Virtual Restoration of Artefacts Using 3-D Scanning System

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Abstract—**Humans today belong to a Global village with easy and fast cultural exchange resulting in a growing global culture. However, people have a largely different but equally glorious past culture and history. Preservation of all these cultures is important. This paper explores the method of virtual restoration and subsequent fabrication of repaired design. In this paper an 800 years old (material) statue is restored virtually using 3-D scanning, CAD operations and 3-D printing, in the systematic sequence. The statue is a bust of Lord Buddha originally sculpted in 2nd century A.D. The Gandharan Buddha is seated in the lotus position (padmasana), with his hands in the gesture of meditation (dhyana mudra), referring to the Buddha's periods of meditation. The sculpture is presented at Government Museum and Art Gallery, Sector 10 Chandigarh.**

Index Terms—**Archaeology, artefacts, virtual restoration, 3-D scanning, 3-D printing.**

I. Introduction

Reverse Engineering is a technique which extracts the design/concept/information regarding the product and reproducing the product with modifications if required. This involves detailed analysis/ measurements of a product by using the 3-D scanning technology and using the prototype technology to reproduce the products [1], [2]. The research in the field of 3-D scanning got inspired in the late 1980's. This technology can be used to capture images for creating holograms as it supports applications requiring human body imaging (e.g., medical, sports performance, garment creation, security), import real-world objects into computer games and preserving the Artefacts and other simulations [3].

Creation of replicas for study is now possible at any scale, and in almost any material. Replicas are valuable from research, exhibit, and restoration perspectives, and they can enhance the general public's appreciation of the museum or heritage site [3]-[5].

3-D scanners are similar to the cameras, cameras capture colour and surface information with in his field of view (creating images) while 3-D scanner uses images to acquire 3-D data (distance and the surface with in the field of view). It creates a point cloud of the surface and each point indicates its distance from the surface.

There are many types of 3-D scanners available in the market, contact and not contact. Non-contact does not require any physical contact to fetch digital points from an object, instead measurements are taken on reflected and radiated light with minimum human interaction to capture entire object. Non-contact scanners are di-vided into passive and active. Passive scanners capture's ambient light reflected off the object. In Active the radiation/ light is projected on to the object making millions of samples per scan. Triangulation is a major principal used in this type, the camera and the emitter forms the triangle, as the distance between the emitter and the camera forms the one side of the triangle and it is known and the angle of the emitter corner is also known then the angle of the camera corner is determined by the laser stripe swept across the object in the cameras field of view.

3-D scanning emerged in the field of archaeology in 2000 by the students and professors of Stan-ford university digitized the sculptures and architecture preserved in the museum of Italy [6]. In the initial stage it just started as the digitization due to the limitation of the technology [7]. Soon the technology grew, the restoration and reconstruction of the sculptures took pace in this industry [8]. Some of the benefits of using 3-D scanning in the field of archaeology are:

- Accurate form of capturing data from the museums and storing the 3-D models of the acquired data, making it accessible for the present and future generation.
- This provides the access for the digital museums which could be accessed easily by a click of a button.
- The replicas can be easily printed by the use of 3-D printing technology.

These days the 3-D scanning is being used to restore the damaged historical Artefacts by creating the missing part by the use of 3-D designing software and printing the same part which can easily be fitted.

History of Gandhara Sculpture: The Gandharan Buddha is seated in the lotus position (padmasana), with his hands in the gesture of meditation (dhyana mudra), referring to the Buddha's periods of meditation during his quest for enlightenment. The Buddha is depicted with a protuberance on the top of his head called an ushnisha, considered as a sign of the Buddha's wisdom and enlightenment. The Buddha has long earlobes that recall the heavy earrings he once wore before he renounced his wealth. The tuft of hair between his eyes, the urna, is a symbol of wisdom. Halo at the back defines the holiness. The raised right hand with exposed palm and webbed fingers are suggestive of divine characters. The Gandharan Bodhisattvas, or the future Buddhas have a head-dress, elaborately draped clothing belted at the waist, and jewelry typical of a contemporary ruler. Jewels were sometimes set into the head-dress and neck ornaments. The Bodhisattvas are usually standing.

The main objective of the present study was to virtually reconstruct and restore the artefacts. The objectives are listed as below:

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- To propose the methodology for the virtual scanning of artefacts.
- To virtually restore the Non- anatomical shapes using geometric properties.
- To virtually restore the Anatomical shapes using mirror reference, anthropometric data and Golden ratio.

II. Methodology and Materials

Fig. 1. Methodology of virtual restoration.

