enterprise (Oy Ars Longa Ab) leased a laser cleaning system from France. The cleaning device was mainly used for cleaning *plaster of Paris* and *white marble* but it was also applied on some painted surfaces. The laser device was primarily leased for cleaning of a rather big marble memorial stone but the type of the marble proved to be unfit to be cleaned by laser.

When selecting the laser system device, attention has to be paid on its suitability as well as on mobility and naturally on price. In our case all factors could not be anticipated. The leased device was of the type in which laser beam is guided by light fibre. The working end of the fibre got damaged easily and due to this the fibre had to be cut repeatedly. This maintenance procedure was difficult and time consuming. Thus, regardless of the laser technology's speed in conservation work, no significant saving in working time did occur compared to more traditional methods.

Due to these continuous breaks in working process, the leasing period of the device had to be extended which lead to increasing costs. The problem of the constant damaging of the light fibre and re-cutting did not even vanish after the device had been sent back to France for maintenance during work process.

However, despite these technical problems, the cleaning results were most satisfactory. The suitability of the device in cleaning untreated plaster surfaces was extremely good and this is an undisputed advantage since untreated plaster is difficult to clean with traditional methods without causing damages to the surfaces.

In spite of good cleaning results, some yellowness was observed on the treated surfaces. This phenomenon may be due to damaging of the surface, patina or dirt residue and needs to be investigated in more details.

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Laser Cleaning of Paintings

Technical Aspects

Modern technology, such as lasers, can offer valuable tools to support conservators and restorers in their work. At Art Innovation, an innovative laser restoration tool for non-contact cleaning of painted art objects has been developed.

This laser workstation has proven to be a valuable tool for solving the problem of fire-damaged paintings. Soot deposit, often a serious problem for conservators, can easily be removed from the surfaces using an ultraviolet (UV) laser. Since only low laser energies are needed for efficient removal, the effect of the UV laser light on the residual material is minimal.

Results using the first professional laser cleaning station, equipped with a modern mechatronic engineering tool for accurate beam manipulation ('optical arm'), will be presented.

Several practical aspects of laser cleaning will be dealt with such as the working procedure, how an intelligent combination of software and hardware enables accurate control and how to safely deal with the variable properties of the delicate artworks to be treated.

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Laser Cleaning of Paintings

The Conservator Approach

There are cases where normal and conventional cleaning by solvents is very dangerous or harmful to paint layers. In addition, in some cases solvents are not always able to dissolve varnishes (artificial resins). Sometimes, a removal of part of the varnish layer by laser can indeed be a better alternative.

In this talk, four case studies will be presented to illustrate the possibilities of laser cleaning.

1) Partial varnish removal on a 19th century oil painting. This example describes how far the removal could be conducted safely in a case where the type of varnish was known from former information by documentation.

2) Partial varnish removal of a 17th century oil painting. In that case it was important to save the 19th century overpainting on the background. The original paint was very worn and there was no need of touching the overpaint.

3) Partial varnish removal of a 20th century oil painting. The varnish was synthetic and insoluble except in Butylamine. Excessive treatment with Butylamine could dissolve the relatively fresh paint.

4) Removal of soot on a painting with severe fire damage. Even the fragile blisters could be saved and stay undamaged

The results obtained in all these examples were satisfactory. Nevertheless, a lot of continuous and fundamental research is necessary in order to perform safely cleaning treatments on paintings.

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Laser Cleaning of Paper

The Conservator Approach

The removal of loose and partially bound foreign matter (dust) from paper artefacts is yet an unsolved problem in paper conservation. Dry cleaning methods like brushing, dusting or mainly using different erasing materials often prove to be insufficient. This is especially the case when the dirt particles have penetrated the bulk of the paper or when trying to remove dirt from tears or from degraded, sensitive papers. This is due to the fact that paper is a porous material because of its fibrous structure. Dirt on paper is not a rough surface layer, but adheres to a 3-dimensional net structure. Laser cleaning seemed to be a promising technique to replace common dry cleaning methods in paper conservation. First feasibility studies showed convincing results, but before recommending the laser as a cleaning tool for paper, immediate and long term effects laser radiation exerts on cellulose substrates had to be investigated.

