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Segmentation in Application to Deformation Analysis of Cultural Heritage Surfaces

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Abstract

The geometry comparison is promising for the deformation assessment of cultural heritage (CH) surfaces over the decade. In this work, the potential reliability of the developed changed-based segmentation method was explored in quantifying the deformation on an object. The proposed method was tested using two parts of a single model, considering one ideal in shape and the other part is deformed over time. This study explains how deformation using changed-based segmentation can be identified successfully with millimeter level accuracy in the measurement and inform future conservation treatment. The method is insensitive to the noise of surfaces and the cross-time alignment of two models with a known reference of no change. The technique allows identifying the deterioration based on deformation detection with clear colormap visualization and its significance as a preventive measure without using a physical marker as a reference. The threshold values were fed to the method based on the known respect of no change and quantified as minor and major based on the object's size. The presented result in this paper suggests that the method can be effectively used to enhance 3D documentation of monitoring both indoor and outdoor environments and perform preventive interventions irrespective of the object's size.

Keywords: Conservation, Changed Based Segmentation, Deformation assessment, Geometry Comparison, Documentation, Visualization.

Introduction

The assessment of geometry deformation over time by comparing two 3D models [1] is joint in various 3D applications. This is an important study in the field of CH to improve 3D documentation. But comparing two models always seeks perfect alignment [2], and the traditional approach of nearest neighbor point comparison [3] fails on complex and noisy surfaces [4]. The goal of this study was to identify the deformation that has been developing on the chosen object over time. The novelty of this work lies in assessing deformation on the object applying a change-based segmentation approach. Each surface point was computed for similar deformation behavior over time based on its local distribution and its local distance histogram. The segmentation method could overcome the cross-time registration considering the known no-change part of the surface without using a physical marker.

For this analysis, we considered an object to analyze the deformation of the object. The globe (Figure.1a) is untitled and was created by "A. Nowosielski, Zakład Litograficzny (Lithographic Department) W. Główczewski" a bit after 1920. The measured diameter of the globe is 17,2 cm; the total height of the globe with the wooden stand is 45 cm; where the height of the wooden stand is 21 cm, and the diameter of the wooden base is 19,4 cm. The globe is made of cardboard covered in primer composed of gypsum and chalk. The stand is made from alder. The lower supporting part of the globe has severely deformed over the years due to its weight and extended use.

The objective of this work was to compute the deformation on the bottom supporting hole with respect to the top supporting hole of the object. Using the Structured Light (SL) method the 3D model of the object was reconstructed prior to any conservation intervention. Using the recorded model and changed-based segmentation [5], the differences to the shape of the upper supportive part of the globe (Figure.1b) and the lower (Figure.1c) were computed and assessed. The upper part was treated as the reference shape (with the assumption that its shape is the ideal), and the deviation between it and the shape of the lower part was calculated.

(a) (b) (c)

Figure 1. Globe object: a) its photo and the close image of b) the reference part at the top and c) the deformed part at the bottom.

The applied global geometry comparison of P2P_ProjectionAlongNV [5] approach failed to provide clear information about the deformation on parts of the object due to the lack of finding corresponding surface points from the changed surface, and the results were affected by the cross-time registration error of the two models. To overcome these issues, we have tried the developed changed-based segmentation method [5] to analyze the deformation. This method efficiently could provide a clear colormap visualization about the deformation on the object's surface. Also, the behavior of each surface point considering its corresponding neighborhood points could give detailed information about its local geometry. This information was assessed by forming a local distribution from the reference (top) to the changing surface (bottom).

Background

In the state of the art, for geometry analysis of cultural heritage surfaces the study showed analysis of change on global basis. The very traditional approach of distance computation is calculation of absolute distance between the nearest point from the reference surface to changing surface i.e., C2C (Cloud to Cloud). But this method fails to provide information regarding the direction of change. However, this method works good in terms of providing an overall information regarding the changes on the surface over time. Several works have been followed this method for documenting changes on cultural heritage surfaces [6, 7].

