Standardizing NDT& E Techniques and Conservation Metadata for Cultural Artifacts

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Abstract. Conservation activities, before and after decay detection, are considered as a prerequisite for maintaining cultural artifacts in their initial/original form. Taking into account the strict regulations where sampling from art works of great historical value is restricted or in many cases prohibited, the application of Non-Destructive Testing techniques (NDTs) during the conservation or even decay detection is highly appreciated by conservators. Non-destructive examination include the employment of multiple analysis approaches and techniques namely Infrared Thermography (IRT), Ultrasonics (US), Ground Penetrating Radar (GPR), VIS–NIR Fiber Optics Diffuse Reflectance Spectroscopy (FORS), portable X-Ray Fluorescence (XRF), Environmental Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (ESEM-EDX), Attenuated Total Reflectance-Fourier Transform Infrared Spectroscopy (ATR-FTIR) and micro-Raman Spectroscopy. These produce a huge amount of data, in different formats, such as text, numerical sets and visual objects (i.e. images, thermograms, radargrams, spectral data, graphs, etc). Moreover, conservation documentation presents major drawbacks, as fragmentation and incomplete description of the related information is usually the case. Assigning conservation data to the objects' metadata collection is very rare and not yet standardized. The Doc-Culture Project aims to provide solutions for the NDT application methodologies, analysis and process along with their output data and all related conservation documentation. The preliminary results are discussed in this paper.

Keywords: Conservation · Cultural objects · Non-destructive testing techniques · CIDOC · Dublin core · Metadata · kNN classifier

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1 Introduction

Conservation activities are considered as a prerequisite for maintaining cultural artifacts in their initial/original form [1]. On the other hand the use of NDT techniques is highly appreciated by conservators for art works and monuments of great cultural value, where strict regulations prohibit invasive testing during the conservation or even decay detection [2, 3, 4]. Up to now, different teams of researchers, materials and electronic engineers, conservators, etc, involved in the cultural heritage maintenance use NDT techniques in a non-standardized way, and consequently are unable to exchange data and share knowledge. Also, these techniques usually produce a large amount of data sets (typically a series of images, spectral data and graphs). Therefore, it is imperative to work towards the management of the data output, in order to achieve a comprehensive analysis from a single method and, if it is possible, to combine different sets of results from different methods. Finally, the output data (raw or deriving from specific data process methods) should be integrated either with the objects' metadata or incorporated in a decision support system.

This paper aims to present initial results on the research work done by the DocCulture project[1]. Three research teams have collaborated, namely the NDT standardization team, the Computer Science and Image Processing research team and the Information Science research team. Each research team focused on different aspects of conserving museum artifacts, while the National Archeological Museum - NAM (Athens, Greece) acted as the test-bed for the project's needs. This paper contributes in providing a valuable insight into the way data derived from application of conservation techniques are handled along with cultural artifacts' basic documentation.

The paper is organized as follows. In section 2 an example of NDT standardization process is depicted, using FORS & XRF methods. In section 3 an example of NDT data output analysis is presented using the k-NN approach for FORS pattern recognition. In section 4, the metadata standards employed to host both the standardization process and the output data are discussed whereas in section 5 an innovative Management Information System for NDTs is introduced, integrating all the components (NDT standardization, output analysis tools and extended metadata schemes) occlusions and future work are discussed. Final section presents conclusions and future work to be done.

2 Non-destructive Testing Techniques Standardization

The overall objective of the NDT research team is the development and standardization of the appropriate NDT application methodologies on specific cultural objects categories for the materials characterization/ evaluation, as well as the decay detection and assessment of conservation-restoration interventions compatibility.

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[1] Development of an integrated information environment for assessment and documentation of conservation interventions to cultural works/objects with NDT&E techniques, for more information see www.ndt-lab.gr/docculture

In this context, 82 cultural objects were selected from the NAM collection as well as from other archeological sites around Greece. These artifacts were classified into categories such as wall paintings, marble statues and figurines with or without existing traces of polychromy, copper based objects, golden objects and mosaics. Archeologists, conservators and material scientists collaborated in order to provide a complete metadata description with information like type, structural material, origin, dating, dimensions, preservation state, description / historical and archaeological data/ previous analyses / previous conservation-restoration interventions/ references etc..

