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The Combination of 3D and Multispectral Imaging for Scientific Visualization – Tool for Conservation and Heritage Specialists

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Abstract

Information and communication technology applications and the preservation, research and popularization of heritage have attained an important position in the management and studies of cultural heritage. Over the past couple of decades, instrumental studies, imaging and survey technologies have developed very rapidly due to information technology solutions and have become ever more important tools in documentation. Cultural heritage has lot of different aspects and there is often a need of continuous scientific research and preservation to gather valuable information from our history and provide better understanding for future generations. 3D survey and multispectral imaging provides enriched information about heritage objects that may considerably help conservation and heritage specialists especially when it is accessible over the Web.

Introduction

Estonian Academy of Arts, Cultural Heritage and Conservation Department co-operation with Estonian Art Museum, Rändmeister LLC, St Mary's Cathedral (Tallinn) and Archaeovision LLC have unique opportunity to use modern approach to gather and disseminate scientific information during the conservation works of the retable of St. Mary's Cathedral, made by Christian Ackermann's workshop in 1686-1696.

Ch. Ackermann's retable and wooden figures (Fig. 1) are heritage objects with a great public and research interests. This masterpiece provides an excellent opportunity for the wider information analysis of complex object documentation, visualization and archiving.

Based on knowledge gathered during previous project "Comparative technical analysis of the medieval altarpieces by Hermen Rode in Tallinn and in Lübeck" our team was convinced that key factor for a successful results is adaptable workflow and data accessibility. In terms of the complexity and sizable, were these two altarpieces excellent test objects, combining polychromic sculptures and paintings, i.e. the specific attributes of two- and three-dimensional art. The results of previous study demonstrated that complex artefact surveys can be successfully and cost-effectively committed [1, 2, 3, 4, 5].

Such an approach, which provides the opportunity for studying and familiarization with different research methods and the creation of synergies among specialists from different fields, can also supplement imaging and information technology solutions and make them accessible to researchers and general users.

Thanks to recent advancement research in the domain, jointly to the increasing use of detailed 3D model in latest-generation of web-based information systems [6], we can provide additional and reliable information on the whole life cycle of the cultural object [7].

To date the protection and enhancement of Cultural Heritage, particularly when dealing with significant monumental complexes, is supported by a series of digital devices not only used for reliable documentation, but also for carrying out in-depth scientific analysis on the work of art and, further, to facilitate programmed maintenance work. Therefore, web-based ICT systems can offer increasingly updated tools for the Cultural Heritage management, mainly for querying and storing worksite documentation, but also for presenting and processing (if possible) gathered data, and providing access and the opportunity to reuse those solutions, which is extremely important in broad-based analysis and interpretation, besides of providing a smart 3D navigation system, always accessible to the users via web.

The background of retable documentation

The retable of St Mary's Cathedral was presumably built according to the plans of the Swedish royal architect Nicodemus Tessin the Younger. In terms of architectonics and ornamentation, the more than eight-meter-high and five-meter-wide Italian-like retable is reminiscent of Tessin's work at the Riddarholm church in Stockholm.

The objective of the project is to rescue Ch. Ackermann – the most scandalous and talented carver of Estonia's Baroque era – from oblivion. Ackermann, who was dubbed Tallinn's Pheidias (a sculptor in Ancient Greece, ca. 480-430 BC), broke free of the strict centuries-old guild system, and between 1680 and 1710 almost all of the most noteworthy elements of church interiors in Estonia were produced in his workshop.

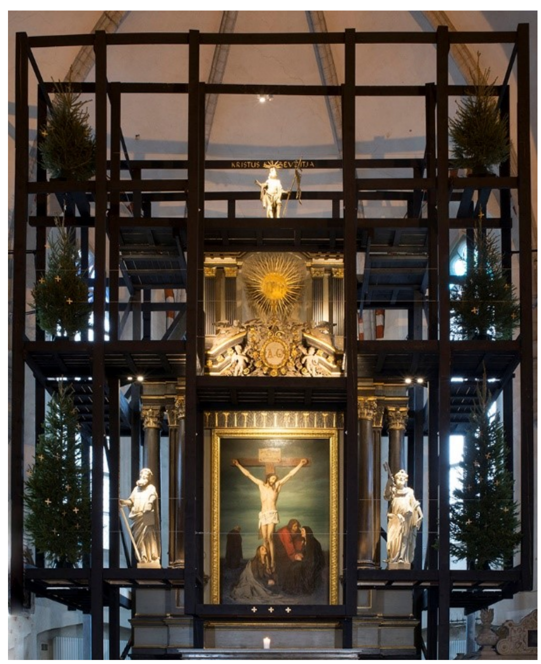

Figure 1. Specially designed and built long-term scaffoldings in front of the St. Mary's Cathedral's retable. Photo: A.Uueni, 2017

In the course of the project, contemporary methodology and technology, as well as criticism of sources, will be employed to re-evaluate the retable walls, pulpits, baptistery and other artistically valuable objects attributed to Ackermann. The top specialists will participate in the examination of the materials used for Ackermann's carvings and cabinetmaking, along with the techniques, typology and polychromy.