To find the direction of change on the surface in [8], the C2M (Cloud to Mesh) method was used to monitor degradation on the cultural heritage surfaces overtime. But in this approach, the surface information was lost while creating the mesh of the point cloud.

However, a study in [4], showed that M3C2 (Multiscale Model to Model Cloud Comparison) approach works better in geometry comparison without compromising the resolution of the data and irrespective of surface noise. Several recent works have used this method for monitoring and documenting changes on cultural heritage surfaces [9,10]. In [10], the comparison was also presented using C2C and C2M method for geometry comparison. In the M3C2 approach, each surface points on the reference surface were computed to its corresponding change point to the changed surface along the direction of the normal vector. But all these methods were sensitive to the cross-alignment of two models of two different time interval to the same time frame.

In [11], a segmentation method was developed to identify the damaged areas in heritage surfaces using local geometric variations computing on voxelated cloud. However, the method was limited in detecting cracks and other surface defects that result in a change in geometry equal to or larger than that of voxelating grid step size. The method was sensitive to the resolution of the input data or density of the point cloud. In [5], a changed-based segmentation was shown which could identify the changes on the surfaces irrespective of size, resolution, and noise of the input data. Although the method needed a couple of threshold inputs to classifying surface parts into minor and major change, but the method was promising even to get rid of the cross-alignment issue of the two models if a part of the surface was known to be unchanged.

Methodology

The whole shape of the object was successfully recorded from 3D scanning and the deformation at which the lower supportive part of the globe was calculated with respect to the upper part. The cross-registration of both the parts of the globe was done using the Iterative closest point algorithm (ICP) [12]. In this work, we have tested several approaches to assess the global deformation of the object. The traditional approach of geometry comparison was performed using the comparison method of C2C, C2M, M3C2 and the developed technique of P2P_ProjectionAlongNV [5] and the calculated results were compared. But only in the global geometry comparison, the information regarding the deformation was not clear.

For the further query to check the local geometry change behavior of the supporting hole, we have performed a changed-based segmentation [5], which is a grouping of similarly behaving change points from the surface and represent it using a simple colormap visualization. In this approach, the missing information that the global geometry comparison could not provide (Figure 3) was also assessed. And for the segmentation approach, the computation was performed using the entire two parts of the globe as in the developed segmentation method; it was possible to overcome the cross-registration error considering the reference of no change parts of the globe. The outcome of the segmentation method was more cleared and appropriately resembled the deformation of the object.

Results Analysis

The aim of this analysis was a partial shape analysis of the globe. The upper part was assumed to have zero deformation (which might have been caused due to the age of the object and its use) as a reference surface and the bottom as the changed surface for the comparison. Basically, the conservators wanted to compare the deformation of the supporting holes of the globe. To analyze the deformation on the supporting bottom hole, we have decided to consider both top and bottom parts separately.

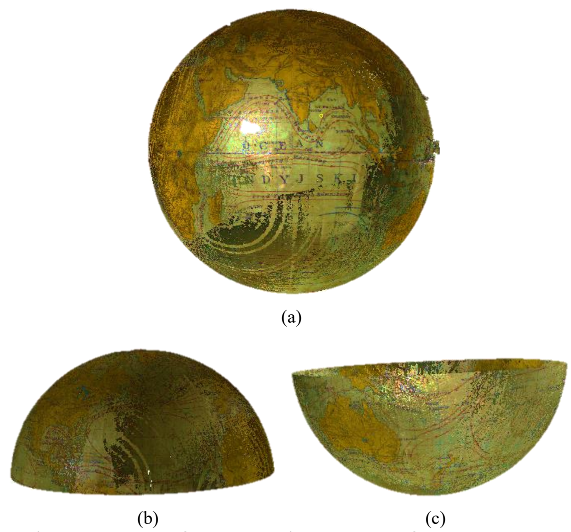

Figure 2. a) The 3D model of the globe, b) the top part of the globe (reference), c) Bottom part of the globe (to be compared)

The two parts were globally compared using the approaches mentioned in Methodology section using CloudCompare. The calculated result from each technique is shown in Figure 3-5 respectively.