A. Materials

The restoration of the bust was carried out using Artec Eva handheld scanner. Artec Eva handheld scanner works on the safe-to-use structured light scanning technology and can be carried to the remote areas and museums due to its portable nature. It acquires multiple scans and merges them into a single and complete 3-D model. The software creates a mesh file in the STL format, universal format for the 3-D images and this format directly gets imported into the modelling or retouching software and into 3-D printing machine too.

Materialise 3-matic Research, Dassault systems Catia V5 and GOM Inspect were used for the modelling/ retouching of the STL file created by the Artec Studio. Materialise 3-matic software works on triangulated (STL) files making it suitable for the freeform 3-D data with the combination of CAD tools having meshing capabilities. Catia V5 design software having all the combinations of the CAD/CAM/CAE tools. GOM inspect an editing software with specialization in repairing and analysing 3-D measuring data.

Rapid prototyping machine based on extrusion process was used to print the 3-D objects. It uses the FDM (Fused Deposition Modelling) technology. FDM technology uses layer-by-layer to construct the parts from the bottom to top by heating and extruding thermoplastic filaments. FDM produces complex geometries and cavities easily. The RP machine processes the STL file by creating sliced layer of the model. The INSIGHT software used, prepares the STL file for the printing. The material used was ABS (Acrylonitrile Butadiene Styrene)

B. Methodology

Step I: Selection of Artefact; Due to the limitations in the 3D scanning process, the Artefacts that can be successfully scanned are limited by many factors like colour, transparency, size, available workspace and lighting conditions. Scanners are unable to detect the Transparent, Black and shiny surfaces or the light transmitting surfaces as this works on the principle of triangulation. Scanning an Artefact of a minute size is very difficult because the part features are not clearly visible. Working area of the selected scanner ranges from 0.4m to 1.3m for better results. Some Artefacts are very sensitive towards the light as they degrade if exposed under adverse lighting conditions. The Bust of the Buddha ji was taken up from the museum. The Artefact needs to be reconstructed at specific areas shown in the Fig. 2.

Defect Index	Type of defects
1.	Broken Back
2.	Missing Ear
3.	Broken Hand
4.	Left arm

Fig. 2. Selected Artefact with defects.

Fig. 3. Scanning of Artefact.

Fig. 4. STL file (front view and Side view).

Step II: Scanning of Artefact; Scanning done through handheld scanner has a major advantage, it does not require any reference points to be marked on the surface. Scanner takes about 15-20 minutes to capture the Artefact. The movement of the scanner had to be nominal so that it should not lose the previous reference, if lost then it overlaps the frames and accuracy of the Artefact gets affected.

Step III: Preparation of STL file; the scans were prepared in the Artec studio software. The Auto-pilot function produces the final product. This function uses all the required algorithms automatically. Using pre-defined tool kit followed by registration, fusion and post-processing. The final scans were saved in the SCAN format. SCAN format has the texture + Geometry. The files are exported in the form of STL format (only Geometry) as shown in Fig. 4. The STL formats are the universal format for the modelling or retouching software and for the 3-D printing technologies.

Step IV: Reconstruction of STL; There are four defects which needs to be reconstructed

a) Back.
b) Right ear.
c) Right hand.
d) Left arm.

a) *Reconstruction of Back*: - The back was reconstructed by using sketching and extruding commands on an offset plane. The plane offset parameters were wisely selected and the plane was kept parallel to the back and at an offset. Then a circle was made by taking the nose of the artefact as a centre or projecting the outlines of the back on the plane, the circle which superimpose on the circular arcs was obtained and merged with the other projected curves. The extrusion parameters for the sketch were chosen and Boolean operations was used to connect the extruded part to the main STL file. The Fig. 6 shows the complete form of the sketch, depicting all the circles, curves and lines.

Fig. 5. Unrepaired sketch.

After creating a sketch, the extrusion command was used to provide the thickness to the constructed part as shown in the Fig. 6. This extruded part needs to be connected to the main STL file. The Boolean command was used to connect the back to the main STL file which was reconstructed. Fig. 8 represents the reconstructed back. After the use of Boolean operation, the removal of bad edges, shells, inverted normal were carried out to prepare the final STL file, which can be directly sent to the 3-D printing.

Fig. 6. Extruded back support and boolean operation.

b) *Reconstruction of Right Ear*: The reconstruction of ear was carried out only as one side of the artefact was cracked and the other side was available in good condition. The mirror reference was used to reconstruct the ear. Central plane was created such that it should exactly pass through the centre of nose as shown in Fig. 13, passing from the centre of nose by choosing at least 3 points. Mark a point on centre of forehead, on the centre of nose and on the centre of lips.

Fig. 7. STL file with missing right ear.

Fig. 8. STL file with original left ear.

