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REVERSE ENGINEERING OF MUSICAL INSTRUMENT BY COMBINING STEREO IMAGING, 3D RECONSTRUCTION, CAD PRIMITIVES AND PARAMETRIZATION

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Abstract: *The paper focuses on 3D scanning and shape reconstruction of an object using different measurement volumes. The paper presents a methodology which numerically completes the missing data such as voids in areas which are optically not accessible. Optically scanned and polygonized meshes are smoothly combined with meshes generated by processing and tessellation of CAD primitives. The procedure is applied to reverse engineering of an antique musical instrument named 'lira'.*
Key words: *reverse engineering, stereo-photogrammetry, triangulation, combined meshes*

1. INTRODUCTION

1.1 Problem definition

The problem at hand is reverse engineering of the antique instrument 'Lira' by digitalization and 3D reconstruction of the overall points cloud of all surfaces. This implies both external and internal surfaces without object disassembly, Fig.1, as well as processing and exporting the points cloud in the STL format.

Fig. 1. Antique instrument 'Lira'- original

As the object has a relatively complex shape and small dimensions (l = 450 mm), the 3D stereo-photogrammetric scanning was performed using different measurement volumes (MV), 250 & 65 mm, GOM (2011). This approach can provide high-quality overall geometry as well as increased resolution and accuracy of selected details. Both sets of points clouds then have to be merged and aligned in high accuracy, whereby the portions of the points cloud obtained using the MV 250 need to be dismissed from the overall data-set in areas which are also covered by the 65 mm measurement volume. The fusion of the data-sets and alignment are implemented based on non-coded reference points which are recognized in both volumes.

1.2 Objective

The objective of the paper is to verify how point clouds obtained in different 3D scanning projects (different measurement lens sets, separate calibration, etc.) can be merged into a single points cloud, maintaining the high accuracy of measurement. Another challenge is to reverse- engineer the invisible parts of the instrument housing by combining measurement point clouds with tessellated meshes numerically generated based on interpolated CAD primitives. The actual quality of merging different point clouds is verified by comparing the parts of the object scanned within both setups and evaluating the respective surface deviations. The reversely engineered object will be remanufactured using CNC machines.

1.3 Previous work

Bohm at al. (1984) and Farin (1993) have provided extensive reviews of geometric modeling and mathematical surfaces. Sarkar & Menq (1991), Cyganek & Siebert (2009), Peng & Gupta (2007), Ristic & Brujic (1997), etc. provide elements of the procedure which involves acquisition and processing of 3D points clouds, triangulation and surface reconstruction. Best-fitting mathematical surfaces to point clouds is discussed by Eberly (2011), Piegl Les & Tiller (2001), Ma & Kruth (1998).

2. METHODOLOGY OF SHAPE ACQUISITION

2.1 3D scanning

The instrument was scanned within three projects, using the 250 mm and 65 mm measurement volumes, Fig.2. All projects consisted of multiple scans which were combined using non-coded reference points. The 65 mm setup was used for the neck and head of the instrument. Both sides of the instrument were scanned and combined via the registration process using selected common reference points. The same registration procedure was used to merge scans obtained by different measurement volumes. The respective calibrations were carried out by applying calibration objects with coded reference points.

Fig.2 incrementally shows the new part of the points cloud, but also shows the surplus points that belong to the table, which are to be erased. The procedure of triangulation provides for 3D reconstruction from the separate data-sets of the two cameras. Processing of the points cloud including polygonization is implemented to regularize the resulting mesh.

The scans with the 250 mm setup have used the 3 mm reference points to align the respective multiple scans. However, the smaller 1.3 mm reference points were also registered and have later been used to merge the points cloud with the one obtained by using the 65 mm setup, since they can be recognized in both configurations.

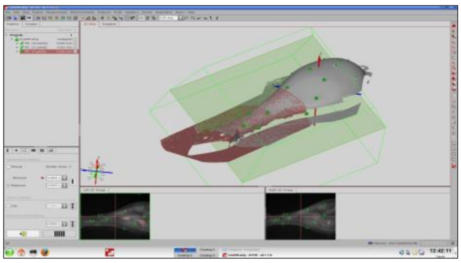

Fig. 2. The scanning procedure, 250 mm measurement volume

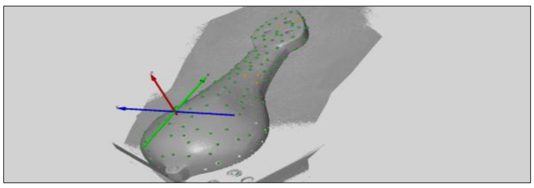

Fig. 3. Common reference points to merge point clouds of different measurement volumes

The procedure of combining the two projects by defining the common reference points is shown in Fig.3.

2.2 3D scanning using MV 250 and MV 65

In order to verify the merging of different point clouds based on selected common reference points, a surface deviation graph was produced for portions of the overall surface scanned in both initial point clouds. This graph, showing very good agreement, is shown in Fig.4.

