Project no. COOP-CT-2005-017861

InART

Innovative Laser Based System and Technologies
for In-Situ Cleaning of Painting Artworks

Instrument: Cooperative Research

Thematic Priority: Horizontal Research Activities involving SMEs

Final Activity Report

- Publishable -

Period: from 01 February 2007 to 30 November 2008

Start date of project: 01.02.2006 Duration: 34 months

Project coordinator names: Dr. Helena Gouveia and Dr. Paulo Morais

Project coordinator organisation name: ISQ Final version

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Publishable final activity report

1.1 Project execution

The main objective of InART is the development of specific technologies for controlled material removal from the surface of painted artworks of interest for Cultural Heritage Conservation and Restoration. The prototype developed in the project integrates a laser source that transmits its radiation to the artwork surface through a mechanical device controlled by the end-user. The prototype also comprises diagnosis and monitoring tools for the control of the cleaning operation. Such device is necessary due to the very sensitive nature of pigments, binding media and varnishes, which require a precise and controllable cleaning tool. In parallel, cleaning methodologies for the most relevant problems encountered in painted artworks have been studied and integrated in a specific database.

The project involves a consortium of 11 organisations: 4 RTD performers, 5 SMEs and 2 participants entering in the project as Other enterprises or End-users. The following table lists the full participants of the project:

Participant short name	Participant full name	Country	Type
ISQ	Instituto de Soldadura e Qualidade	Portugal	RTD (Coordinator)
SIGNINUM	Signinum - Gestão de Património Cultural, Ltd	Portugal	SME
DANART	Danart, Ltd	Romania	SME
BRESCIANI	Bresciani materiali ed attrezzature per restauri S.r.l.	Italy	SME
NICOLA	Nicola Restauri S.r.l	Italy	SME
IVAM	Instituto Valenciano de Arte Moderno	Spain	Other enterprise or End-user
EMR	Estudio Métodos de la Restauración, S.L.	Spain	SME
QUANTA	Quanta System S.p.A.	Italy	Other enterprise or End-user
INFLPR	National Institute for Laser, Plasma and Radiation Physics	Romania	RTD
RTM	Istituto per le Ricerche di Tecnologia Meccanica e per l'Automazione S.p.A.	Italy	RTD
AIDO	Asociación Industrial de Óptica, Color e Imagen	Spain	RTD

The project coordinator is ISQ in the persons of Dr. Helena Gouveia and Dr. Paulo Morais. The contacts are:

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Degradation of paintings both in the interior as in the exterior of buildings such as monuments and churches is mainly caused by non-controlled microclimate conditions, leading to degradation of both the

original materials as those applied over the time, for example in restoration. The degradation of the applied materials can also lead to further degradation of the original ones.
Mural paintings and easel paintings have polychrome surfaces and many of them an extremely complex structure with several composed layers. The most superficial painting layer is also multi-composed by several pigments and binding media, which can have organic or inorganic composition. Cleaning such complex surfaces is a very delicate task because of the often bad conservation conditions. Therefore it is necessary to find cleaning methods with selective and controllable characteristics.

Conventional cleaning methods like chemical agents (solvents or aqueous solutions) or mechanical tools (scalpels…), are in many cases not sufficiently efficacious or may involve a lot of risks for the safety of artwork and/or restorers. For example, liquid solvents can penetrate the painting layers and cause immediate or long term harmful chemical reactions. Mechanical tools often can not discriminate between the different layers and are not sufficiently controllable and selective. Furthermore, mechanical cleaning methods are also time consuming.

In the following conservation problems, which were put forward by the small and medium enterprises which are part in the project and also end users (conservators and restorers), conventional techniques are inadequate to satisfactorily treat easel and mural painting artworks and an alternative or complementary treatment or tool is requested by the professionals of the field:

- Insoluble resins (highly oxidised varnishes, burnt varnishes, synthetic resins);
- Oil-based overpaints;
- Deposits (dirt, soot, tar, grease…).

