PRECISE 3D-DOCUMENTATION OF CULTURAL HERITAGE WITHIN THE POLISH LONG-TERM GOVERNMENT PROGRAMME CULTURE+ BETWEEN 2010 AND 2014

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ABSTRACT: The purpose of this presentation is to show the effects of collaboration between the Museum of King Jan III's Palace at Wilanów and Warsaw University of Technology, Mechatronics Faculty in developing technology for cultural heritage documentation based on precise three-dimensional measurements. The accomplishment of the certain goals of those two institutions was possible due to the financial support from the long-term Government Programme Culture+. The authors' intention is to share the overview of the achievements on their way on developing procedures that meet the specific needs of museums. Their technology is presented in terms of: 1) the challenges that they had to face, while they worked with different objects of art; 2) the prospects of development.

1. INTRODUCTION

Since 2007, the Museum of King Jan III's Palace Museum at Wilanów is cooperating with Warsaw University of Technology (WUT), Faculty of Mechatronics in developing technology for cultural heritage (CH) documentation. The digitization technology is based on precise three-dimensional measurements using structured light as the underlying measurement technique [1]. This collaborative work is partially being performed under the Polish long-term Government Programme Culture+. The Museum of King Jan III's Palace has already achieved financial government support for four times in order to expand this path of documentation.

At the crossroads of humanities and scientific studies, neither the instrumentation nor the dedicated software can be viewed as an instantly developed product, but rather a continuous process of expansion and adaptation to the needs of CH documentation. The developed software is useful as a protective measure just as much as a research tool. The development of different aspects of the technology is crucial as we meet different museum's expectations during subsequent case studies.

The main aim of the presentation is to show where and how the expertise of the museum and the university meets, resulting in elaboration on innovative, precise technology. We describe what has been created so far and what our plans for the future are.

2. FACING THE CHALLENGES

During the conducted studies, several objects of varying types have been digitalized. Thirty ceramic figurines made of biscuit, four objects made of English stoneware, ten woodcuts and two paintings have been scanned with resolution ranging from 1000 up to 2500 points per square millimetre (MSD – measurement sampling density) [2]. The measurement systems implemented for this purpose consisted of a custom designed, high-resolution structured light measurement head with automated digitization system. The automation was achieved by fixing the system to an industrial robot arm or another manipulator system supporting automatized acquisition of partial 3D scans [3].

While performing the 3D documentations we discovered that each object type requires a different approach. In consequence, to measure each group of objects we had to develop a unique methodology and modify our measurement systems specifically for the particular task [4]. With each new experience, the data processing environment and the software applications needed for visualizing the resulting data also had to evolve.

We pay special attention not only to the museum's expectations and standards but also specific object's requirements. For example, when we were approaching the task of measuring the "Great Dürer Trilogy" (Fig. 1) we knew that we had to achieve high spatial density [3]. The scan of a single "Four Horsemen of the Apocalypse" woodcut ultimately consisted of 381 measurements (resulting 277 GB of measurement data).

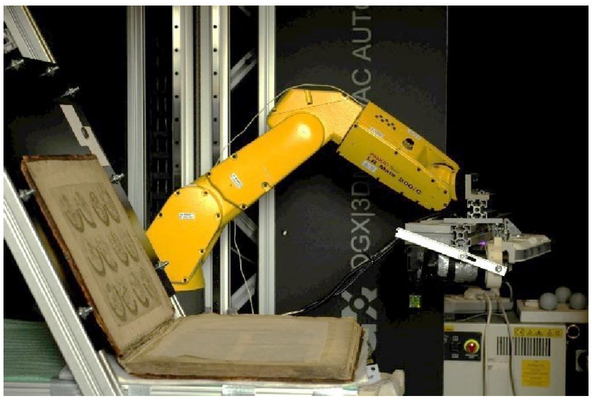


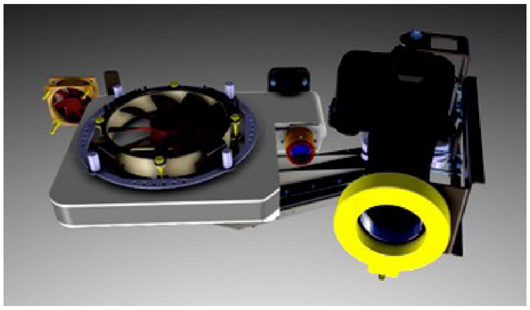
Figure 1: Measurement system with a robotic arm

