SYDDARTA: new methodology for digitization of deterioration estimation in paintings

Luís Granero-Montagud[a], Cristina Portalés[b], Begoña Pastor-Carbonell[a], Emilio Ribes-Gómez[a], Antonio Gutiérrez-Lucas[a], Vivi Tornari[c], Vassilis Papadakis[c], Roger M. Groves[d], Beril Sirmacek[d], Alessandra Bonazza[e], Izabela Ozga[e], Jan Vermeiren[f], Koen van der Zanden[f], Matthias Föster [g], Petra Aswendt[g], Albert Borreman[h], Jon D. Ward [i], António Cardoso [j], Luís Aguiar [j], Filipa Alves [j], Polonca Rópret[k], José María Luzón-Nogué[l], Christian Dietz [l]

[a]AIDO, Optics, Color and Image Institute of Valencia, C/ Nicolás Copérnico, 7 - 11, 46980 Paterna, Spain; [b]IRTIC (Instituto de Robótica y Tecnologías de la Información y las Comunicaciones), Universidad de Valencia, C/ Catedrático José Beltrán 2, 46980, Paterna, Spain, [c]FORTH, Foundation for Research and Technology Hellas, P.O. Box 1527, GR-711 10 Heraklion, Greece; [d]Optical Non-Destructive Testing Laboratory, Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands; [e]CNR-ISAC, Consiglio Nazionale delle Ricerche, Via Gobetti 101, 40129 Bologna, Italy; [f]XENICS NV, Ambachtenlaan 44, BE-3001 Leuven, Belgium; [g]VIALUX GmbH, Am Erlenwald 10, 09128 Chemnitz, Germany; [h]AVANTES BV, Oude Apeldoornseweg 28, 7333 NS Apeldoorn, The Nederlands; [i]Gooch & Housego Ltd, Dowlish Ford, Ilminster, Somerset, TA19 0PF, United Kingdom; [j]SIGNINUM - Gestão de Património Cultural Rua Sete, n. 85, Paredes, 4845-024 Rio Caldo, Portugal; [k]IPCHS, Institute for the Protection of Cultural Heritage of Slovenia Metelkova 6, 1000 Ljubljana, Slovenia; [l]RABASF, Real Academia de Bellas Artes de San Fernando Alcalá , 13, 28014 Madrid, Spain

ABSTRACT

The SYDDARTA project is an on-going European Commission funded initiative under the 7th Framework Programme. Its main objective is the development of a pre-industrial prototype for diagnosing the deterioration of movable art assets. The device combines two different optical techniques for the acquisition of data. On one hand, hyperspectral imaging is implemented by means of electronically tunable filters. On the other, 3D scanning, using structured light projection and capturing is developed. These techniques are integrated in a single piece of equipment, allowing the recording of two optical information streams. Together with multi-sensor data merging and information processing, estimates of artwork deterioration and degradation can be made. In particular, the resulting system will implement two optical channels (3D scanning and short wave infrared (SWIR) hyperspectral imaging) featuring a structured light projector and electronically tunable spectral separators. The system will work in the VIS-NIR range (400-1000nm), and SWIR range (900-2500nm). It will be also portable and user-friendly. Among all possible art work under consideration, Baroque paintings on canvas and wooden panels were selected as the project case studies.

Keywords: 3D digitization, pattern projection, hyper-spectral imaging.

1. INTRODUCTION AND OBJECTIVES

SYDDARTA project is focused onto the development of a portable system prototype for monitoring artwork deterioration and for pigment identification in art, in particular, in canvas and paintings from the European Baroque period. To achieve this goal, the prototype will be based on 3D digitization and hyperspectral imaging techniques where both of them are taken simultaneously. These optical techniques are non-invasive and non-destructive.

The merging of these two techniques, 3D digitization and hyper-spectral imaging, will permit faster in-situ analysis of artworks, generating digital results, that will allow information transfer between investigation teams and organizations and will enhance the conservation processes of these art pieces. The system will also be available as an additional tool for other applications, such as authentication and hidden layers detection, thanks to the SWIR radiation depth penetration. Moreover, the equipment will make use of a specific database of materials and pigments which could be exploited independently. Additional analytical techniques, such as FTIR [1] and Raman spectroscopy [2,3] are used to collect this reference data during the project phase.

