







Approach to Analysis the Surface Geometry Change in Cultural Heritage Objects

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Abstract. The three-dimensional digitization of the cultural heritage objects during different stages of the conservation process is an important tool for objective documentation. Further data analysis is also important to monitor, estimate and understand any possible change as accurately as possible. In this work, the cultural heritage (CH) objects were selected for 3D scanning, analysis and visualisation of the change or degradation on their surface over time. The main goal of this work is to develop analysis, and visualization methods for CH object to assess local change in their surface geometry to support conservation processes documentation. The analysis was based on geometrical analysis of change in global distance between before and after chemical cleaning for a chosen object. The new local neighborhood distance histogram has been proposed as a local measure of surface change based on optimized k-neighborhood search algorithm to assess the local geometry change of a focus point.

Keywords: 3D scanning · Surface data analysis · Monitoring of conservation process · Cultural heritage digitisation · 3D visualization · Surface geometry

1 Introduction

3D imaging is a technology that can be accomplished through various methods [1]. It can be used for disparate applications, ranging from quality and process control in factory automation to scientific imaging and research and development of algorithms in 3D model acquisition [2, 3]. The image related application is the natural fit for an algorithm course. They can be demonstrated graphically and have the property that they usually contain large enough number of surface points. There are various virtual reality applications [4] for which a number of researchers are working for its further development in terms of 3D imaging technology and acquisition technology like remote sensing, GIS, cultural heritage, etc. The use of geometric tools in analysis of detection change information i.e. spatial information works efficiently in solving the 3D problem [5].

The understanding of 3D structures is essential to many scientific endeavors. Recent theoretical and technological breakthroughs in mathematical modeling of 3D data and data-capturing techniques present the opportunity to advance 3D knowledge

into new realms of cross-disciplinary research [6]. 3D knowledge plays an important role in archaeology [7]. In conservation science, the restoration phases of cultural heritage objects can be digitized with various techniques [8]. Cultural heritage analysts and scientists are continuously trying to develop the more objective and automated techniques that could document of different phases of the conservation pipeline and could give the scientific visualization for the changes detected [1]. The work shows the application of structured light techniques to the analysis of a CH object before and after conservation. In order to detect and visualize changes the authors applied a local geometry analysis and presented the outcome through a global and local distance histogram. The goal of the work is in line with the application of optical metrology techniques to CH questions.

2 Related Study

The study on 3D imaging reveals applications in the area of surface change analysis. Robert Sitnik and *et al.* [9] researched on monitoring the marker-based surface degradation process using the 3D structured light method of scanning and visualize the 3D surface geometry. They analyzed the mutual overlapping of neighboring point clouds. The simulation of the work was validated using CloudCompare (v2.9.1) software based on the distance parameter. The main drawback of this work is the necessity of attaching physical markers to the object surface.

Pintus Ruggero and *et al.* [10] presented the recent techniques for performing geometric analysis in cultural heritage applications focusing on the factors of shape perception enhancement, restoration, and preservation support, monitoring overtime, object interpretation, and collection analysis. The survey was based on the geometric scale at which the analysis was performed and the cardinality of the relationships among object parts exploited during the analysis.

Manfredi Marcello and *et al.* [11] developed a reliable RTI method for monitoring changes in cultural heritage objects to get detailed information on the object surface. In this work, they captured the RTI and compared the normal vectors to the limits: the method was able to detect the damage automatically. The RTI method of analysis works well on collecting the detail information of the object's surface but for geometrical analysis of change, it is not convenient. Also in [12] E. Marengo and *et al.* presented another development technique based on multi-spectral imaging for monitoring the conservation of cultural heritage objects which is based on the change in color information rather than geometric analysis of change.

3 Measuring System

Due to the requirements concerning resolution, accuracy and illumination conditions, we developed a custom measurement set-up. We decided to use the structured light technique (SL) [13, 14] for geometry measurement. The phase-shifting method combined with Gray codes for improved phase unwrapping has been chosen as the most accurate SL implementation. We select six phase-shifts after careful assessment of the

developed measurement head intensity transfer nonlinearities. We used an SL calibration method based on modeling of phase distribution concerning detector coordinates [15].