For each one of the aforementioned object categories, an optimization and recording of the developed NDTs application methodologies was specified, taking into account certain restrictions. The example that follows describes the identification of coloring material (pigments) saved on marble statues using different NDT techniques.

Cultural Object under examination (GL-1827)

A. Type: Female statue, Structural material: Marble, **Origin:** Cyclades, Delos, House of the Lake**, Date:** Copy made in the 2nd c. BC of an original dating from about 300 BC, **Dimensions:** 1,75m height, **Preservation state:** Intact. Loses at the fingertips of the thumb and the index of the left arm. The tip of the nose… **Description / Historical and archaeological data:** … (see Fig. 1)

Fig. 1. *In-situ* measurements on color traces saved on Object No GL 1827 (i.e. red color remains on the sandal)

B. NDT methods used

Portable X-Ray Fluorescence (XRF), **output**: X-Ray Fluorescence spectra (data file of energy data vs counts per second data) and Portable VIS-NIR Fiber Optics Diffuse Reflectance Spectroscopy (FORS), **output**: Diffuse reflectance spectra in the spectral range of 350-1000 nm (data file of wavelength (λ) data vs reflectance (R) data)

C. Restrictions

Micro-sampling was not allowed from the selected marble figurines and statues for a more detailed study by means of advanced laboratory methods (e.g. ESEM-EDX, ATR-FTIR, micro-Raman) and therefore, our optimized analytical methodology consists only of two steps (Steps 1 and 2) that combine the application of portable XRF and FORS techniques, as described below.

D. Standardization procedure: Following are the steps of the optimized NDTs application methodology for the identification of pigments saved on the selected marble figurines and statues category (with existing traces of polychromy).

- **Step 1 - XRF Analysis (method used for elemental analysis and chemical analysis, particularly in the investigation of metals, glass, ceramics and building materials):** XRF spectrum collected from a red spot saved on the sandal of the Object GL 1827 revealing high Ca and Fe contents. The identification of red ochre pigment in the form of Hematite (Fe_2O_3) and Calcite ($CaCO_3$) coming from the substrate (marble) is suggested. The high Pb content indicates the application of a white lead [$2PbCO_3.Pb(OH)_2$] surface preparation layer (substrate), in order to achieve a better adhesion to the upper color layers.
- **Step 2 - FORS Analysis (method used for the identification of pigments and for the analysis of color and its variation on paintings):** FORS spectra obtained from the red color traces saved on the sandal and hair of the statue (Object GL 1827) verifying the presence of red ochre in the form of Hematite (Fe_2O_3) as the main component of the pigment producing the red color.

3 NDT&E Techniques Output Data Analysis and Process

The overall objectives of the Computer Science and Image Processing research team are the development of a complete set of techniques and software tools for digital image analysis and processing of the NDT techniques output data, as well as the development of an Integrated Information Environment for the documentation of NDT processes and its implementation model. Digital image processing includes a variety of techniques, namely contrast increase/enhancement, histograms, re-coloring, advance annotation etc. On the other hand, the NDT output data processing includes mainly the implementation of algorithms for graphic pattern detection (detection of areas, patterns, colors etc.).

For example, a complete data management solution was developed, that combined a library of known reference pigments/colors of ancient objects, along with a proposed novel pattern matching technique. This technique allows for the automatic classification of any new pigment that is recovered from cultural objects based on FORS and/or XRF measurements, coupled possibly with input provided by the human analyst. To be more specific, the overall system consists of two standalone subsystems, whose goal is to estimate the correct label (class identifier) corresponding to a given feature vector or a template, based on prior knowledge obtained through training (supervised learning) [5, 6]. The aforementioned subsystems, namely the FORS-based and the XRF-based classifiers, work independently of each other and yield separate decisions. Then, in a second stage, the system combines one or both of the automatically generated recognitions, with possible input from the human analyst (that could be used to solidify or reject the automatic selection) and produces an overall decision (pigment).