After successful creation of the plane, the ear was selected. Mirror command was used, giving the central plane as a plane of reference for the mirroring. Then the ear was properly aligned by using Interactive translate and Interactive rotate as shown in Fig. 9. Boolean command was used to join the ear. Fig. 9 represents the reconstructed right ear. The STL file shown in the Fig. 10 represents the missing ear and Fig. 8 represents the original ear from which reference was taken for the reconstruction of the ear.

c) *Reconstruction of Right hand*: The hand preferably of the person whose anthropometric data matches with the requirement was scanned using 3D scanning system. Then the finger were selected using Wave Brush Mark. The selected finger was imported to the main STL file of the artefact. The imported finger was mounted on the hand by the use of interactive translation and interactive rotation. The scaling ratio was taken from the Table 2 to reconstruct the hand. The Fig. 11 shows the scaled ratio of the little finger only. The little finger was connected to the hand by the use of Boolean command as represented in the Fig. 17. Same steps were used to mount the index finger and ring finger too. Fig 13 represents the final reconstructed STL file of the hand.

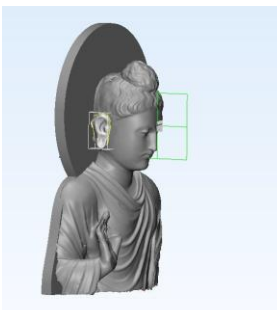

Fig. 9. Alignment of ear.

Fig. 10. Repaired ear.

TABLE I: ANTHROPOMETRIC DATA

	Thumb	Fore Finger	Middle Finger	Ring Finger	Index Finger
Mean Length	67.928	74.234	80.161	75.112	65.204

TABLE II: SCALING FACTORS

Scanned hand	**Length [L]**	**Required length [RL] AC x ratio = RL**	**Scale [S] S = RL/L**
Fore Finger	73.2	70.98	0.959
Middle Finger	82.0	76.7	0.935
Ring Finger	74.13	71.82	0.968
Index Finger	64.31	62.33	0.969

The thumb length was taken up as reference for the scaling factor. The ratio of thumb to the fingers taken is Thumb: Fore: middle: Ring: Index = 1: 1.092: 1.180: 1.105: 0.959. Actual length (AC) of the Buddha thumb = 65mm

d) *Reconstruction of Left arm*: The local area which had to be repaired was selected wisely and removed. The area was reconstructed by using the fill hole commands. The fill hole command maintains the tangency of the surface at edges. The Artefact was reconstructed using the CAD operations. Wrap the STL file for the printing purpose.

Step V: Printing of 3-D model; The FDM technology involves two basic steps: -

a) *Pre-processing*: STL file was imported into the INSIGHT software. Using the slice command, it converts the solid part in to a number of layers depending upon the slice height. Fix the problems if detected in slicing. Create the support to produce a successful built. Create the Toolpath, it's generated for support and model depending upon the geometry and parameters. Inspect the toolpath to avoid problems. Click on the Built option to feed the job in to the machine. After checking the time and material in the control centre, job building is started.

Fig. 11. Selection of fingers.

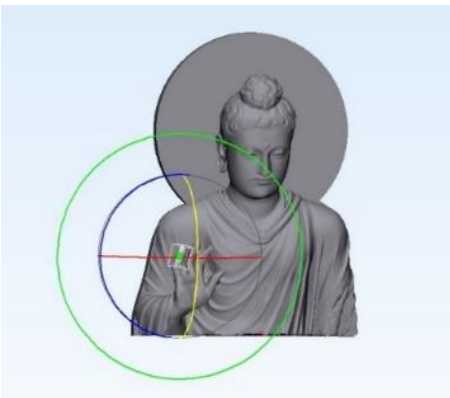

Fig. 12. Translation and rotation.

Fig. 13. Final STL file.

b) *Post-processing*: Removal of support material.

The Fig. 14 represents the final 3-D printed and restored bust of the lord Buddha with his hand showing gesture of meditation (Dhyana Mudra) in the perfect condition.

Fig. 14. 3-D printed sculpture of Lord Buddha.

III. CONCLUSION

3-D Scanning, CAD/ CAM and 3-D Printing techniques were extremely helpful in the field of archaeology for reconstruction and preserving of the cultural heritage. Our study concludes that:

- The proposed methodology for the reconstruction of artefacts proved to be fast, reliable and effective.
- Use of appropriate software's helped in proper and effective virtual restoration of the artefacts.
- The 3-D handheld scanner accurately scans the delicate, non- moving objects due to its mobile nature.
- Using the anthropometric data, reference plane and sketching technique the hand, ear and back supports of the artefact were successfully reconstructed.
- The 3-D scanner captures the geometry and texture both, this leads to a digital storage of an artefact.
- The FDM 3-D Printing was a fast, reliable and cost effective technique which can be used for the virtual restoration of the artefacts.

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