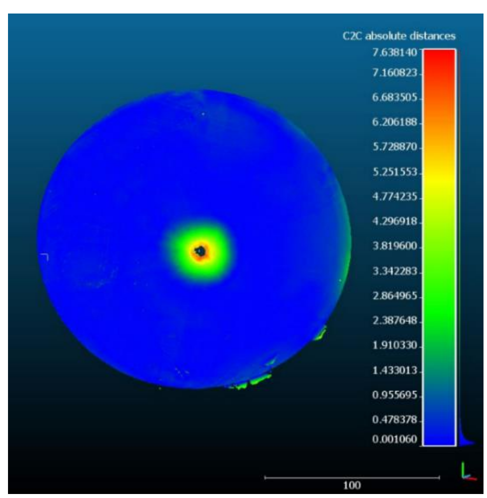

Figure 3. The results from the distance calculation of C2C method.

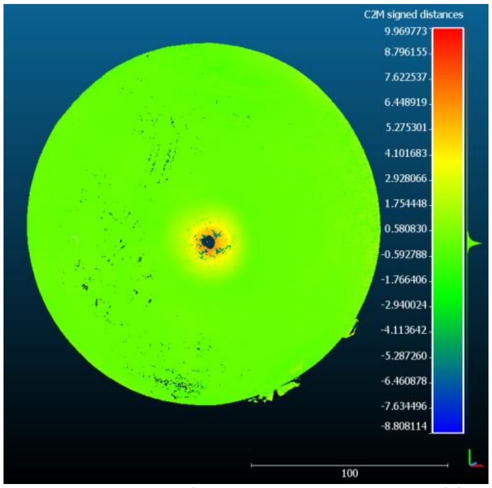

Figure 4. The results from the distance calculation of C2M method.

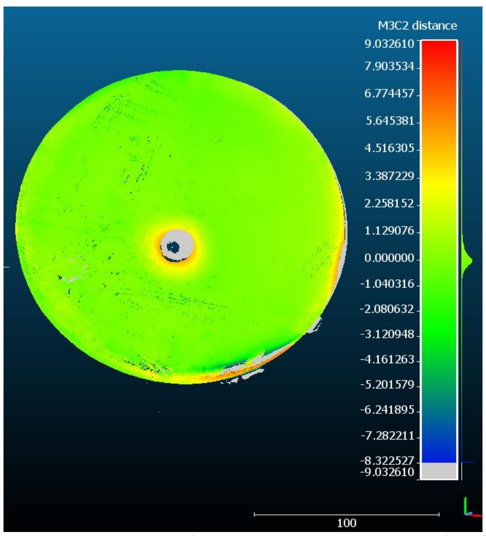

Figure 5. The results from the distance calculation of M3C2 method.

From the results inspection it was clear that each method has some benefit as well as some bias in the visualization. The C2C method could clearly provide a deformation despite of the direction of change. The C2M method could provide the direction of change compromising the less accurate results creating mesh from the point cloud where some surface information was lost. The M3C2 method failing to provide information around the supporting hole but it works good irrespective of surface noise and proving cloud to cloud distance towards the direction of the normal vector. But all the methods were highly affected by the quality of the registration of the two models and unable to provide clear information on its visualization.

The P2P_ProjectonAlongNV method was computed in FRAMES which is developed in Faculty of Mechatronics Warsaw University of Technology Poland, written in C++. The corresponding changed point was searched for each point from the reference surface to the changing surface with a radius of 2mm. The calculated result is shown in Figure 6, where a part around the supporting hole showed a missing information as the method could not find the corresponding changed point with 2mm radius. As suggested in [5], to insure about the missing information, the search radius was increased and set to 5mm and calculated result is presented in Figure 7. The calculated result showed a change of 6.2 mm towards the negative Z-direction.