3.1 The FORS-Based Classifier

The FORS-based subsystem constitutes basically a kNN classifier [7, 8] whose implementation can be divided into two major phases, namely the design phase, and the running phase. Although we initially experimented with various ML algorithms, the k-NN's performance is very satisfactory for the needs of the application at hand.

This fact, combined with the simplicity of k-NN, both in its design/ implementation phases, were the main reason for the aforementioned selections.
A brief description of the steps involved during the design phase, as well as an outline of the proposed algorithm that is executed during the running phase, is given in the following paragraphs.

Design Phase

The design phase of the system consists of the following steps:

- *Training & Validation data sets*: The training data set comprises the knowledge of the system regarding the different classes it is able of recognizing. For the specific system at hand, the training data set consists of 10 reference measurements from each of the pigments mentioned in Table1 (see below). The validation data set on the other hand, represents a sample of the future (unknown) measurements and can be used in order to estimate the system performance in real conditions. For this task, we selected measurements taken form from real cultural objects (with known pigment content) and we used them in the final design stage for the evaluation of system performance and the selection of its parameters.
- *Preprocessing*. We have designed a preprocessing procedure, tailored to the specific needs of the FORS measurements, with the goal of data enhancement. More specifically, in the preprocessing step the linear trends that are present in many FORS measurements and obscure their true class-dependent characteristics, are removed through linear regression, and the resulting measurements are then normalized.
  - *Specification of system parameters*: We have conducted a series of experiments using the validation data set, with the goal of maximizing system performance, with respect to the following degrees of freedom: (i) Number of patterns per class (pigment), (ii) value of k and (iii) employed Distance Function.

Table 1. Pigment Library automatically detected using FORS method

Class ID	Pigment	Class ID	Pigment
Red Color			
1	Caput mortum	9	Malachite
2	Hematite	**Brown Color**	
3	Minium	10	Sienna Raw
4	Red ochre	11	Umber Burnt
Yellow Color		**Blue Color**	
5	Sienna Burnt	12	Azurite
6	Yellow Ochre	13	Egyptian Blue
7	Massicot	14	Ultramarine
Green Color		15	Indigo
8	Green Earth		

Algorithm.

Input: FORS measurement array of unknown class (pigment).

The steps that are executed during the running phase are the following:

1. *Preprocessing*: apply the same procedure used for training data.
2. *Calculate distances* of input template form the patterns of the training data set.

3. *Sort* the resulting array of distance values.
4. *Count* the memberships of each class in the first k labels of the sorted distance array.
5. *Assign* the class with the highest membership to the input template.

3.2 The XRF-Based Classifier

The automatic characterization of the XRF measurements constitutes a feature-based system, meaning that the classification procedure depends on the successful extraction and identification of class-specific features. Similarly to the FORS-based subsystem, the implementation of the XRF classifier is divided into the design phase, and the running phase.

- *Training & Validation*: For the collection of the training and validation data sets is a procedure identical to the one followed for the kNN classifier, was adopted. Contrary to the kNN classifier however, here the training measurements are used in order to guide the feature selection step in the system design phase, and the way they are used when the decision made, but the data themselves are not used in the latter phase.
- *Preprocessing*. The preprocessing was focused on the enhancement of the original measurements with respect to two aspects, namely, a)the smoothing (i.e. denoising of the curve) and b) the elimination of the baseline drift [9] that is present in many measurements.
- *Feature Selection*: As it is to be expected, in the case of XRF measurements, the aforementioned features are related to the element-indicative characteristic peaks of the XRF spectrum. More specifically, the feature set upon the classification is made consists of the most significant peaks of the spectrum, ordered with respect to the area below each peak (i.e. the integral of the spectrum in the interval occupied by the peak).
- *Specification of system parameters*: The impact of the following design aspects was examined, with the help of the validation data set:
  - Peak identification procedure.
  - Number of the significant peaks that the decision will be based on.
  - Ordering and normalization of peaks.