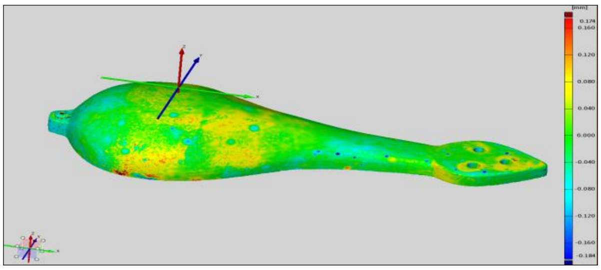

Fig. 4. Surface deviation between different scanning setups after merging of point clouds

2.3 3D reconstruction of optically inaccessible parts (inner surfaces)

The inner part of the object geometry is not optically accessible for the cameras except for the little fraction visible through the cover plate of the instrument body. Therefore a procedure was devised to fill the voids based on existing data and approximation. First, a surface was defined to cut the cover plate from the overall points cloud, Fig.5, exposing the inner parts for processing.

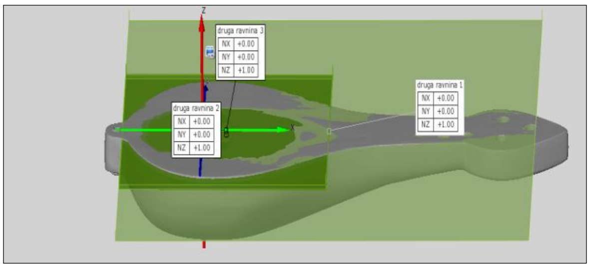

Fig. 5. Creating the cut surface for the instrument cover plate

Fig.6 shows the parts of the inner surface that were scanned and which will serve as basis for approximating the remaining parts of the inner surface.

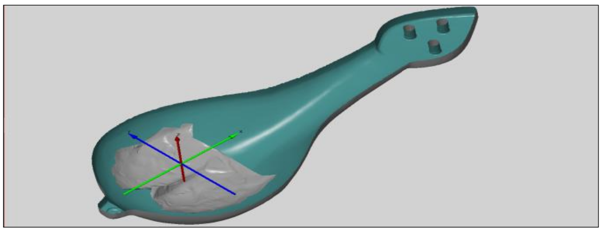

Fig. 6. Inner parts of surface after scanning, cover plate removed from points cloud

The 'recovering' of the invisible inner surface is somewhat arbitrary, since the inaccessible shape could not be scanned. Therefore an approximate procedure was developed. First, a short cylinder was numerically generated co-axially with the corresponding portion of the outer surface of the instrument body. Fig.7. Then the CAD cylinder primitive was tessellated into a mesh following the inversion of the corresponding normal. Subsequently, a number of bridges were created connecting the scanned part of the inner surface with the numerically generated cylinder mesh such that the points cloud positions and the corresponding slopes be continuous, Fig.7. Finally, the holes were filled using surface patches such that the points positions and the corresponding slopes are continuous.

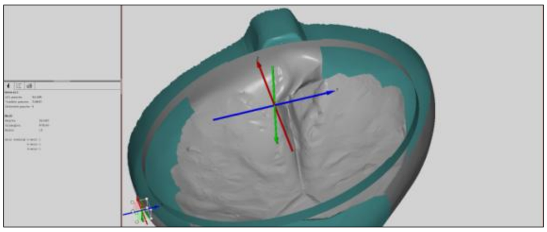

Fig. 7. Completing the inner surface using the CAD cylinder mesh, bridges and surface patches to fill holes and maintaining continuity of point positions and slopes

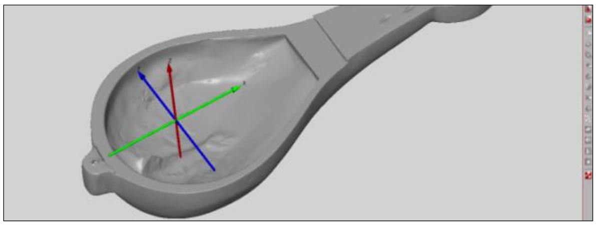

Fig. 8. Completed reverse engineered body of musical instrument

The result of the developed procedure is a full 3D model of the object combined from scanned and numerically generated portions while obeying respective continuity constraints.

3. CONCLUSIONS

A procedure for reverse engineering of the body of an antique instrument was developed and successfully applied. It involves the application of different measurement volumes for 3D scanning, stereo-photogrammetric data acquisition, triangulation and polygonization. Point clouds originating from different projects were merged. Optically invisible inner surfaces were generated by using CAD primitives, tessellation into meshes, creating bridges between different regions which maintain point position and slopes, and surface patch interpolation which preserves C^0 and C^1 continuity.

The reverse engineered instrument was fully prepared for CNC machining. Having a full 3D model of the instrument also opens all possibilities for numerical analysis and simulation.

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