The project will start with an examination and documentation of the sculptor's masterpiece – the retable of the Tallinn Cathedral, which was produced in Ackermann's workshop. The research project will result in an exhibition at the Art Museum of Estonia's Niguliste Museum in 2020.

Ch. Ackermann project is in starting phase and several papers are prepared considering art history, conservation, imaging and information and communication technologies (ICT).

This project requires collaboration between conservation, history, cultural studies and also other areas of humanities and ICT.

Aims and solutions

Starting the Ch. Ackermann project we have planned several documentation and ICT works. One of the main targets beside large-scale conservation works is to create functional web-based prototype to support conservation works and test how different image and research data can be accessible and usable via website. Other areas of interest are: to test usability of the combination of 3D and multispectral imaging for scientific visualization, virtual colouring of the 3D models and also to test different methods and tools to achieve cost-effective and flexible workflow (Fig. 2).

For the research and documentation purposes will be created selection of image data: visual (VIS), high dynamic range (HDR), near infrared (NIR), short-wave infrared (SWIR), ultraviolet fluorescence photography (UVAF) and roentgenographic images (X-ray).

Multispectral information is collected by way of cameras: objects are photographed at different wavelengths and different intensities. The structure of the object under investigation can be discerned during multispectral examination. Even if colours are visually identical, it is possible through multispectral analysis to identify clear differences, including chemical and physical characteristics. [8]

Multispectral imaging is in use in many domains e.g. bioimaging, environmental assessment, water quality assessment, skin and vein imaging, etc., but the multispectral imaging has also proven its importance in cultural heritage during the conservation works. In Ch. Ackermann's conservation project, we are using multispectral examinations because selected imaging is noninvasive, it is also useful to detect valuable information about the artefacts. Mainly we are using modified (converted) digital single-lens reflex (DSLR) camera (sensitive at wavelengths between 230-1040 nm) and indium gallium arsenide (InGaAs) infrared reflectograph (sensitive at wavelengths between 900-1600 nm).

NIR and SWIR information can provide base drawings containing carbon, such as the pencil, charcoal or ink that are beneath the layer of paint or varnish. The display of ultraviolet fluorescence (360 – 400 nm) makes it possible to gather information on changes later made to the painting layer and different materials [9]. It is possible in this way to find evidence of later restoration of the paint layer, corrections and, for instance, changes in authorship.

Ultraviolet radiation causes the luminescence of materials and they can fluoresce, depending on the composition of the materials of the object. The light source has a controlled spectrum and a special light bulb, and a flashbulb with a coverslip that operates in the safest range of ultraviolet radiation, notably UVAF: 370–390 nm.

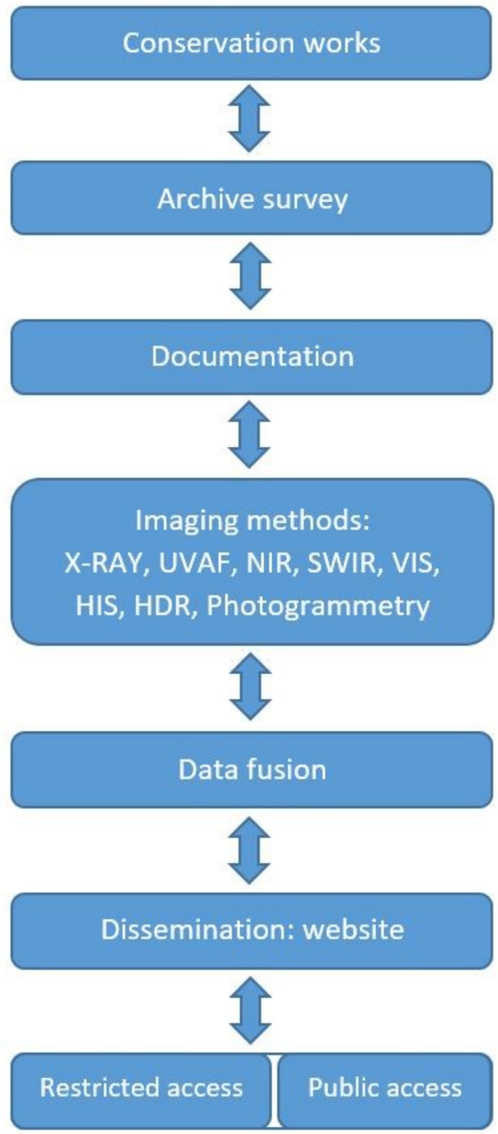

Figure 2. All the components of the documentation workflow must be flexible and adaptable according to the artefact conservation process. A. Ueeni, 2017.