The 3D scanner we used was designed and developed in the ZTRW laboratory and it is a completely functional prototype that is ready to perform valid measurements of objects surface (Fig. 1). The main units in the 3D scanner are the projector and detector. They are mounted on a special base made from carbon fiber composites. Using such composites prevents the deformation of the scanner construction caused by thermal expansion and ensures that the projector-camera system can be treated as a rigid body. As a projector, we have used a LightCrafter 4500 from Texas Instruments [16]. The matrix detector – a color camera from IDS [17] captures images of projected patterns (each single measurement consist of 14 frames). The fringes projection and image grabbing is synchronized by external microcontroller build on Atmega (we've used Arduino UNO) [18]. Custom made software for calibration and measurement [14] is saved on microcomputer IntelNUC. The Maximum Permissible Error for the scanner has been estimated as $EMPE = 0.25 \text{ mm}$ [19].



Fig. 1. Custom-designed 3D scanner.

4 Experimental Object

To analyze the change that appeared on an object surface, an object from the cultural heritage field was chosen from Studio of Conservation and Restoration of Ceramic, Faculty of Conservation and Restoration of Work of Art, Academy of Fine Arts in Warsaw Poland. The object is a ceramic tile and the area of interest was decided as the front of the object shown in Fig. 2(a) at the initial state and in Fig. 2(b) there is presented its photo after the cleaning process.

The chosen object which is a ceramic tile is a part of an element of the top of the tile stove which is from the end of the 19th century. The origin of the tile is demolished stove from one of Warsaw's tenements houses. The tile was made in one of the ceramic factories in Velten near Berlin. It was formed in plaster mould from a ceramic mass. It



Fig. 2. The chosen object and area of interest (Front) before (a) and after (b) cleaning.

was burnt to biscuit at temperatures up to 1000 °C. This type of tiles in the 19th century was not originally covered with enamel or painted. The basic tiles in those tile stoves were covered with a white glaze, but the decorative elements were in the natural color of fired clay.

The floral ornament decorating of the tile is a precise carving decoration. During about a hundred years of use of the tiled stove, the apartment owners covered the upper part of the tiled stove with several layers of paint (oil and emulsion painting) as a way of unprofessional renovation treatment - instead of cleaning the tile surface. In this way, the visibility of sculptural decoration details was lost. During the conservation works, it was decided to remove the over painting. This made it possible to regain the original ethical values of antique decoration.

5 3D Scanning and Analysis

5.1 3D Scanning

The 3D scanning of the chosen object, with our measuring system, was done in Studio of Conservation and Restoration of Ceramic, Faculty of Conservation and Restoration of Work of Art, Academy of Fine Arts in Warsaw. The scanning process was done after setting the measuring system in day light condition. In Fig. 3 the scanning process is shown. To scan the area of interest for the chosen object we needed a total of 13 scans to get the complete area chosen.

The second scan after cleaning the object was done choosing the same environment and in the same lighting condition as before. The object was scanned at the same studio and the complete scanning of the object it needed a total of 20 scans for the entire area of interest.

5.2 Reconstruction of the Object

The obtained point clouds from each scan were stitched to reconstruct the 3D model for the chosen object. For each scan, some noisy points appeared where the surface of the object is not smooth or has a discontinuity due to the nature of the 3D scanner. The point groups which are at a distance from the main point cloud based on some given

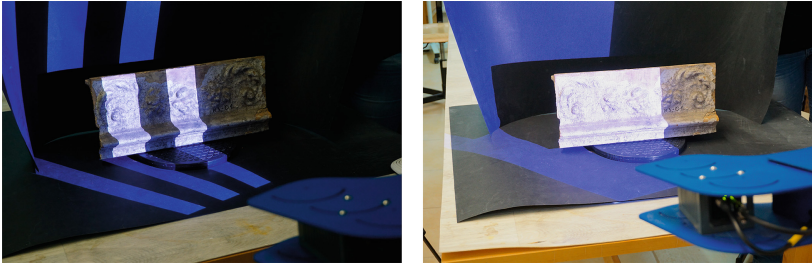


Fig. 3. Area of interest of the object while scanning with the measuring system.

threshold value were considered as noise. The resulting noise was filtered based on the Hausdorff distance criterion. After the removal of the noise point groups, the point clouds were put into the best-fit plane to reconstruct the 3D model based on iterative closest point algorithm [20] both for the before and after the cleaning process.