Algorithm

1. *Peak Identification.* Every identified peak constitutes a quadruplet of values, namely the two endpoints of the interval it occupies in the spectrum, the position it attains its maximum, as well as the maximum value itself.
2. *Area Estimation.* For each of the identified peaks, we use a well-known method of numerical integration (namely the trapezoidal one) for the approximation of the measurements integral within the endpoints of the peak interval.
3. *Order* the identified peaks with respect to their estimated areas, excluding pigment-irrelevant elements such as Ca, which is mostly due to substrate materials and not due to the used pigment.

4. *Peak assignment (or labeling).* With the help of a lookup table specifying the position of every known element in the XRF spectrum, label each identified peak, with respect to the position of its maximum, i.e. assign the peak to a chemical element.
5. *Selection* of the top K most significant elements, (where K equals usually 2-3), based on the ordered set of the significant peaks.
6. *Pigment recognition*. Decide on the used pigment by comparing the ordered set of elements provided in the previous step to the expected set of elements for each of the considered pigments (determined in the design phase). The latter sets are provided by the human analysts during the design phase. It is important to be stressed here that, since the chemical fingerprint (or at least its most significant elements) does not uniquely define a pigment, the reached decision is specific to the point that the identified allow for it (e.g. Fe is characteristic element of both red and yellow ochre). In many cases, the recognition provided by the XRF system specifies a whole family of pigments (e.g. the Fe-based ones) rather than a unique pigment.

The experimental evaluation results of the proposed techniques showed that data management is both effective and efficient. The obtained results are indeed very favorable, thus encouraging the exploration of other similar approaches within the NDT framework. Initial feedback from the proposed system is promising because it would allow automation and thus a radical decrease of time for pigment/color matching and provoke further critical restoration actions. In this direction a feedback step was incorporated in the implemented k-NN classifier, so that its training data set can be constantly updated with new measurements (entered by the user) so that it can best adapt to the nature of the encountered environment.

Finally, we are currently experimenting with a more elaborated, Bayesian-like classifier, where the decision for the correct label of the measurement is based on the likelihood of a pre-selected, class-dependent set of features being present. Such features include e.g. the maximum and minimum positions, the rate of steepest slope, the curvature in specific intervals, etc.

4 The Metadata Scheme Outline

The vast information produced during the conservation procedures is crucial for further documenting the cultural artifact and successfully applying any future conservation interventions. A domain model was developed to accommodate both information referring to the cultural artifact itself, as well as the various conservation related techniques employed (see Fig. 2). Specifically, five main entities were identified [7]:

1. Object defined as the cultural artifact and comprises a series of relevant properties that describe the object.
2. ***Conservation*** defined as an “event”. It entails a series of relevant elements defining time, duration, type of event and description. Type of conservation comprises a property that is describing the technique used and it is perceived in the domain model as a property of conservation.

3. The entity ***Measurement*** is defined as an "event". It entails a series of relevant elements defining time, main body of responsibility, type of event and description. Type of measurement comprises a property that is describing "sampling" and it is perceived in the domain model as a "property" of measurements.
4. ***Equipment***, defined as a physical object that comprises a number of properties describing the equipment utilized for conservation and measurement actions
5. ***Digital documentation*** is an entity linked to all the others, as it refers to depicting both any digital representation of the cultural object as well as any digital documentation, imagery or dataset produced throughout the course of conservation and measurement actions.