Within the framework of the Eurocare project 1681 LACLEPA (Laser Cleaning of paper and parchment) the interaction of laser light and cellulose was examined using two laser types running at three different wavelengths (308 nm, 532 nm, 1064 nm, fluences below 1.2 J/cm²).

The use of an Excimer-Laser working at 308 nm (near UV) causes photo-oxidative degradation of paper cellulose accompanied by an increase in the content of oxidized groups and a severe decrease in the degree of polymerisation (DP). The use of a Nd-YAG Laser emitting at 1064 nm (IR) leads to inter- and intramolecular cross links of ether origin, which increased the degree of polymerisation (DP).

No immediate effects of the laser treatment were observed with a Nd-YAG laser emitting at 532 nm at moderate fluences below 1.2 J/cm² - making this laser type/ wavelength probably best suited for application in paper-conservation – whereas higher fluences increased the rate of degradation of paper cellulose during accelerated aging (90°C, 65% RH).

Laser cleaning (308 nm, 532 nm, 1064 nm; fluences below 1.2J/cm²) of artificially soiled paper samples led to excellent results concerning the removal of dirt particles but caused severe yellowing of the paper surface. Using the Excimer-Laser at 532 nm and 1064 nm, yellowing did not change the DP. The mechanism of yellowing is still under investigation.

A prototype Nd-YAG-Laser, specially designed for paper restoration purposes at the Laboratory for Thin Film Technologies at BAM, Berlin, was used in cleaning tests on historic paper artefacts and also in a study on the removabilty of fungal residues on paper. Preliminary results will be discussed.

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Laser Cleaning of Organic Materials (Cotton, Linen, Wool, Silk)

Technical Aspects

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Traditional wet or dry cleaning of organic fibrous materials, such as cotton, linen, wool and silk fibres, may lead to undesirable alterations of surface structure or composition as a consequence of physical contact with the artefact. Thus, especially for chemically sensitive or physically fragile materials, non-contact laser cleaning offers certain advantages, since material handling can be minimised. Besides, unprecedented spatial accuracy can be achieved. However, organic materials are susceptible to heat and light damage and may be sensitive to (chemically) reductive conditions during the Nd:YAG (1064 nm) pulsed laser cleaning process. The laser treatment thus needs to be evaluated with respect to the possible negative side effects and the cleaning parameters need to be optimised, before the technique is applied on historical materials.

The influence of Nd:YAG laser (1064 nm) fluence and number of repetitions on soiled cotton, linen, wool and silk fibres is reported. The results demonstrate that a single pulse of higher fluence is generally more advisable than a high number of repetitions of lower fluence.

Laser Cleaning of Glass

The Conservator Approach

The legibility of illustrations depicted on stained glass windows depends decisively on the transparency of the coloured and painted glass. Atmospheric or biogenic corrosion of the glass due to its exposure to air pollutants and humidity may result in surface layers such as corrosion crusts and bio-layers. Additional surface layers may consist of soot, dust or residues of organic polymers due to former conservation treatments. Although most surface layers can be removed by conventional cleaning methods, so far no acceptable method is available for the removal of well adhering, dense layers of corrosion products, bio-layers or aged and insoluble organic polymers.

In 1997 a three-year interdisciplinary research project "Laser cleaning of stained glass windows" (funded by Deutsche Bundesstiftung Umwelt, Osnabrueck, ref. Nr. 11472) was launched in Germany, with the aim of systematic investigations on applying laser radiation for the removal of superficial deposits from historic stained glass. The involved team consisted of: glass scientists from the Fraunhofer-Institut fuer Silicatforschung (ISC) Wuerzburg/Bronnbach, laser specialists from the Laserzentrum Fachhochschule Muenster (LFM) and biologists at the University of Erlangen, Institut fuer Werkstoffwissenschaften. Conservators and art historians from the cathedral workshops in Cologne and Erfurt provided a vital link to conservation practice. Based on the results of former independent feasibility studies the KrF-excimer laser operating at the wavelength of $\lambda = 248$ nm (UV-range) showed to be a suitable wavelength for the removal of encrustations as well as the ablation of organic polymers and bio-layers and was chosen as the main source of laser radiation. In order to study the impact of laser radiation, model substrates were used to define alteration and ablation thresholds for all relevant materials involved. As a self-limiting process is not applicable for these types of materials, different sensoring systems, including LIBS (laser induced breakdown spectroscopy) and fluorescence microscopy were evaluated. In a final step, cleaning experiments were performed on a limited number of selected originals, in order to evaluate the transferability of the obtained results into conservation practice.