All over Europe, conservators encounter similar problems as the ones described above, which can only be solved combining and improving the skills and scientific knowledge in a transnational and multidisciplinary project. The proposed solution is based on laser technology. A laser-based tool appears as an alternative solution to selectively remove the unwanted over-paintings or other encrustations, without affecting the paint layers.

The relatively recent development of the laser technology and laser based techniques has led to the progress of less intrusive and more controllable conservation methods. Particularly, lasers have already proved to be a suitable ‘non-contact’ and localised action tool for the cleaning of paintings, capable of removing thin layers of undesirable material and leaving the underlying layers intact, with minimal thermal effects.

An innovative strategy for the cleaning of *in-situ* artworks is envisaged by developing a new laser based system able to be displaced and integrated in the conservation/restoration operations of artworks *in-situ*. This will provide conservators/restorers with an alternative tool to complement the conventional cleaning methods.

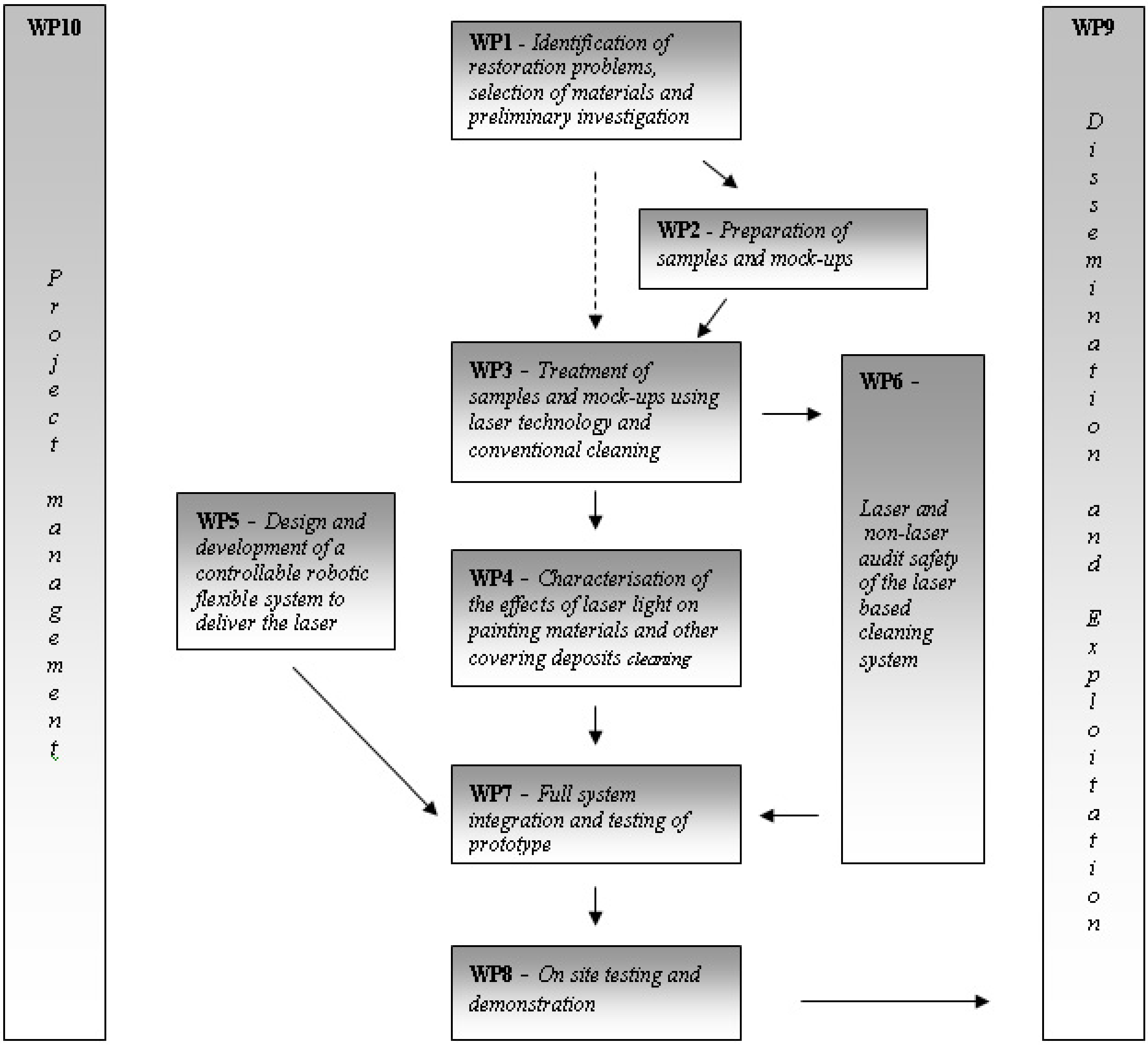
InART contributes towards preserving and enhancing the environment. By developing a clean technology, it will allow reduction of environment impacts through the non-use of hazard chemicals, traditionally used in the conservation field, and thus contributing to better working conditions and better environment. Additionally, safety at work will be improved by reducing the amount of work associated with toxic and corrosive solvents. Eliminating or minimising the emission of dangerous chemicals will also protect the health of the citizens, improving the quality of life.