The main target of SYDDARTA project is to develop a pre-industrial prototype for diagnosing the deterioration of movable assets by the acquisition of 3D-hyperspectral imaging through non-invasive scanning. Such images contain spectroscopic information of the object to be analysed in different bands of the spectrum, giving chemical composition, and the formation of different materials and layers in the actual 3D surface by means of a very narrow screening bandwidth and the use of volumetric digitization.

2. PROJECT METHODOLOGY

2.1 Project Members

The consortium is formed by members of 9 European countries. The list of companies and centres which participate in the SYDDARTA project is shown in Table 1:

Table 1. Consortium members. (*) For more detailed information see the paper's author list.

Partner (*)	**Partner type**	**Country**
AIDO	Coordinator: Research Centre	Spain
FORTH	Research Centre	Greece
TUD	Research Centre, University	The Netherlands
CNR-ISAC	Research Centre	Italy
XENICS	SME	Belgium
VIALUX	SME	Germany
AVANTES	SME	The Netherlands
G&H	Multinational corporation	United Kingdom
SIGNINUM	SME	Portugal
IPCHS	End User, Restoration Institute	Slovenia
RABASF	End User, Museum	Spain

The Research Centres are the members responsible for technology merging, prototype development and assembling, and preliminary task testing. These preliminary tests will offer a first validation result for the technical performance of the prototype. The Private Companies are responsible for providing the dedicated system main components and equipment for the construction of the prototype, according to design requirements and specification. The art-related research centres, end users and companies are responsible for setting the initial desirable system requirements, preliminary artwork experimentation and prototype validation, by performing a complete set of tests with real pieces. taken from the collections under their custody. They will also perform comparative and functionality analysis of the system.

2.2 Techniques

Nowadays, the art sector incorporates commonly used 3D digitization [4-10] and spectral imaging [11-17] techniques. The use of devices based on such technologies is constantly increasing and currently constitutes a strong approach to applications such conservation and restoration. In this way, SYDDARTA is conceived as a tool which aims to merge, in a unique system, two different applications, one of them being the 3D digitization and geometrical analysis, and the other the hyper-spectral imaging and non-invasive chemical analysis.

The project target is to develop a system which delivers a point cloud containing all the geometrical information of the piece analyzed which, in addition, containing additional point-wise information about the spectral signatures, which provide chemical information of the different compounds present in the piece. Every time the system generates a 3D model of an object, this model will contain morphological information about the original object, spectral data on the different materials composition, the different pigments used, under-layers hidden after restoration/modification tasks, etc.

Considering all the above, hyper-digitizations of paintings are generated, containing information on the morphology of the analyzed work and of its spectral content, with the possibility to relate changes in these spectral signatures with the physical and chemical deterioration of the work. Regarding pigment identification, there will be a spectral database of the Baroque period pigments (this could later be expanded to other periods), which will be used as a reference for classification purposes. Although the objective of the SYDDARTA project is to assess deterioration, pigment identification and classification is seen as a needed step, as different pigments may behave and degrade in different ways.

In the SYDDARTA project, the consideration of a 3D channel working in the visible range will be useful to perform degradation and deterioration analysis that are related to color changes or surface alterations in the upper layer. The study for assessing degradation will be based on prepared samples that will be artificially deteriorated. Data will be recorded before and after deterioration with a so-called middle demonstrator – a collection of devices and pieces of equipment which generate data similar to that the SYDDARTA prototype will generate –, and comparison and classification methods following a similar implementation as in [11], will be carried out in order to describe how deterioration affect each of the studied pigments. For instance, pollution may cause a general darkening on the artwork, whereas the effect of UV may cause color change of some pigments, for instance, yellows may acquire a whiter tone.

Concerning the spectrometric analytical methods and classification strategies, a hypercube will be generated. From this hypercube, pigment spectra will be generated for each of the hyper-pixels. Such acquired pigment spectra will be compared to those pigments at the database, and pigment identification will be carried by means of nonlinear modeling techniques, such as neural networks and support vector machines. It will be investigated which of the available bands are most reliable for this purpose. This will be done over the whole range of interest (400-2500nm).