This presentation will give a short introduction of the laser equipment used within the project. The degradation processes of stained glass and the resulting problems are explained. An overview of the results with emphasis on the information obtained from the cleaning tests on originals will discuss the possibilities and limits for the application of lasers in stained glass conservation, with special relevance to the conservator's point of view.

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Laser Cleaning of Metals

The Conservator Approach

The effectiveness of laser cleaning in many stone conservation problems was reported in a number of works, including laboratory tests and cleaning treatments on historical façades, cathedrals, statues and other artefacts. On the contrary, for the laser cleaning of metals the literature is relatively poor. This can be attributed to two main reasons. Firstly, the observation in laboratory tests of various undesired laser irradiation effects due to the opacity and the thermal instability of many metal minerals, and sometimes to the low melting temperature of the metal itself, have strongly limited the experimentation on original objects. Secondly, the availability of various mechanical and chemical techniques, which provide well accepted cleaning results, have not encouraged the investigation of new approaches requiring expensive devices and careful optimisation phases such as the ones based on laser ablation.

Despite this not promising background, during the last five years, my research group performed several feasibility studies focused on possible improvements provided by a suitable integration of the laser ablation in cleaning procedures of metals. Here, a critical review of the work will be presented, aiming at demonstrating the real usefulness of the laser approach in conservation treatments of valuable bronze masterpieces, archaeological finds and other metal artefacts.

At the first step, the thermal transformations of the main copper, silver and iron minerals usually encountered on encrusted metal objects were investigated. The following irradiation tests were performed by applying Nd:YAG lasers (1064 nm) with different pulse duration (6 ns-50 μs). The measurement of the laser fluence thresholds, associated with various thermal effects, provided indications of suitable pulse duration and operative ranges for specific deterioration typologies of uncoated metals, while the physical analysis helped to give estimations of the optimum laser pulse duration for cleaning metal films.

Following the example given by the first successful cleaning tests performed on archaeological bronze fragments and coins, important conservation problems were investigated. The Minerva from Arezzo, the gilded bronze panels of the Porta del Paradiso by Lorenzo Ghiberti, the gilded decorations of the Santi Quattro Coronati by Nanni di Banco, and very recently the David by Verrocchio are exemplary application cases of the laser cleaning. As a general rule, the laser technique was first optimised as stand-alone then integrated in the conservation interventions of these valuable masterpieces.

In conclusion, there are enough demonstrations that the suitable integration of optimised laser ablation in the conservation procedure can provide significant improvements of the cleaning result and sometimes unique solutions of difficult conservation tasks. This especially when mechanical means do not allow safeguarding of fragile surface textures, metal films and others or when the chemical treatments provide unsatisfactory selectivity among different materials and layers.

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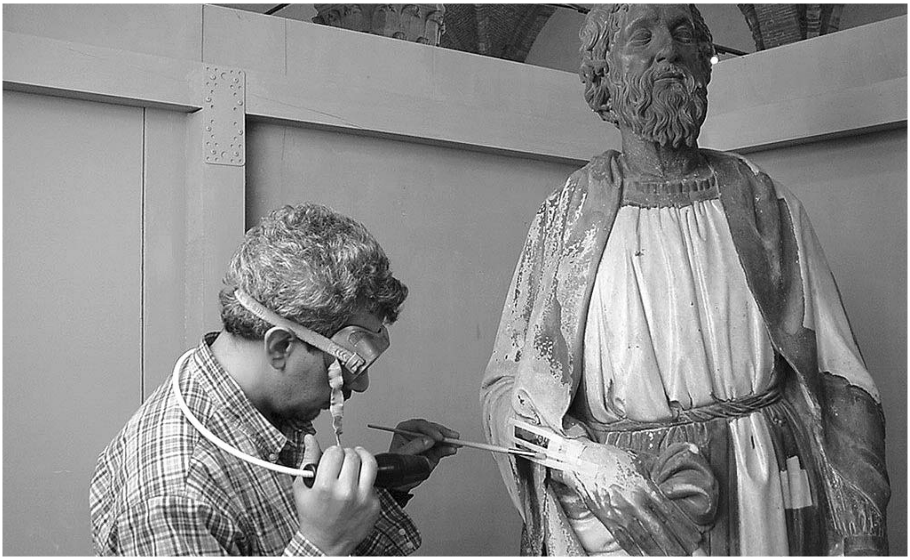