This project has potential for the improvement of the employment, either in terms of professional skills and qualifications as in terms of job continuity and potential increase in employment. The European social and economic cohesion will also benefit from this project, because the project bring together partners from different parts of Europe, in the attempt to create a unified approach to solve a problem that is very important to the whole of Europe. The expected impact on employment will result from the introducing of new and innovative technologies, such as the ones envisaged in this project, which demand a higher qualification of the personnel involved in restoration, opening new opportunities for education and training and more prepared and skilled personnel for a competitive market.

Benefits to the general economy are also expected on the long term coming from the increase in the tourism industry. From this point of view, developing a product that helps to conserve and restore artworks can make cultural heritage in a very profitable sector, since more cultural attractions will be available and accessible to the general public. In addition, the quality of life may be improved by returning the society, cultural objects to be viewed and enjoyed. These social, environmental and cultural benefits will balance the possible higher cost of the new technologies compared to the traditional methods.

In order to validate the cleaning of painting artworks (easel and mural paintings) with laser radiation, research on the interaction of the laser with the artworks is imperative for the acceptance of the technique in the restoration community. Knowledge about the immediate and long-term effects of laser radiation on the constituents of artist's materials is essential in the evaluation of the cleaning method. In order to promote its acceptance, it is important to develop a set of well-defined and quantifiable criteria for its evaluation together with the end-users: conservators and restorers. Conservators will pose the question in which cases laser cleaning takes preference over conventional cleaning techniques.

The work in the project has been divided in a set of workpackages whose designations and relationships are given in the schematic below:



Therefore, the following research objectives were the centre focus of the research program in InART project:

- Definition of the boundary conditions in which laser cleaning at different wavelengths (from the ultraviolet to the infrared, using Excimer, Nd:YAG and Er:YAG lasers) can be safely applied to a wide range of easel and mural painting materials and characteristic deposits;

- Developing of a new laser based system, mobile and flexible to be used *in-situ*, supported by diagnosis and control tools (Laser Induced Breakdown Spectroscopy technique for monitoring in real time the cleaning operation, multispectral device for monitoring and artwork characterisation and colorimetry system for detection of chromatic changes upon laser cleaning), but also allowing human intervention through remote control of the cleaning system.