Regarding the deterioration and degradation identification methods based on spectroscopy, most studies regarding to artwork deterioration are based on FTIR and Raman spectroscopy, which usually cover the range starting from around 2500 nm. There are also some studies in the visible range due to the fact that deterioration is mainly observed in the upper layers of the paintings, and it also causes color changes. Furthermore, they do not cover the problem of pigment identification and do not offer a study on the artwork deterioration.

With the development of SYDDARTA both the spectroscopic and 3D-scanning methodologies will be fused into one procedure and one single piece of equipment. Thus, the analysis of artwork and cataloging of the artworks, as well as previous analyzes processes of restoration and conservation will be carried out much faster,

2.3 Tasks

The project commenced on the October 1st, 2011, and has a total duration of 30 months. The methodology revolves around seven work packages (WPs) from which WP1 and WP7 are management and dissemination activities. The scientific and technical work is distributed in the remaining WPs which are grouped in two major areas: art and technological development and are described below.

WP2 takes care of the art heritage materials analysis and deterioration study. The objectives are to investigate and highlight physic-chemical deterioration processes in cultural movable assets due to the impact of environmental changes (temperature, relative humidity, light, pollutants) and to identify spectral signatures of selected materials and pigments belonging to movable cultural heritage objects. Moreover it studies the pigment degradation as a function of climatic parameters (temperature, relative humidity, light).

WP3 is dedicated to the integration of the different hardware and software components and the design and construction of the prototype. The specific objectives are to identify system requirements and functionalities and the system design, to ensure requirements completion from the different work areas and guarantee cross-functionality amongst modules. Finally it monitors technical progress in other technological working packages in order to manage system integration and produces the prototype of the 3D hyper spectral system.

WP4 is in charge of the hardware development and modules construction. The objectives are the development of a hyperspectral illumination unit based on light pattern projection and a capturing module, the integration of the system components for system optical triangulation and the development of the system mechanical support structures and encapsulation.

WP5 is dedicated to all tasks related to the software implementation, including hardware components control, system calibration, data gathering, processing and display results. The specific objectives are the development of the system control application, the development of the hyperspectral data processing algorithms, and 3D data generation algorithms. In addition, the equipment will make use a specific database of materials and pigments monitoring that will be exploited as well to develop spectral correlation algorithms for chemical characterization and to develop algorithms for art asset data fusion. With the developed software, users of the system will be able to see the 3D painting surface with automatically detected degradation (such as non-flat surface, holes, cracks, aging or removed varnish) labeled on different layers.

W6 supervises the tests and the performance evaluation. The objectives are to test and evaluate the prototype in real environments and to interpret 3D and spectral processed data for environmental deterioration estimation and assessment. Besides it has to gather and present comparative studies and evaluation results to the consortium and to give feedback after testing redesigns to other work packages. Finally it will establish a standardized procedure for chemical feature extraction in art heritage.

3. SYSTEM DEVELOPMENT

3.1 Prototype scheme

The basic working sketch of the proposed system inside the SYDDARTA project has two main parts: one of them is the 3D channel for volume information capturing – together with spectral information registration in the visible range -, and the other is the Shortwave infrared Hyperspectral Imaging channel (SHI-channel) channel for spectral information capture.

The 3D channel will be responsible for the acquisition of the 3D surface information and as also for the hyperspectral imaging data in the visible region. For that purpose, a digital light projector (DLP) with a LED light source will project a special pattern of fringes of variable width and phase onto the piece. This pattern will be deformed over the surface of the piece, and this deformation will be captured by the digital 4MP monochrome CMOS camera, which will register them. After fringe image processing, a high resolution point cloud is be obtained, representing the object surface variability.

The SHI-channel will be used for hyperspectral imaging in the infrared range of 0.9µm-2.5µm. To that purpose, there will be a light source which will emit radiation covering the entire spectral to be analyzed. An acousto-optic tunable filter (AOTF) will be employed to isolate the spectral responses of the object in the range of study. As a capture device a camera MCT based sensor (HgCdTe) will be implemented.