Laser cleaning of gilded decorations on the Santi Quattro Coronati by Nanni di Banco

Laser Cleaning of Metal / Textile Composites

Technical Aspects

The treatment of composite artefacts containing different materials that cannot be separated is often a compromise where we try to clean or stabilise one element without damaging the other. The cleaning of metal threads in textile is one example among others. Until recently only mechanical or chemical techniques were used to remove the tarnish on gilt silver, silver or silvered copper threads. Since these treatments are likely to damage both the metal and the textile, other approaches were suggested. Electrolytic procedures have turned out to be quite satisfactory, provided that the metal part is considered the most important one (fringes).

Metal threads are often inserted in dyed textile. In addition to the physical damage to the textile, the immersion of the artefact could lead to the dissolution of the dyes. Laser cleaning appears here as an interesting alternative but its non damaging effect on textile has to be checked. In addition, the parameters of the treatment have to be defined and optimised in order to obtain a result that both respects the artefact and is aesthetically acceptable.

Our first approach has been to determine a laser device that would give the most interesting result on an aesthetic point of view. These preliminary tests were conducted at FORTH, Heraklion in Greece. It appeared that the Nd:YAG-3rd harmonic laser (emitting ultraviolet radiation) used gave a good cleaning on tarnished silver coupons that could be controlled (audible bangs) although a whitening effect was observed when the fluence increased. This whitening is certainly due to the redeposition of silver vaporised during the cleaning process.

While studying the effect of the environment (with or without oxygen, dry or wet), it appeared that the presence of oxygen and heat favoured another side effect, the yellowing of the surface due this time to the oxidation of the silver redeposited.

Similar tests were conducted in parallel on textile samples (silk dyed or not). Neither modification of colour nor damage were observed for the optimal conditions defined with metal coupons. However, when applying these tests on real artefacts severe side effects occurred (burning of the textile and staining of the textile around the metal threads during the cleaning process) and new cleaning conditions had to be determined.

Laser cleaning of metal threads in textile appears to be a promising technique although some optimisation is still required. Yet, several aspects remain to be considered, for instance the problem of the dull appearance of the cleaned metal threads and the effect of the laser impact on the long-term conservation of the materials. No tests have indeed been conducted to determine how reactive the metal is after cleaning. Finally, the effect on the textile has to be clarified.

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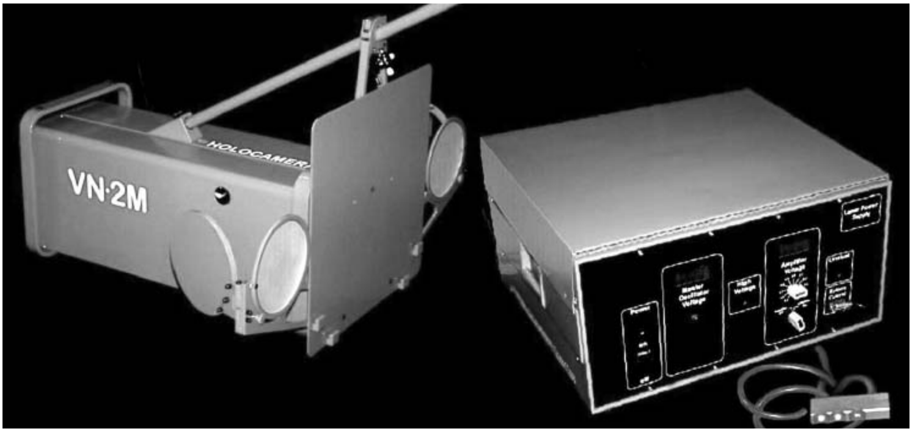
Other Applications of Laser Techniques