The main results achieved during the whole duration of the project involved several steps:

- Identification of specific conservation problems found in canvas and mural artworks by conservators and restorers and selection of materials and art objects available for studies, as well as a preliminary investigation of these objects and definition of a detailed case-specific work plan;

Taking into account the representativeness and geographic location, the main studied materials were:

- Pigments (blue smalt, red ochre, cinnabar, raw sienna, green earth, lead minium, malachite, azurite, lead white, yellow ochre, ultramarine blue, cobalt green, chrome yellow, cinnabar, extra zinc white, Mueller's Green medium and light, titanium white, emerald green, red cadmium, venetian red, natural sienna);
- Varnishes (mastic, dammar, shellac);
- Deposits (incrustation, soot, bee's wax, lime-wash, oil-based, tempera-based and casein-based overpaitings, candle smoke, grease, acrylic spray paint, mineral oil, engine oil, concrete);
- Other materials, such as gold and brass purpurins, were also selected;
- The main binding media used for canvas paintings was egg tempera and linseed oil.

▪ Preparation and artificial ageing of samples and mock-ups according to the test system design made in the previous item;

  Samples have been prepared in order to simulate as best as possible real conservation problems of mural and easel paintings. Samples and mock-ups were aged with artificial ageing facilities using daylight fluorescent tubes and UV light.

▪ The laser cleaning of a set of aged samples constituted of different materials using different conditions with various laser types and wavelengths, namely Excimer (248 nm), Nd:YAG (1064, 532, 355 and 266 nm) and Er:YAG (2.94 µm) lasers. Evaluation of samples and mock-ups laser and traditional cleaned;

  The boundary conditions in which laser cleaning at these different wavelengths can be safely applied was determined whenever possible (safe, ablation and discoloration thresholds). For each studied material a conclusion was reached on the best laser type, wavelength and experimental conditions (such as pulse energy and repetition rate). The suitable laser parameters for efficient removal of unwanted layers were determined and both successful and non-successful results were documented.

▪ The analytical characterisation of the produced results of laser cleaning using a set of analytical methods;

  Several techniques (FITR and Raman spectroscopies, X-ray photoelectron spectroscopy, Laser induced breakdown spectroscopy, Atomic force microscopy, colorimetry, X-ray diffraction, among others) were employed on non-irradiated and irradiated samples and a comparison study of the results was made.

▪ Definition of cleaning strategies taking into account the results of the analyses of the treated samples and mock-ups (chemical and physical changes), as well as the visual evaluation made by the conservators;

  The definition of cleaning strategies took into account the following items:

  - Material characteristics;
  - Laser radiation wavelength;
  - Laser pulse length;
  - Laser radiation fluence, intensity, frequency and pulse number on the same spot;
  - Transversal distribution of the energy in the incident spot;
  - Irradiation geometry;
  - Identification of diagnostic methods to control and monitor the laser effect on the irradiated area;
  - Laser and non laser safety knowledge.

- Integration of the obtained results in a database system specific developed for the project;

  Two different databases were created for the compilation of laboratorial and on-field test results:

  - A database that is integrated in the prototype control system, which includes the obtained results achieved when using the cleaning prototype (process data), as well the materials and work references databases;
  - A database more dedicated to laboratory tests, which could be used and easily exchanged among the partners during the project and is not integrated in the cleaning prototype software. This database is highly flexible and configurable, with each tested parameter being able to be individually treated. Different types of sorting, queries and reports can be executed with the database. The exporting function allowed the users to compile the test results, and link them to the cleaning prototype database.

- The laser based cleaning prototype development, with hardware and software integration, including the main different parts: laser source, robotic cell, optical delivery system, laser scanning head (with focusing system), monitoring and control tools (multispectral cameras capable of analysing from the UV to the IR producing various imaging modes and colorimetry analysis, and Laser Induced Breakdown Spectroscopy system for the control of the laser cleaning operation), main control system (integrating the database of the project research results) and user interface.

  The cell is composed by three major components:

  - The robot system, comprising the robotic manipulator, the optical laser delivery system and the scanning-head;
  - The laser power source;
  - The control cabinet, with the user interface.

  The robotic system is the largest component inside the cleaning cell. The system positions and delivers the laser beam from the laser source to the artwork as well it allows the positioning of all sub-systems present in the scanning head through its manipulator. A 3 linear axis Cartesian robot was specified and built during the project in order to cope with the project specifications.