In order to increase the spectral resolution of the final system, a Liquid Crystal Tunable Filter (LCTF) with 20nm bandwidth will be integrated, therefore obtaining a large amount of spectral information of the artwork.

In the implementation chart shown in Figure 1, we can see the different agents and steps involved in the project. In green are exposed the modules that have been completed.

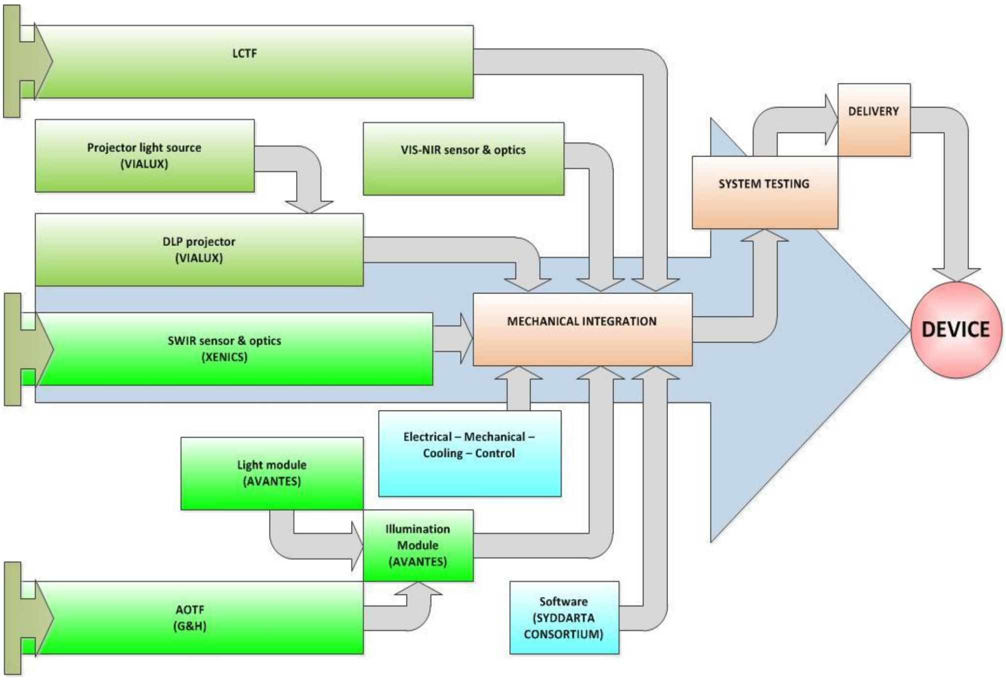

Figure 1. Implementation chart for the SYDDARTA resulting prototype.

3.2 System functionalities

The system will be able to acquire data and store them in a specific format based on a software platform. After that, data analysis will be performed and through a database the system will be able to characterize materials and their deterioration. The system will be able to assist the user to easily acquire the 3D information and spectral images from the sample. The user will be able to visualize the 3D surface information from the sample and also to compare this with the spectral information in the visible and infrared region.

The analysis of the 3D surface information will provide user with information related to the inhomogenity of the surface structure of an artwork indicating areas where deterioration might exist. Furthermore, spectral information in the visible range will provide information related to the possible chemical composition deterioration, and spectral information in the infrared will enable imaging of the deeper structures of the sample like underdrawings and deterioration of other paint materials.

The spectral data from both the visible and infrared wavelengths will be compared in a database and with the use of PCA techniques mapping of specific pigments and deterioration areas will be mapped.

4. RESULTS

The first year of SYDDARTA project has been mainly focused in the acquisition of sample data and in the design of the software and hardware modules. At the same time, several software implementations have been completed and initial design and construction of some of the prototype components has been done. Additionally, a middle demonstrator has been prepared to register sample data before and after degradation.

In WP2 the main tasks achieved are: (i) the preparation of sample data with pigments as used in the Baroque period, (ii) the acquisition of the spectral curves with FTIR and RAMAN spectroscopy, (iii) the replica of sample data to be kept in the deterioration chambers and the replica of sample data to be exposed in an open area for pollutants deposition. The research carried out has been concentrated on Baroque paintings composition, in order to select materials for setting up paintings models in support of the prototype tests planned in the project. After that, canvas and panels paintings have been prepared using the chosen materials. The models were subjected to carefully planned, artificial ageing conditions.