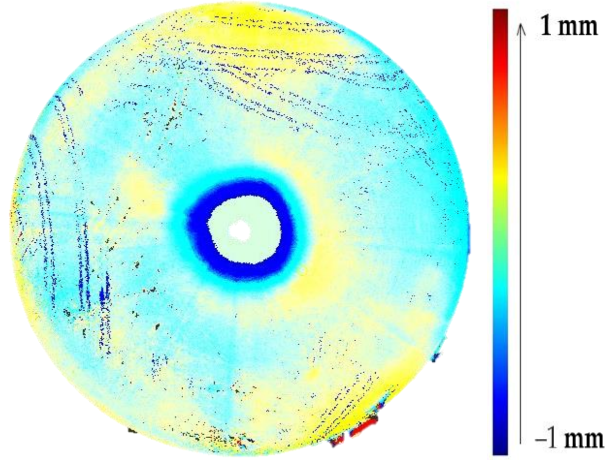

Figure 6. The results from the distance calculation along the direction of the normal vector with search radius 2mm.

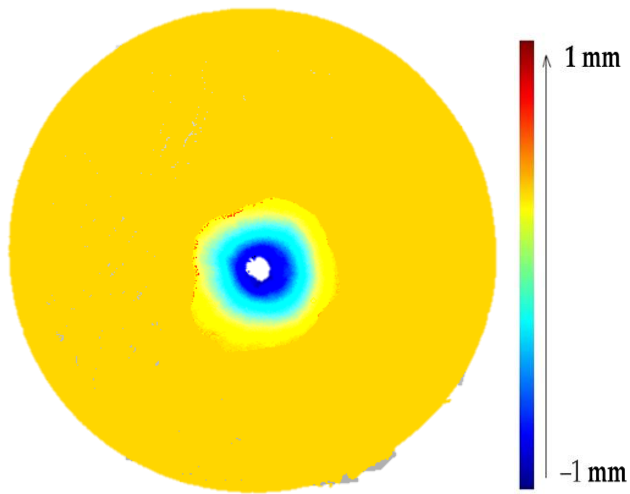

Figure 7. The results from the distance calculation along the direction of the normal vector with search radius 5mm.

The tested global geometry change assessment approaches were affected by the cross alignment of the two parts of the globe, creating a bias on the visualization of the distance calculation. This comparison was unable to provide information from the parts where it could not find the corresponding change point, which is shown in Figure 6, around the supporting hole setting distance value as zero. Also results calculated by increasing the search radius as shown in Figure 7 could not provide much detail regarding the deformation behavior.

The segmentation approach could overcome both problems by providing a clear colormap of the deformation of the globe. The known unchanged parts of the globe was considered to find the threshold value for the cross-time registration error. Several values were provided for the segmentation approach for this chosen object which is shown in Table 1. The size of neighborhood points i.e knn_count to identify each selected points' geometry behavior is calculted by the user input scaling factor. The more the scaling factor it will increase the search radius (radius = scaling factor × sampling distance) of the input data; for each selected point and it's respective knn point count. The method was normalized to sampling distance to make it independent of the respective input data and its sampling density. In this work, we have decided to set the scaling factor value as the default one which is 5 as chosen in [5] and based on the threshold values given the respective minor and major deformation is shown in Figure 8.