  The laser has the capability to delivery three different wavelengths - 355 nm (UV), 532 nm (visible) and 1064 nm (IR) - which demanded an accurate optical delivery system in order to obtain a high homogeneity of the laser beam spots with each one of the 3 wavelengths. The implemented solution for the optical delivery system is based on a set of broadband mirrors (BBDS) able to work with the 3 wavelengths without significant decrease of performance.

  The scanning head mounted on the robot has all the devices needed to perform the cleaning, the monitoring and the controlling of the system operations. It is formed by a set of tools, namely the laser focusing system, the control tool (LIBS), the distance sensor and the multispectral and colorimetry cameras. The scanning head position is controlled by the end-user through the control system using a friendly interface. This solution, based on a set of cameras, allows the cell to perform real-time monitoring of the laser cleaning process, colorimetry measurements and capture of video and images of the artwork in different imaging modes (in the UV, visible and IR). The imaging system is composed by three cameras and their respective illumination lights: a stand-alone colour camera for live monitoring of the laser cleaning and the work area scanning, a stand-alone UV camera for the UV spectral range (300 to 420 nm) and a monochrome multispectral high-resolution CCD camera (400 to 1000 nm). This later sub-system acquires the spectral data from the visible to the near-infrared spectrum allowing colorimetric measurements to be obtained. To complete the system a dual white line lights is used to illuminate the artwork.

The overall control system allows the user to control all the devices in an integrated manner, providing a flexible away to laser clean the artworks and to control, monitor and document the cleaning process.

The final prototype is a movable laser based system for the accurate in-situ cleaning of easel and mural painting artworks and on-line control of their quality with the following main functionalities:

- Working area of ~ $1m^2$ (the displacement of the cleaning system allows higher areas to be treated);
- Laser source with 3 interchangeable wavelengths: 355, 532 and 1064 nm (up to ~ 1.1 J in the IR region, pulse length of 6 ns and repetition rates up to 10 Hz);
- Spot size on the artwork surface depending on the lens/mask combination (default configuration with ~ 3 mm x 3 mm);
- Scanning device with accurate radiation delivery of 0.1 mm;
- Live video for monitoring the cleaning process;
- Multispectral tools for imaging capture in the range of 300 nm to 1000 nm, with different imaging modes (UV reflection, visible reflection, UV fluorescence, false colours infrared, user-selectable wavelength imaging capture) and colorimetric analyses;
- Chemical identification and process control with LIBS (Laser induced breakdown spectroscopy) from 200 to 980 nm.

The laser based cleaning system integrates the control software, which allows the user to control all the available tools through a computer, having the following abilities:

- Definition and parameterisation of the area or areas to be cleaned or analysed;
- Control of the laser cleaning process allowing the configuration of the different laser parameters: wavelength, energy, repetition rate, number of pulses, etc.;
- Definition and parameterisation of the various available operations: live video, multispectral analysis, colorimetry and LIBS;
- Moving of the scanning system (manual joystick, jogging, etc);
- Online controlling and monitoring of the different processing operations;
- Registering of the work history and possibility to document the different procedures;
- Accessing of relevant information during offline process;
- Providing a set of databases with materials information, laser experiments and analytical results obtained during the project. New and updated information can be inserted and managed in the database system.

The software presents an intuitive and friendly graphical user interface developed using a flexible and modular architecture that allows the introduction of other tools in the future.

This cleaning system will provide conservators/restorers with an alternative tool to complement the conventional methods. The developed device is capable of cleaning artworks that previously were unsatisfactorily treated by conventional techniques, avoiding at the same time the inherent problems related to the use of harmful chemical products. The laser-based system will provide SME end-user companies in Europe with an efficient and reliable advanced restoration tool that can be also integrated and combined with traditional methods. This new technology would increase their global competitiveness due to the new possibility of restore artworks that were not possible to treat before.