The registration of the before state point clouds based on the ICP algorithm resulted in a total of 13 204 857 points after reconstruction. The registration was done in Frames which is developed in Warsaw University of Technology using C++. For the registration and to fit the point clouds in the best plane, it took a couple of minutes resulting in an RMS of 0.32 mm. In Fig. 4 the 3D model obtained after registration is shown.



Fig. 4. Reconstruction of the object before cleaning and the density of the point cloud

Following the same algorithm the 3D model of the object after the state was obtained as well. The reconstruction of the scans after cleaning obtained a total of 13 298 867 points with an RMS of 0.31 mm. The 3D model obtained after stitching the point clouds were presented in Fig. 5.



Fig. 5. Reconstruction of the object after cleaning and the density of the point cloud

5.3 Analysis of the Obtained Data

The analysis of the 3D models obtained after reconstruction was done. During the analysis, the change that appeared on the object surface was measured by calculation according to the chosen parameter of the distance between the point cloud before cleaning and the cleaning plane of the object. First of all, both the reconstructions obtained after registering the point clouds were tried to register to base on the best-fit plane. The reconstruction was stored in two different nodes as *original_cloud* and *changed_cloud*. This registration stored the global transformation of the *changed_cloud* concerning the *original_cloud*. The registration obtained with an RMS error equal to 0.15 mm.

5.4 Analysis of Global Distance

The registration of both before and after state 3D models was done to computationally analyze the global distance between these two reconstructions. In this section, the 3D distance from each point from the before state point cloud was calculated (Fig. 6) to the plane of the after state point cloud plane.

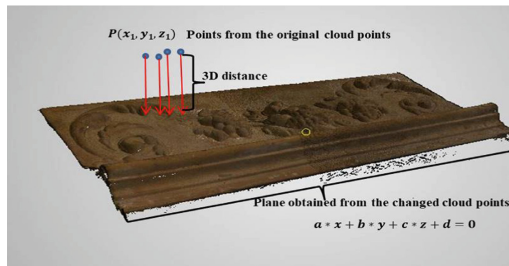


Fig. 6. General representation of the global distance analysis

Pseudo code1:

Input data: Two integrated models from before and after object state in form of XYZ, RGB, NormalsXYZ. They are stored in two nodes: original_cloud and changed_cloud. Radius.

- 1) Get the 3D details (x,y,z) for each point in the point cloud of original_cloud
- 2) Get the 3D plane $(ax + by + cz + d = 0)$ from the point cloud of changed_cloud with the input radius.
- 3) For(int i=0;i<size_of_original_cloud_points;i++)
 - a. Calculate the perpendicular distance to the plane obtained in 2.
 - b. Store the value of maximum and minimum distance obtained (3a).

Output: global distance histogram and the visualization of the surface with a color map.

In this analysis, a constant value of radius 3 mm is considered to calculate the plane for the points in changed_cloud. And results obtained ranging from a minimum distance 0 to a maximum of 2.73 mm is shown in Fig. 7 as ‘global distance histogram’. The color map visualization from the calculated distance is also presented.

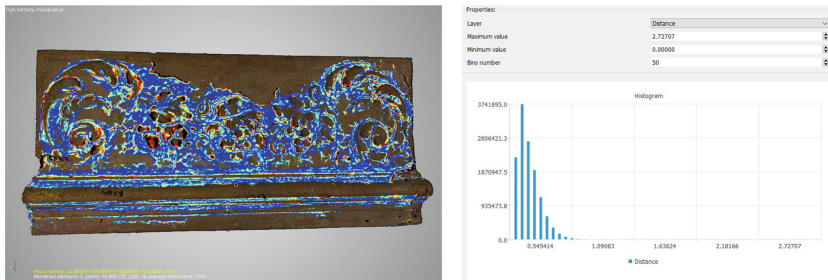


Fig. 7. Results analysis on parameter distance and global distance histogram

5.5 Local Neighbourhood Analysis

In In this work, the goal is to propose a new local measure for change assessment and discrimination on different types. The general idea behind this proposed algorithm is to calculate the neighborhood points for a focus point where we want to assess the change occurrence up to a user-specified range of neighborhood size. And based on this local neighborhood analysis our goal is to visualize the results only for that focus point to present the results like in Fig. 8. The general logic behind this approach is to categorize