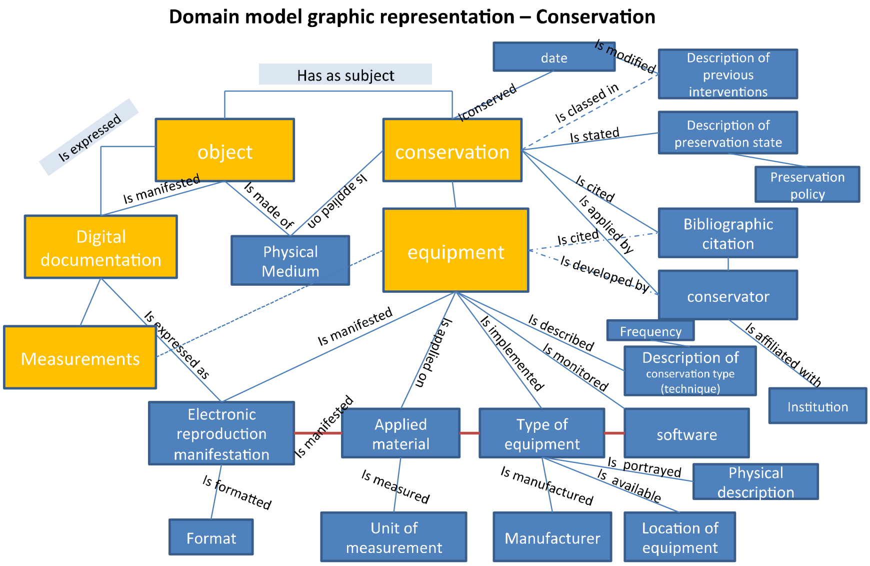

Fig. 2. Domain model graphic representation – conservation

Two well-known metadata standards were used to define the properties of the aforementioned entities. In particular, Dublin Core Metadata Initiate (DCMI) and CIDOC Conceptual Reference Model (CRM) were adopted. Both standards (CIDOC CRM and DCMI) are international, well-established and adopted from various Information Organizations for handling cultural information and allow either the incorporation of extensions on the basic structure of the model (i.e. CIDOC CRM) or provide the ability to employ elements from other standards, in order to address the specific information needs of both objects and processes (i.e. DCMI). However, the artifact collections of every museum are unique and thus require special treatment. The same applies for the conservation procedures these cultural artifacts undergo. CIDOC CRM and DCMI provide a variety of different elements and sub-elements and thus address the majority of the documentation needs of each cultural artifact and a large portion of the conservation process [10, 11]

Nonetheless, there was still information regarding both the cultural artifact and the conservation intervention that needed to be considered. Two new CIDOC-CRM extensions are identified under the sub-classes *E7: Activity* and *E4: Period* in terms of describing the conservation process performed on cultural artifacts. The proposed extensions are *E94: Conservation activity* is assigned to the *E7: Activity* to describe in detail the process of conservation and *E95: Frequency* is identified under the *E4: Period* to further describe the frequency of the time span [12, 13]

In the context of formulating "application profiles" and employing different specialized vocabularies, four additional to DC metadata standards namely Metadata Object Description Schema (MODS), Resource Description and Access (RDA), PREMIS and Muse Meta were adopted (see Table 2).

Table 2. Additional to DCMI standards adopted

Standard	Element	Scope Note
RDA	placeOfOriginOf-TheResource	Relates a work to the country or other territorial jurisdiction from which a work originated
RDA	has affiliation	Relates a person to a group with which a person is affiliated or has been affiliated through employment, membership, cultural identity
RDA	appliedMaterial	Related a resource to a physical or chemical substance applied to a base material of a resource
RDA	productionState-ment	A statement identifying the place or places of production, producer or producers, and date or dates of production of a resource in an unpublished form
MODS	location	Identifies the organization holding the resource or from which access is obtained
Meta Muse	unitMeasurement	A measurement standard; e.g., metric
PREMIS	fixity	Information used to verify whether an object has been altered in an undocumented or unauthorized way. Validates the authenticity or integrity of the Content Information: for example, a check sum, a digital signature, or a digital watermark. (Fixity Information)

5 Management Information System for NDTs

In this section, we present and describe an innovative information system for Cultural Heritage Management (CH), with support for NDTs output data. It is built upon open source technologies such as Apache, MySQL, JavaScript, PHP. The benefit in building upon such open platforms is their modular architecture and wide choices for extensions development and deployment for any data centric service that additional functional specifications are required or may be needed in the future by experts/archaeologists and conservators.

The User Interface has been designed with a responsive HTML template, such that its Graphical User Interface (GUI) is user-friendly and the functionality is efficiently adapted to the screen of the device each time (especially for small screens such as tablets and smartphones). In this point, we stress out that all data and metadata produced or stored in the management information system can be public or private.