3. 3D DOCUMENTATION PROCESS

There are two main aspects connected with the development of a 3D documentation pipeline: the involved technology and process planning. Below we describe only the most important aspects of the methodology developed. Our main assumption is that each 3D documentation process starts with a definition of requirements connected with the virtual representation. The representation can be defined by the sampling density (number of measurement points per square millimetre) and by the measurement uncertainty (measurement accuracy in each point). Some additional requirements are also specified (example: colour acquisition, allowance of limited spectrum or low energy illumination due to the state of the object's surface, etc.). The next step is the acquisition planning, which includes all of the specified requirements, object's characteristics (surface properties) and the data processing pipeline. For example, during our first attempts we separate 3D documentation from data processing (including view integration) thus we had to a re-scan some parts of the more complex objects due to lack of immediate preview for currently documented surfaces.

3.1 MEASUREMET HEAD

The developed measurement head is custom-built to meet conservators' requirements. Neither ultraviolet nor infrared emission of radiation was allowed in the direction of the measured object. Only low intensity of visible light (400-700 nm) is acceptable and the emission occurs only during measurements, while being blocked (light sources are turned off) during other operations. Such a measurement head is built on the basis of a commercially available multimedia projector (Casio XJ-A250) with custom projection lenses, allowing for close range focusing (250 mm from the device) and small image size (50 mm x 50 mm). The new optical system blocks excessive light and transmits no heat or UV radiation towards the image. This design requires a completely modified cooling system, which was carefully designed to additionally ensure a low level of vibrations, which could introduce errors during measurement. After modifications, a series of tests have been performed to ensure that the projection system meets the conservator's demands. Among those tests, the projector's emissive spectrum towards the object has been measured using a spectrophotometer at the WUT laboratories. The tests prove that neither ultraviolet nor infrared radiation is emitted. The visible light projected onto the digitized object's surface cannot transfer too much energy. The exposure values (measured in lx*h) for typical lighting conditions in the museum are equal to 50 lx up to 100 lx. Exposure measured after the projector modifications for each part of the measured surface are equal to 2 hours of illumination in 50 lx conditions. The measured amount of energy emitted during measurements (after modification) was low enough to be accepted by art conservators. Many different setups of the measurement head have been constructed (exemplary setups are shown in Fig. 2) during the described works.

a) 

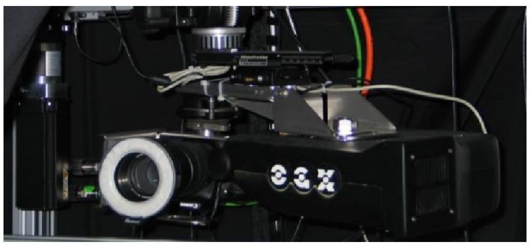
b) 

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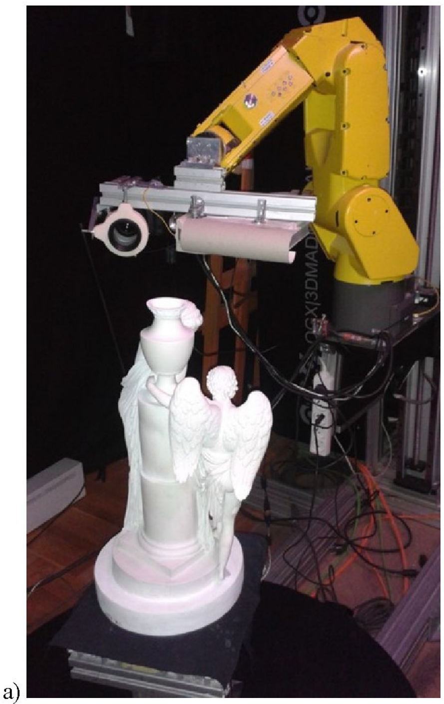
Figure 2: *Two exemplary measurement heads developed for CH objects 3D documentation: a) CAD model and b) a photo of SAPO measurement head, c) OGX|AUTOMATED measurement head*

Typical measurement head parameters depend on the detector used, but an average measurement uncertainty is the order of 10^{-4} relative to the dimensions of the field of view.