Table 1. Theshold values set for the changed based segmentation

Nonchnaged Theshold (N_t)	Deposit Theshold (D_t)	Loss Theshold (L_t)
200	1mm	5mm

The mentioned theshold values in the Table 1 has an importance in terms of data processing for the segmentation of the change behavior. The Nonchnaged Theshold value was chosen based on known reference of no chnaged parts on the surface. This values is basically avoiding the cross time alignment error which we have from the ICP algorithm avoiding them by multiplying a theshold value for the distance distribution comparision i.e the bandwidth of the local distance histogram. This theshold was normalized to calculated noise ($\frac{Noise}{knn\_count} \times N_t$) and sampling distance ($\frac{Sampling\ Distance}{knn\_count} \times N_t$). The default value of this theshold was shown as 1 in the developed changed-based segmentation. The proper selection of this value, one needs a known refrence of unchnaged part [5] of the surface or experience in the conservation studies i.e factors like composition of the object and monitoring period [13] and it can make the visulization much better.

The Deposit and Loss Theshold are basically as the terms itself represents one is for positive change and negative change with respect to the reference. This values are set to categorize the minor and major change on the object which is quite dependent how one user wants to represent and visualize them. As an example we can say for a bigger object change of 1mm maybe be conisdered as minor change but the same can be said as major for a micro object. The theshold values were chosen carefully based on the calculted minimum and maximum distance values from global geometry comaprsion. The Nonchnaged Theshold was set considering the reference of unchnaged part of the globe.

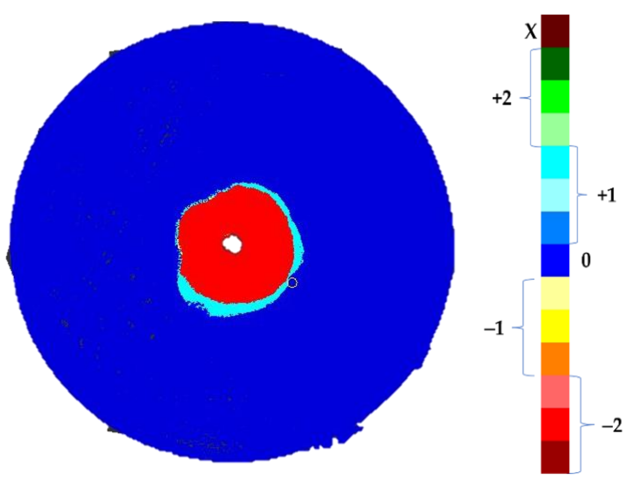

Figure 8. Changed based segmentation and its results with the respective colormap visualization

From the results of the local geometry segmentation approach, we could classify the points with similar change behavior. The colormap represents that the major change is red in color, which is more than 5mm in the negative Z-direction. The color cyan on the surface showed a very few parts of the surface had a minor displacement towards positive Z-direction around the supporting bottom hole, which is less than 1mm. The unchanged part is shown in blue, which was considered as a reference and could be presented as no change. The parts, where in global geometry analysis, showed zero values due to not finding corresponding change point also has a tendency to change towards negative Z -direction which is deforming towards the center of the globe.

Conclusion and Discussion

This study aims to measure the deformation which provides digital documentation of the object for its preventive actions in the future. The work showed a comparative analysis of point clouds through evaluating the existing geometry compassion methods and expanding it to deformation detection and characterization workflow method in [5]. From the results calculated from each comparison method the change-based segmentation approach provided a clear information of the deformation. This study proposes to use this approach as a cultural heritage monitoring tool to detect changes on its surface recorded over time by means of 3D scanning. The method can clearly identify the damages and provide conservators with quantitative information to use for planning physical interventions.

The distance calculation among the points in sets of point clouds allows to have overall detection of changes on the surface. But this distance calculation might be affected due to the alignment of two different interval models in a same time frame. But the change-based segmentation approach could provide information about the local geometry features for each point on the surface proving change behavior over time. This method also provides a solution to resolve the alignment issue up to a certain point based on known reference of unchanged or based on a conservator's expertise where a particular time can be considered as no-change for some objects in particular monitoring environment. This study shows the efficiency and reliability of the developed method of change-based segmentation which can be used as a monitoring tool to identify changes on CH surfaces. The method can provide a clear visualization of damages in simple colormap using highly precise preventive measure.

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