The core subsystems are: Image Processing - Numerical Analysis - Metadata Management - Image Annotation - Documentation Management. Similar efforts that include all these functionalities and support NDTs output data process are limited [16].

The Image Processing Subsystem is used to allow the application of filters on images of cultural objects. Currently lots of types of filters are available and there can be added more if needed, e.g. the grayscale and the color analysis. For example a filter, when applied, produces a new image that displays the color composition of the original one and assists conservators to take the right decisions related to future conservations.

Numerical Analysis provides functions for the manipulation and final identification of previous conservation processes (such as FORS or XRF NDT techniques) that have been applied to a cultural object. Moreover, it can detect possible lesions on the surface of the cultural object and propose a suitable NDT method for its restoration. To achieve this, the conservator provides the measurement results that contain the output of an NDT method (e.g. Infrared Thermography, XRF, FORS, etc.). Next, the file is given as input to an algorithm that decides to which class of known colors the measurement belongs. The color class is decided/ chosen with a certainty percentage and then it is up to the conservator to make further decisions.

The numerical analysis service enables the researcher to analyze and visualize (see Fig. 3a) the measurement result into a diagram in order to further detect colors of pigment under review. The system keeps an archive record of all previous analyses that follow the particular cultural item under research for its lifetime within the system.

The metadata framework adopted is in essence an extension to the basic Dublin Core metadata standard. In other words, for each column of a content type in the database there exists a respective metadata element.

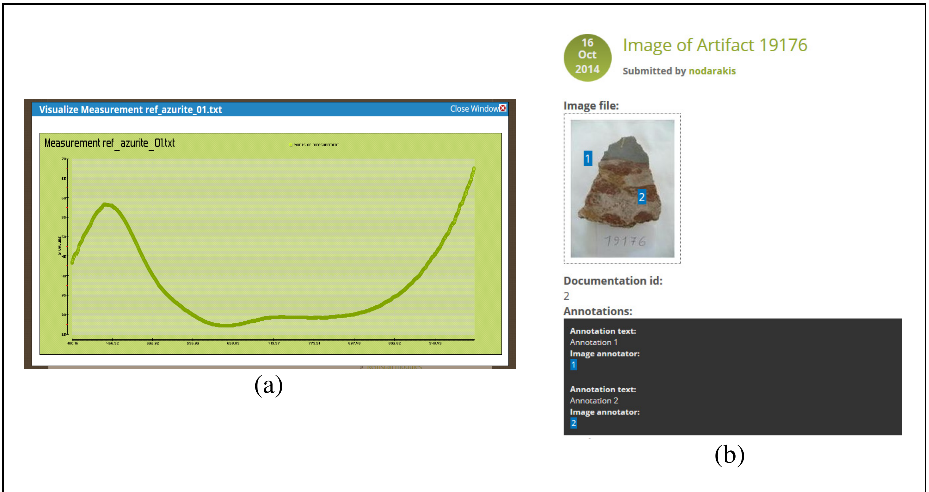

Fig. 3. (a) Visualization of measurement, (b) annotations of a cultural item image online

The Image Annotation subsystem (see Fig. 3b) enables an expert to add annotation marks or areas to an image together with respective information pertaining previous conservations. The conservator may add a marker with a number on an image via drag and drop and add clarifications, conditions and guidelines as well as description that are related to the position of the marker on the image.

Documentation Management functionality implements the metadata scheme as well as the documentation process for conservationists.

6 Conclusions – Future Work

Strict regulations when comes to cultural object conservation (and examination) makes the application of Non-Destructive Testing techniques (NDTs) very important. Non-destructive examination includes the employment of multiple analysis approaches and techniques with different methods of application for each category of object. The standardization of the followed process, when one method is applied or more than one are combined together, is absolutely necessary. Moreover the a huge amount of data, in different formats, produced during NDT&E application request both for advanced techniques of analysis and documentation. This paper aimed to provide initial results for the NDT application methodologies, analysis and process along with their output data and all related conservation documentation.

By the end of the project, all methodologies, tools, the management information system, as well as the metadata schemes extension will be available to the scientific community for use and further development.

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