3.2 AUTOMATION OF ACQUISITION

Precise 3D documentation of large objects requires acquisition of hundreds or even thousands of directional measurements. To speed up the process, we decided to utilize industrial robot arms. We developed algorithms for "next-best-view" (NBV) and collision detection [3]. We have built an application that integrates tools for: robot arm control, manipulation, NBV, collision detection, structured-light measurement and calibration of the whole system. NBV algorithm works in two steps: rough and precise mode. The rough mode is used first. It calculates new measurement directions based on the already known part of the model, while skipping small gaps in the virtual representation. The size of these gaps can be parameterized, the default value is equal to 10% of the field of view. Next, when no direction from rough mode can be calculated, the precise mode starts. It calculates measurement directions to fill all remaining holes in the virtual representation.

a) 

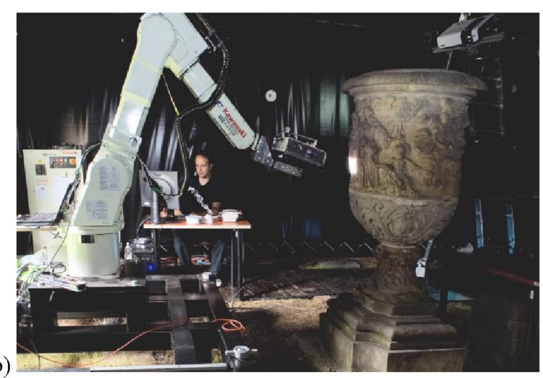
b) 

Figure 3: *Exemplary setups supporting automation of 3D scan acquisition: a) setup consisting robot arm, linear column and rotary stage, b) setup with long range robot arm mounted inside a customized tent*

A collision detection algorithm is used in parallel with the NBV to be sure that no collision can occur with the artefact's surface. Exemplary setups supporting automation of 3D scanning are presented in Fig. 3.

3.3 DATA PROCESSING

The data processing path with utilization of automation techniques on current stage of our work is performed in the following steps:

a) calibration of the whole system including registration in a database,

b) creation of a database structure and records for the new object and system operators,

c) performing a single directional measurement, creating its description and placing all its data to database,

d) filtering and initial fitting of this data to the existing model,

e) manual or automatic "next-best-view" calculation,

f) if NBV exists then go to point c,

g) if no NBV then integrate all views with relaxation algorithms and create final representation.

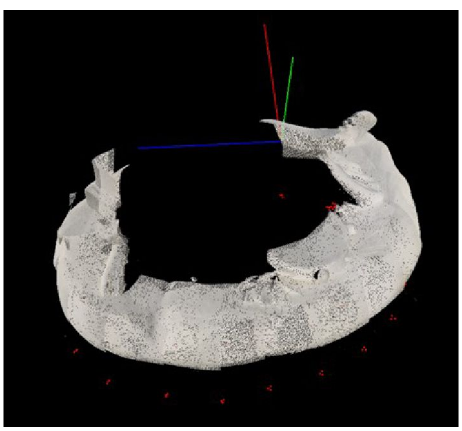


Figure 4: *Visualisation of the initial view integration for a preview of the automated 3D scanning process*

The whole data processing system is guided by an operator, who can override the level of automation (each automated step can also be performed manually). Depending on the object's surface parameters and geometrical complexity, the developed algorithms may yield suboptimal performance.

3.4 REAL-TIME VISUALISATION

For visualization of huge data sets custom application 3DMASSIVE has been developed. It is based on two main algorithms, special volumetric data sorting and modelling of a virtual camera. Modelling of a virtual camera provides information about the effective density of data required for visualization – expressed in pixels. At best, only a small part of data has to be visualized – one pixel for one measurement point. For example, if one wants to visualize a virtual model on a full HD screen, only 2 million of points are required each time per frame. Sorting algorithm with LoD (Level of Details) data organization allows for data selection and reduction depending on current camera parameters (position, orientation and focal length). Additionally, 3DMASSIVE allows for virtual light source manipulation and 3D model annotation. Annotation is an interesting feature that could be used for augmenting 3D clouds of points with additional descriptive data, e.g. pictures, documents, excel sheets and other files. This process starts from a selection of single point that becomes a named reference for annotation record. Exemplary visualization and annotations are presented in Fig. 5.

a) 

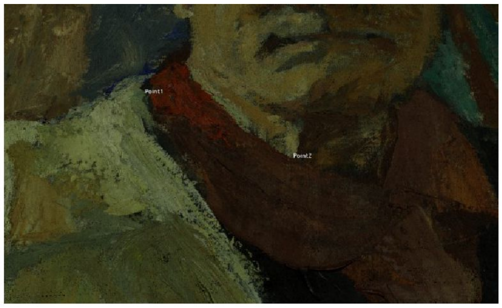
b) 

***Figure 5**: 3DMASSIVE visualisation application: a) fragment of 3D data with directional lighting mode, b) fragment of 3D data with two points annotated.*

4. TECHNICAL METADATA AND SUPPORTING DOCUMENTATION

The whole documentation process is being registered in a database system. The initial data that is stored is the calibration file of the measurement head together with relative calibration of all manipulators used. Each measurement is also stored in a file system with reference to a database (Fig. 6). Due to their size, measurements that may reach hundreds of megabytes are stored in a file system. Additional measurements of calibration targets, used for verification of quality of whole measurements during long digitization sessions, are also stored. Each record in the database is connected to the person that is responsible for that operation. Each data processing operation is also registered but not all of the corresponding, intermediate data is being saved because of the huge file sizes.