For the chemical damage characterisation only one type of support (canvas) was used, painted with all the selected pigments in combination with different binders, and three types of deterioration processes were simulated exposure to UV-VIS radiation, temperature and relative humidity cycling, and pollution exposition. A database has been created, which includes different analysed pigments (degraded and not degraded) of the Baroque period, with their corresponding spectral signatures in each bandwidth. All advances made with already known techniques (Raman and FTIR spectroscopy) have been taken into account, aiming at contributing to the correct development and validation of the prototype. A middle demonstrator for hyperspectral and 3D image capturing was used to acquire deteriorated and non-deteriorated sample data.

WP3 has identified all the prototype requirements (usability and functionality) and has carried out a previous study of the state of the art in the available technologies in IR sensors, filters, illuminations methods, software algorithms for 3D measurements and 3D deterioration and analytical techniques. The prototype design of SYDDARTA has been improved in order to extend its range from the 900-2500 nm to 400-2500 nm. This will allow the system to better identify deterioration, as some degradation effects are seen in the visible range. Because of this improvement, instead of one optical channel, the prototype is being constructed with the consideration of two channels: one for the visible light where the 3D artwork shape will be also acquired (the 3D channel), and other for the hyperspectral images in the short wave infrared (the SHI channel).The calculation of the light optical path and power transfer for both channels has been carried out. In the SHI channel the illumination module has been developed specifically for the project to make sure that the amount of light arriving to the MCT sensor was enough, since, in order to acquire the spectral image, is a limitation in the increment of the exposure time due to sensor restrictions.

In WP4 a detailed design of the prototype module has been agreed between the different partners. Additionally, different components have been selected and/or constructed, which includes: sensing devices, light sources, digital light projectors and electronically tunable filters based on the acousto-optic effect. The optical coupling and cooling of the different components has been completed and all the components are ready to be integrated together.

In WP5 all the hardware control and software modules for the components has been provided and the synchronisation is being done. The 3D data generation software has been implemented: algorithms for fusing 3D datasets containing spatially distributed hyperspectral imaging data with 3D shape information, data compression algorithms for storage and display, meshing techniques for data correlation and augmented reality display, data resampling to a common grid, algorithms for structural deterioration and pattern projection and 3D reconstruction. The algorithms for spectral processing and chemical information extraction have been implemented using the project pigment database which contains spectral signatures from deteriorated samples prepared in WP2 and acquired with the middle demonstrator. Finally the design and implementation of a graphical user interface to control hardware components and visualize 3D results has been laid out with the advice of all the partners.

The investigation of the degraded models by ultraviolet radiation (UVD), temperature and relative humidity cycling (THD), and pollution exposition), has been started by using SYDDARTA methods: single point spectroscopy, micro Raman and micro FTIR spectroscopy, as well as by the middle demonstrator. In Figure 2 some of the preliminary results obtained with the middle demonstrator are shown. These results revealed that at the inspected range (950-1650 nm) it is possible to identify deterioration due to ultra-violet exposure, but not due to the impact of temperature and humidity cycling. The elaboration of the results is still an ongoing process and further discussion will be presented at a later stage. These results will be improved when using the whole spectral range (450-2500nm) and the samples of pollution degradation information.