If the solution for procession DSLR output is rather trivial, then using the InGaAs SWIR camera is more complicated. Usually SWIR camera output is a tiled bitmap image and does not contain necessary exchangeable image file format (EXIF) information e.g. necessary information for photogrammetry. If to convert bitmap image into raster image format (e.g. TIFF or JPEG) and add important EXIF information using special tool (ExifTool, Exif Pilot, etc.), it gives a possibility to use these images to process for photogrammetry. Nevertheless, the InGaAs camera sensor information size is a more complicated due to both the sensor used and the way it works behind the lens. Rather than a standard format sensor, it is actually a line sensor – the sensor itself is 12.8 mm long and 25 microns (0.025 mm) across. However, the total image size

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behind the lens that the camera is scanning is 102.4 mm x 102.4 mm. The method to adapt and to use and usability is under research.

To gather even more valuable image data, in some cases there will be applied also another method – Reflectance Transformation Imaging (RTI). RTI is a computational photography method and it relies on an image-based representation of the object's surface colour and shape achieved by applying and capturing the object under lighting from different directions. The method allows to record 3D surface properties and visualise interactively the surface of the artefact as 2D interactive images.

In the resulting RTI model is a way the lighting direction can be changed interactively and enhancements can be performed to make surface details more visible. The method is very cost-effective and accessible as no special equipment is needed and software for processing the images and viewing the end result is free. This method is useful for the examination and presentation of the details of the wooden sculptures. RTI method helps to gather additional information about wooden sculpture's details like heads, hands, etc. for further investigation of the wood craving. This information is very valuable during the attribution process of other artefacts, attributed to Ch. Ackermann.

The RTI method is based on a mathematical algorithm that calculates the reflection of light from the surface for every pixel in a given series of images; it was created by Tom Malzbender of the Hewlett Packard Laboratory in 2001. [10, 11, 12]

For further examinations we are using X-ray, which can be considered as invasive imaging, depending on equipment. In conducting X-ray examinations, we are doing in co-operation with the Estonian Tax and Customs Board's portable X-ray apparatus, which is designed to emit minimum ionising radiation doses (max 7.5 μSv/h). With the help of X-rays, it is possible to see through parts of the retable and wooden figures of interest, which made it possible to obtain further information on the methods of work used in Ch. Ackermann's workshop and to look at the internal structure of different parts of the work of art. X-ray data helps to gather information for the decision making and for the conservators and for art historians.

The 3D solutions for the conservators

Important part of the project is to collect and provide high resolution photogrammetric 3D models for conservators. At a first phase of documentation works nine wooden sculptures were acquired. There were several points to consider, like how and where to acquire the images of the sculptures. Although the scaffoldings were well-built, the scaffoldings are not firm enough to make photogrammetry and there were not possible to access all the details of the sculptures. Together with conservation professionals were decided, that all the sculptures will be brought down from the altar for a picturing.

During the photogrammetry processing were tested different quality levels, the accuracy of the colour and processing methods [13, 14, 15]. To achieve higher quality 3D models, the combination of 'natural' and coded targets were tested and used. As the wooden figures are very detailed and complex the amount of the pictures per sculpture was very high, average number of the pictures for one 3D model was 168 images. To achieve repeatable results, the photogrammetry pipeline were followed (Fig. 3). For processing all kind of image data manipulation was avoided, including enhancing filtering, although it could change the results easier to achieve. After testing HDR imaging for 3D model processing the HDR solution was declined, as there were no additional benefit of the final result [16].

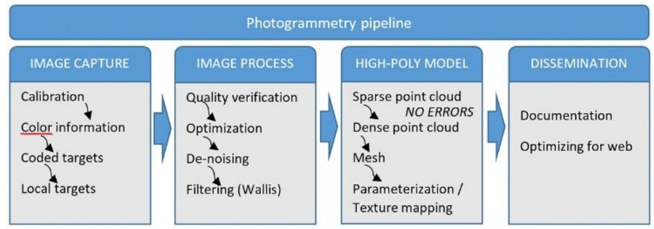

Figure 3. Following the photogrammetry pipeline helps to ensure repeatable results from the same image datasets. A. Uueni, 2017.

During the acquiring process DSLR camera was used. After acquiring, the image data at first were controlled, then colour calibration checking and minimal image processing [17] for further photogrammetric processing [18].

Virtual colouring of the 3D models

During the conservation works has been clarified that all the sculptures of the St. Mary's Cathedral's retable has been repainted in 19th century. The purpose of the virtual colouring is to provide for the wider public examples of the retable's details, how it could be presented in Baroque era. The other important target during the virtual colouring is to test different software tools [19, 20, 21] to achieve most optimally planned result.