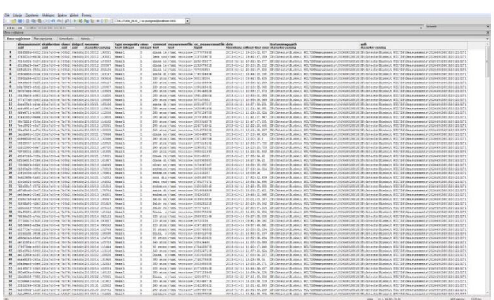


Figure 6: Screen of documentation process database

Additionally, some metadata with visual reference is created for each virtual representation, thus documenting holes and imperfections. Each such area is accompanied by a description explaining why the model is not properly registered in this particular place. Exemplary visualization of such process is presented in Fig. 7.

The final representation of a virtual model consists of:

- A full hi-res model in COPSXML file (a custom, hierarchical open format),
- A simplified COPSXML model with marked and described imperfections,
- A 3DMASSIVE model for real-time visualization,
- A triangle mesh from a simplified model.

***Figure 7:** Virtual model with marked areas of local imperfections*

4. EXEMPLARY RESULTS

In this chapter we would like to present some results that we obtained by putting the developed methodology into practice. In Fig. 8 two exemplary biscuit figurines are presented. First, Laudon Ernest Gideon has the size of 22,9 x 18,5 x 12 cm and consists roughly of a billion measurement points with sampling density of 2 500 pts/mm^2. It has been measured during the first year of the Culture+ program. The second figurine is bigger (35,6 x 25,6 x 23 cm) and much more complex. Due to its complexity, the number of measurement points is greater than 3 billion but also the number of imperfect measurements is larger (because of many obscured surfaces).

During this program we try to discover possibilities of 3D documentation of paintings. An example of this type of object measurement is presented in Fig. 9. It consists of almost a thousand of measurements with a density of 10 000 pts/mm^2. The achieved measurement results could be used very well for remote studying of the object's state.

a) b)

Figure 8: *Two biscuit figurines: a) Laudon Ernest Gideon, b) Victim of Faith*

Another type of a documented surface are old book paintings and drawings. We set up the system presented in Fig. 1 and documented several pages of the "Great Dürer Trilogy". The selected MSD was equal to 2^{500} pts/mm^2. A view of the whole model is presented in Fig. 10.

a) b)

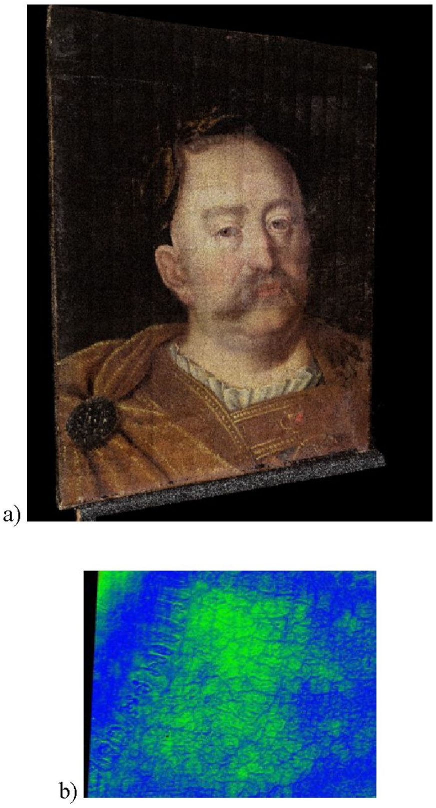
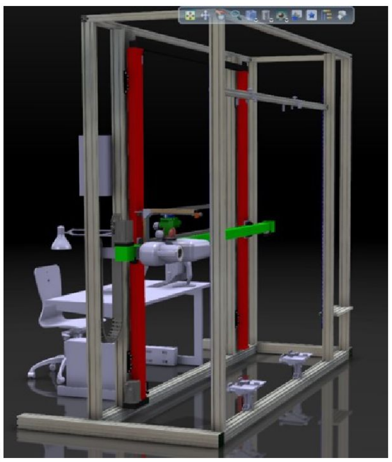