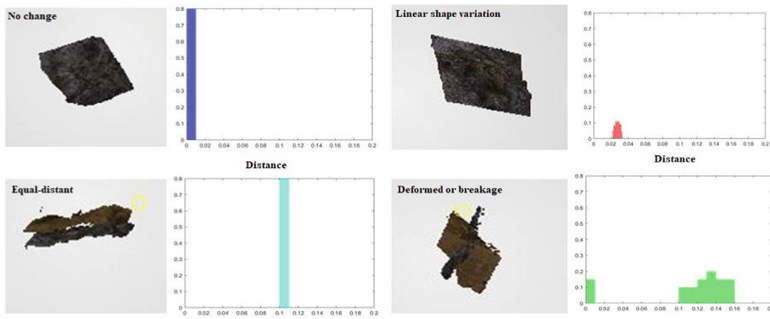


Fig. 8. General representation of the histogram behavior based on the geometry change.

the change occurrences on the surface before and after conservation, based on the behavior of the local-neighborhood distance histogram.

Pseudo code2:

Input: original_cloud, changed_cloud, radius, focus_point, size_of_neighborhood.

Execute Pseudo code1

- 1) Get the details (x,y,z) for the chosen focus_point.
- 2) Calculate the average_point_to_point distance for the original_cloud.
- 3) Find the neighbourhood points for the selected focus point in the range of size_of_neighborhood * average_point_to_point_distance in the original cloud.
- 4) Get the details (x,y,z) of the obtained neighbourhood points.
- 5) For(int i=0;i<size_of_neighborhood_points,i++)
 - a. Calculate the perpendicular distance for the obtained neighbourhood points to the plane of the changed cloud (Pseudo code1: 2).
 - b. Normalize the obtained distance within the range of global maximum and minimum (Pseudo code1: 3(b)).
 - c. Visualize the calculated distance for the neighbourhood points for the focus point to the original_cloud.

Output: local_neighborhood_histogram for different selection based focus points.

The work considered a relatively small area to analyze based on a selected focus point with the size of the neighborhood as 10. The *Pseudo code2* was performed taking different focus points from different parts of the object's surface as in Fig. 9.

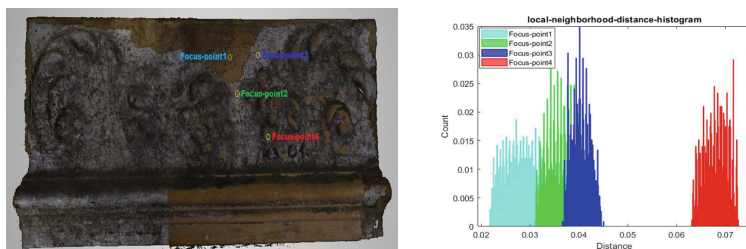


Fig. 9. Selected focus points and the local neighborhood distance histogram

All the distances obtained are almost linear for each focus point since the cleaning was the removal of a layer from the surface. The maximum cleaning part as in focus-point4 reached the maximum value compared to the other parts, focus-point2 and focus-point3 with lesser value in focus-point1 which is presented in local-neighborhood-distance-histogram Fig. 9. The results obtained from both the global distance and local distance analyses are fair enough to justify the amount of material removal from the object's surface.

6 Conclusion and Discussion

There are various techniques and thousands of research is going on to develop the 3D imaging technology both in terms of image capturing set up and based on computational analysis of the captured images. This work introduces the analysis of neighborhood points for a selected point in terms of local histogram calculation and assesses the change of surface geometry for that selected point. This study can solve the real-world bunch of problems in various application areas of 3D imaging.

The challenging part of this analysis was the critical global registration of the obtained scans from the measuring device. This analysis is hard to claim its correctness if the point clouds before and after are not fitted in the same coordinate system. The registration of the scans has been done with minimum RMS ICP to calculate the distance accurately between before and after the state of the object which is very crucial stage to follow the proposed analysis. The cleaning of the object was done on the entire object's surface thus we have no reference for global registration. The results obtained for the analysis is sensitive to the surface curvature.

This object while choosing to work on it due to the unawareness of its change causes the result analysis only linear change type. This analysis will be carried out to analyze the various other CH objects to validate its strength considering all types of categorized change as in Fig. 8. The analysis faced a critical stage of showing inaccurate change while calculating the local neighborhood distance histogram due to its global registration. The future work also includes in solving that critical phase.

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