The colour palette of the sculpture is collected in combinations of non-destructive analytical technique – X-ray fluorescence (XRF) to determine the elemental composition of materials and invasive cross-section technique, collected by conservators and professional chemists. Virtually coloured texture of the 3D model are based on these analyses (Fig. 4), while for the web publishing the virtually coloured 3D model was significally simplified.

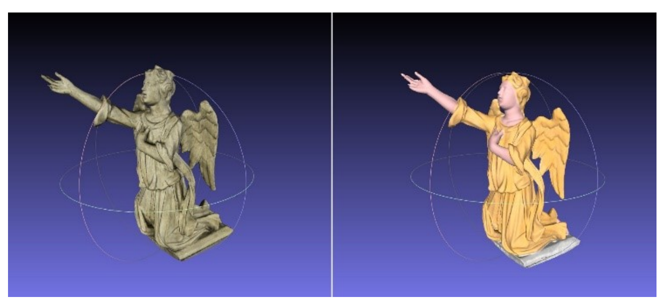

Figure 4. 3D models compared in MeshLab: left: current colour of the sculpture. Right: virtually coloured 3D model. A. Uueni, 2017.

Data accessibility

For the Ch. Ackermann conservation project is planned to implement ICT solutions which can be used by conservators during the conservation and survey. The online solution will be accessible directly from the site via wireless to provide access and to collect all the conservation data during the phase of the current state analysis and implementation of the conservation.

According to the 3D digital models of the solutions, which would allow conservators to organize data, re-check and make decisions during the conservation work. Ideally can conservators work online, adding annotations and indicate local interest points on the 3D models, using a dedicated user interface.

All information entered can be explored and also connected with the 3D models and its sub-parts, viewing in real time on the surface, VIS, NIR, SWIR and X-ray images of the various elements noted by conservators (Fig. 5).

Figure 5. To present accurate multiresolution 3D models the 3DHOP platform has been tested. Web interface allows to combine 3D models, and via local interests points connect also textual and image data. A. Uueni, 2017.

The part relating to the management data information system, based on open-source database tools, implements the classic features of documentation: a time log of all operations performed by the users, repository for different documents (images, pdf, text) that are associated with the various interests points. The information system is fully online.

In addition for presenting 3D models, also other solutions like RTI viewer plug-in is planned to be implemented. Planned 3D model publishing solution: 3DHOP (3D Heritage Online Presenter) is developed by ISTI-CNR is an open-source software package for the creation of interactive Web presentations of high-resolution 3D models, oriented to the Cultural Heritage field. Using latest web standards, based on the SpiderGL JavaScript library, and using jQuery, 3DHOP has proven to be optimal method for the visualization of 3D models via web [22].

Conclusion

During the conservation phase there are several important factors the CH specialists need to decide. ICT solutions should support the decision making it is important to support the CH specialist's better understanding and accessibility we decided that all the information must be accessible via website

Modern CH documentation is an interdisciplinary, accessible and practical way of capturing information concerning an object. Photogrammetry makes it possible to achieve precise results, including storing the most minute differences in the surface texture of the wooden figures. In combination with other data, contemporary 3D methods of documentation make it possible to contribute significantly to carrying out research and to better preserve and present information concerning an artwork. Thus, it is possible to precisely map out on a 3D model previous data, such as the results of instrumental analysis, base drawings, other paintings, information associated with dendrochronology and other such data. By carrying out repeated surveys, it is possible to add the fourth dimension of time to the 3D documentation to establish possible changes over a given period and in an environment.

Scientific visualization from gathered data in web environment: modern ICT and imaging technologies provides better and more detailed trustworthy output for heritage specialists. 3D has a benefit to present more information on complex objects than ordinary set of photos [23]. But 3D survey and multispectral imaging data fusion is able to provide even more: heritage (building) information model - HBIM [24, 25]. So, 3D documentation and multispectral imaging provides unique opportunity for the wider analysis of complex object documentation, mapping, visualizing and archiving information that conservation and heritage specialist can benefit from in their work, especially when it is accessible through the web.

Developments in this direction makes it possible to use widespread solutions that are considerably more cost-effective and universal than earlier technologies. Regardless of which imaging technology is used, the precision and comprehensibility of the information gathered is very important.

Even though multispectral and geometrical surveys are more complicated than ordinary photography, these solutions and, if possible, their corresponding combinations promise a very broad potential for their use.

Information technology also provides the opportunity to concentrate, contextualize, visualize and archive large volumes of different types of research data that accompany the study of cultural heritage [26]. The results obtained can be used to develop scientific knowledge and to broadly popularize results.

The expected impact of this trans- and interdisciplinary approach, which provides workflow and opportunity for familiarization with different research methods and the creation of synergies among specialists from different fields, can supplement imaging and information technology solutions and make them more accessible to researchers and general users.

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