It is expected that the new tool will improve the innovation for the small and medium enterprises with the increase of their market where conservation and restoration is at the core of their activities by improving the quality of the final restoration work. This make SMEs more sustainable and, therefore, more productive, increasing their competitiveness due to their advantage over other SMEs.

SME participants intend to fully exploit project results according to their own interests. The SMEs have established an initial exploitation agreement defining the rights for using and marketing InART results. The RTD main interests are focused on the further development of the technology and improvements of their own consultancy services.

A set of photographs of the final system can be seen in the next figures.

Figure 1 – InART final system

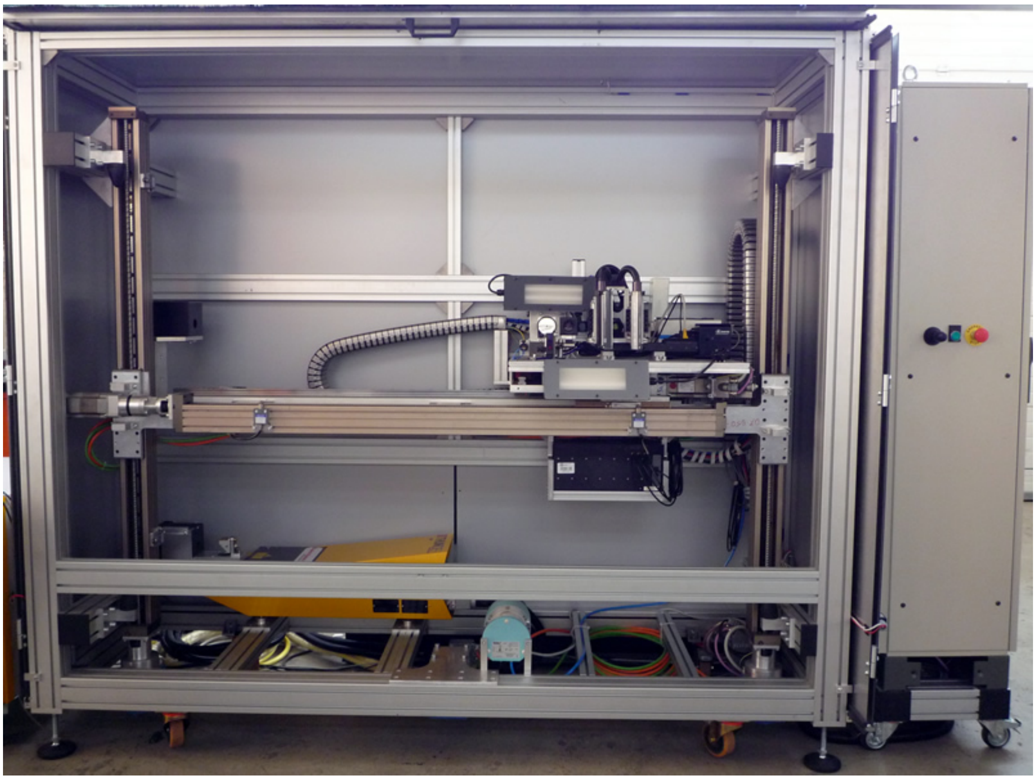


Figure 2 – Front view of the InART main cell

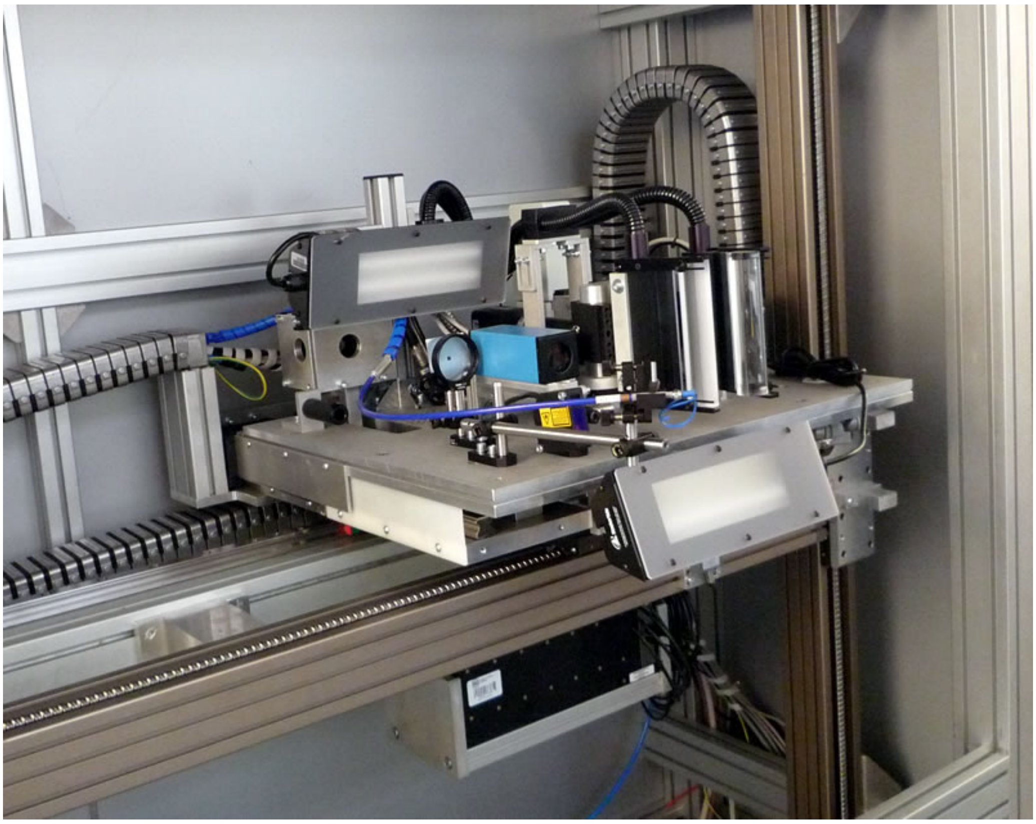


Figure 3 – Scanning device with operation tools

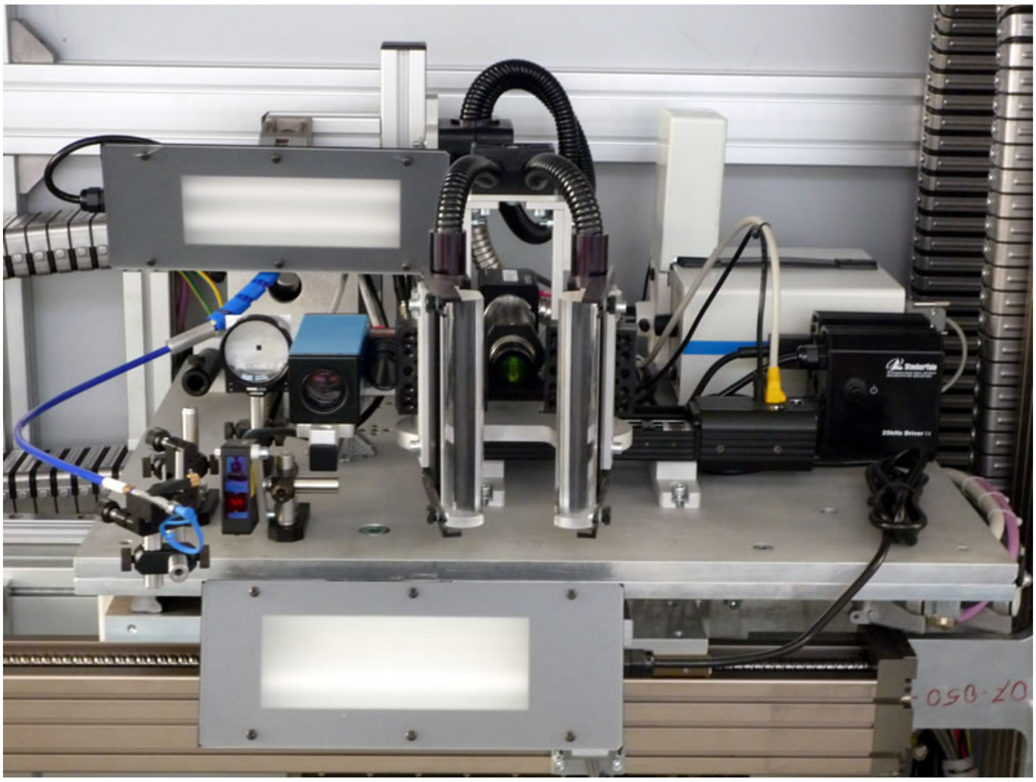


Figure 4 – Front view of the scanning device

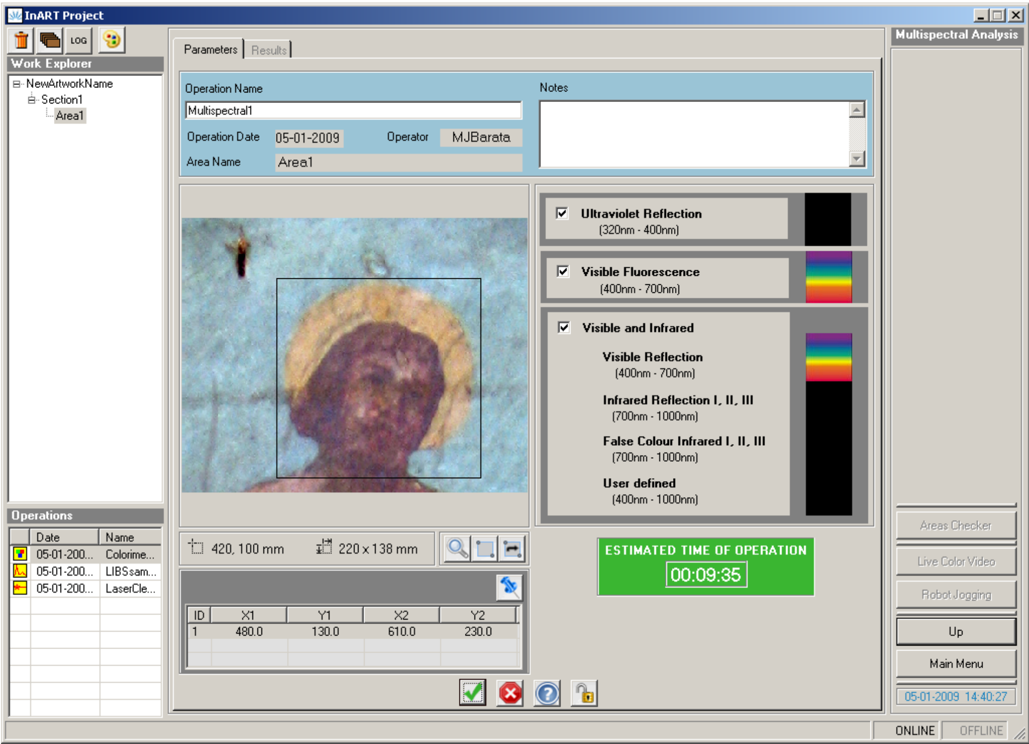


Figure 5 – Screenshot of InART software

A project logo was created to give an image and help the dissemination of the project.

The INART website (http://www.inart-project.net) was created and implemented in the project first semester and contain essentially two areas: a public one containing generic and non-confidential information about the project and a private one where all the documents produced, whereas in the meetings, deliverables, etc., are ready available as well as all the project formal documents including EC guidelines. The website also works as a communication interface, either internally (among partners) as externally (with public in general).

1.2 Dissemination and use

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- Accessing of relevant information during offline process;
- Providing a set of databases with materials information, laser experiments and analytical results obtained during the project. New and updated information can be inserted and managed in the database system.

The website of the project is at www.inart-project.net

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