Figure 9: Exemplary 3D measurement result of painting: a) whole model, b) zoom in with geometry visualization

Figure 10: *The model of a single page from "Great Dürer Trilogy"*

5. PROSPECTS FOR DEVELOPMENT

We put special emphasis on progressing in process automation and constantly have in mind the future of 3D technology [5]. At the second stage of the Culture+ project we have built a fully automatized measurement setup with MSD of 10 000 points per square millimetre (for easel paintings). The projects codename is SAPO and it is currently in a testing phase. The tests are performed by the Warsaw University of Technology. At the beginning of the year 2015, the setup will be moved to a laboratory located inside the Museum.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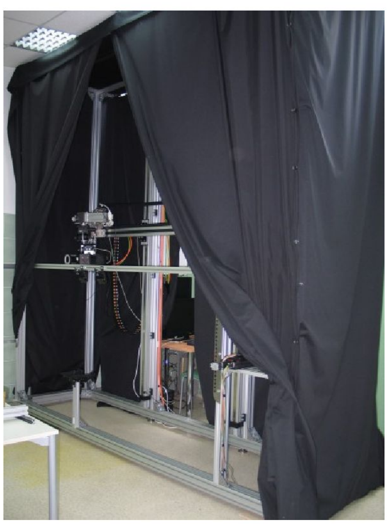
b)

Figure 11: *SAPO system: a)concept, b) photo of real system*

In the case of SAPO, the measurement head is fixed to a servo-controlled, custom built XY positioner. The painting is secured on a specially designed frame, which allows for strainless but at the same time firm placement of the object. This frame is positioned in a distance from all moving parts, ensuring that even in the event of any breakdown or software errors, the painting cannot be damaged by any part of the measurement system. The 3DMASSIVE software is used as a visualization module. A 3D model of the SAPO concept and a photo of its realization are shown in Fig. 11. Exemplary measurement results made by the SAPO system is presented in Fig. 12.


a)

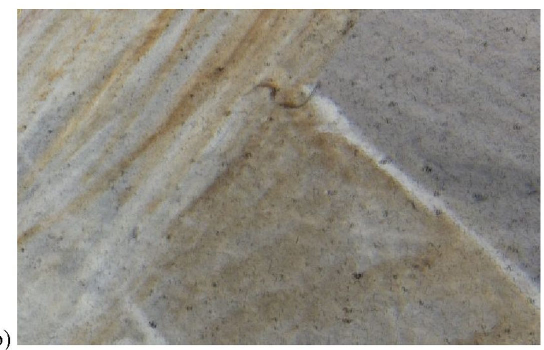
b)

Figure 12: *Exemplary result of SAPO measurement: a) whole object, b) zoom in on a small fragment.*

As part of the project, we have furthermore prepared technical designs of two mobile stations with which the measurements can be conducted in a park setting (in situ). The mobile stations can be used in case of sculptures and architecture for which there is no possibility of transportation to a laboratory. The stations' designs result from the experience gathered during measurements of sandstone vases performed in the Wilanów park between the years 2010 and 2011. The artefacts were ca. 2 meters high. The vases were scanned with the resolution reaching above

1600 points per square millimetre to accommodate for their very detailed relief decorations.

The fourth phase of the long-term project (that will finish in July next year) will involve the building of a new structured light-based measurement head. It will be enhanced with a multispectral acquisition of the surface's colour and an estimation of the BRDF (Bidirectional Reflectance Distribution Function) characteristic using multidirectional illumination. This setup will also introduce an additional automation stage of a moving light source, which is expected to increase photorealism of the resulting model.

6. CONCLUSION

The last few years have seen Poland's museology sector experiencing a digital boom. Traditional forms of documentation are now being complemented by more innovative methods. However, there is still need to establish technical and procedural standards for 3D documentation (i.e. using structured light). The authors of this presentation – on behalf of both museum and scientific institution – are convinced that, in order to speak about three dimensional 'documentation' rather than just a 'visualization' of cultural heritage objects, we need a technology that can describe all vital features of those items in a mathematical form. That is why we strongly believe that it is still essential to develop our technology and share the conclusions based on diverse case studies.

7. ACKNOWLEDGMENT

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8. REFERENCES

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