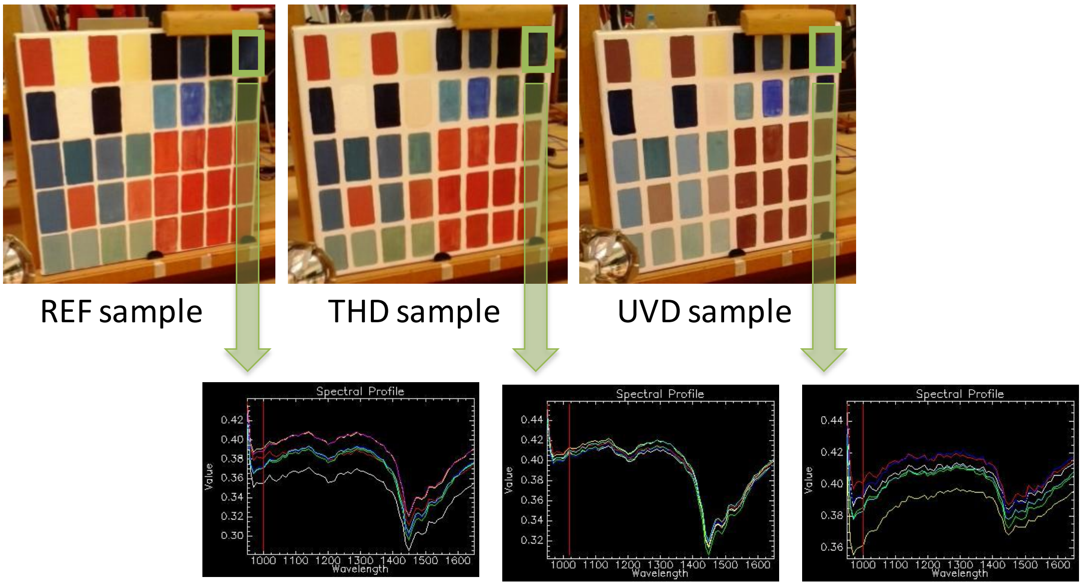

Figure 2. Hyperspectral Signature Classification Results. The sample data was acquired with the middle demonstrator.

An example result of the large scale shape deformation detection module of the developed software is shown in Figure 3. The red labels indicate the large non-flat surface regions, those regions are detected by estimating differences among calculated normal directions to the surface. Both the hyperspectral and shape analysis are described in more detail in [18].

Figure 3. A 3D display view with detected non-flat surface regions layer. The sample data was acquired in WP2.

WP6 is in charge of preparing all the test sessions during the project life. The identification of testing scenarios has been done and the different artworks to be used in the testing has been selected including polychrome on canvas and wooden panel with present signs of deterioration and degradation, so that the prototype can be properly tested. For these art pieces, the adopted inspection techniques – Raman and FTIR spectroscopy, single-point spectrometry – will be selectively applied and compared to the results given by the prototype. A procedure for technology comparison is being prepared, so that the prototype can be compared to other existing equipment and techniques, especially the ones adopted in the project as standard.

WP7 looks after the dissemination and exploitation of results. A Web page for the promotion of the SYDDARTA project has been created with the URL http://www.syddarta.eu/. In this page public information about the project can be found, including the project description and objectives, the consortium description, downloadable data (images, newsletter, leaflets, etc.).

5. CONCLUSIONS

The resulting outcome of the project is a new methodology implemented in a prototype capable of inspecting paintings in a non-invasive and auto automatic way, and being able to offer estimations on deterioration of painting. The system will be a portable equipment to use in the preventive conservation and monitoring of movable cultural assets and will provide rich data sets for deterioration quantification. Moreover, the equipment will use specific databases of materials, substances, compounds and pigments which will also be exploited. The merging of the technologies involved will be very useful for fast inspection of cultural assets and will optimize the conservation procedures of art assets in general, as well as facilitating art digitization and data sharing between the cultural organizations across Europe. The resulting prototype may also be used as a complementary tool in the process of asset authentication, although by no means it will substitute any of the established procedures. However, as the technology and system proposed is not specific for its application in the cultural heritage field, its use may be extended to other areas of research, like biomedicine, health, manufacturing, agro-food, recycling and more generally any activity which requires object surface characterization.

SYDDARTA will produce a prototype instrument that may be used by conservators, a comprehensive tool which will be user-friendly. It will showcase an integrated solution at a competitive cost, which is effective in terms of ease of use by non-specialist operators, and will be suitable for many applications, SYDDARTA will provide a solution to analysing the chemical and physical deterioration in a non-intrusive manner and the process of degradation by providing data on the spectral signature and profile of an object. This data may also be used for authentication purposes. Any changes to these parameters, for example after artwork cleaning or transport may thus be easily identified.

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