Analysis and Diagnostics – A Review

Structural and physico-chemical analysis can be carried out on works of art by a number of laser techniques. Structural analysis generally means detection/monitoring of the shape in terms of geometrical parameters with the aim of identifying structural changes due to ageing, to adverse environmental conditions, to non ideal conservation procedures. Shape deformations evolving on a relatively short time scale can be monitored by comparative methods in which the work of art in its present state is compared to a three-dimensional (3D) record registered at an earlier time. The laser techniques used in this approach are based on the coherence of the laser light which gives rise to optical interference and related phenomena (*e.g.* holography). The laser is necessary both for obtaining the 3D record and for its comparison with the work of art that is performed later. Structural defects at early stage of their evolution can be also di-



Equipment needed for single-shot holograms of extended objects

agnosed by laser techniques. In this case the work-of-art response to a physical (mainly mechanical) stimulus, which is deliberately applied, is measured by a laser technique. The stimulus sets the object into vibration and the response to be characterised is the local distribution (map) of nodes and of regions maximum oscillations. To detect these maps one can exploit the fact that laser light is monochromatic and measure the Doppler-shift of the frequency of the laser light that illuminates the vibrating surface of the object (*i.e.* laser-Doppler vibrometry). Alternatively the space-coherence of the laser light is exploited: the illumination of the object with coherent light gives rise to a characteristic speckle pattern which "moves" due to the vibration with statistical laws that are linked to the modes of vibration (*i.e.* laser-speckle interferometry).

Physico-chemical analytical methods employing lasers are used for characterising the materials with a variety of aims: they are applied either prior to or after restoration, even on-line during laser cleaning, for historical analysis, for monitoring the state of conservation. Here we only discuss the basic principles of the methods. Most of them are derived from laser spectroscopy techniques, such as laser-induced fluorescence (LIF) spectroscopy and Raman spectroscopy, that are widely used in physical chemistry of organic molecules. In fact, both LIF and Raman spectroscopies are analytical tools of investigation because the fluorescence and Raman spectra are somehow fingerprints of molecular compounds. The laser is simply used as an excitation source of high intensity, which allows achieving high sensitivity. In the application to art conservation a short-pulse laser is often used so that a high intensity is delivered to the sample but the fluence (energy per unit area) remains low and the LIF/Raman is actually a no-touch non damaging analysis. In other cases (*i.e.* LIBS: laser-induced breakdown spectroscopy) a high-fluence pulse is applied and the fluorescence/Raman spectrum is measured on a micro-quantity of material which is ablated / evaporated by the laser itself from the sample at the focal spot. Recently LIF spectroscopy techniques have been demonstrated in which the fluorescence decay-time rather than the fluorescence spectrum is measured, an approach that should add selectivity to the LIF analysis of materials for work-of-art conservation.

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Annex

Table 1

Principles of conservation and restoration in combination with laser cleaning

Conservation report regarding to laser cleaning

aspects of preservation of monuments (e.g. worth of age)

natural science report regarding to laser cleaning

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Target of the laser cleaning

↓

Specimen of cleaning

↓

Conservation criticism regarding to laser cleaning

Criticism from the point of preservation of monuments (e.g. aesthetical value)

Natural science criticism regarding to laser cleaning

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Comparison between result and the target

↓

Forecast / Decision

↓

Laser cleaning done by conservator-restorer

Controlling by experts from official agencies of preservation of monuments

Controlling by natural scientists

↓ ↓ ↓

Concept for maintenance

Table 2

Example: Comparison of different methods of cleaning at the Romanesque West portal of St. Stephen s Cathedral in Vienna:

Tool or material	Location	Result	Time in minutes / dm^2
Abrasive, gums, wish-up and fine brushes	Ornamented vault ornaments inside	Pre cleaning	30
Vacuum cleaner	Columns, ornamented vault, flat surface inside	Pre cleaning (only by salty areas)	45
Precise whirlblasting (low pressure with dolomite powder)	Flat surface outside	Pre cleaning	10
Microsandblasting with different powders	Flat surface inside cornices	Pre cleaning	15
	flat surface outside	Final cleaning	20
Laser cleaning high energy	**Sculptures and ornaments outside, flat surface inside**	**final cleaning**	**20**
Laser cleaning low energy	**Ornamented vault, columns, sculptures, tympana (all details inside)**	**final cleaning**	**15**
Compresses with ammoniumcarbonate	Figurative consoles outside	Additional cleaning	20