DEVELOPMENT OF ARTIFICIAL LIMB SURFACE USING REVERSE ENGINEERING METHOD

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Abstract

Collecting accurate geometric data in form of cloud point of residual limb by white light scanner is a precise work, due to its numerous curves with odd shapes. In this work the steps of Reverse Engineering is followed right from registration to surface modeling of residual limb for custom fit artificial limb of an amputee.

Keyword: Reverse Engg., Human Limbs, Surface.

I. INTRODUCTION

Model development of different human organ is the need of the day for different medical work including development of modern prosthetics and orthotics which are supposed to be custom fit. The custom fit organ model is developed only when the measurement of organ is exact and manufacturing of it is précised. Both measurement and manufacturing manually results to inaccuracy, because of irregular shape and size of the organs [3]. For example, the conventional manual manufacturing of artificial limbs by first developing negative and positive cast of residual limbs does not give accuracy which ultimately results to the pain and difficulty to amputees putting artificial limbs on his residual part of live limb [2].

The solution of the above lies in CAD model development by reverse engineering [6]. Although reverse engineering of live human organ is a challenging task but it is perhaps only available and feasible technique which can be applied either to improve or modify the existing manual method of manufacturing artificial limb or altogether gives the near perfection with the help of modern tools like CNC or Rapid Prototyping machine [7].

Surface model of the artificial limb can be developed by cloud points obtained by 3D scanners using reverse engineering. Such model designs have better and uniform quality, shorter production time, automated shape and process recording [4]. The process also preserves initial shape for comparison and future modifications, which is lost in case of manual methods of manufacturing artificial limbs.

In the present work, a surface model of a below knee amputee’s residual limb is to be developed. Problem is identified for an amputee who is having an improper fit of the artificial limb socket which causes sores in the interface area of the artificial limb socket and the residual limb of the surface.

This ongoing multistage endeavor involves acquisition of cloud points through non-contact white light 3D scanner, development of wire frame model and finally the surface model of the residual part of the limb. The processes of reverse engineering followed in steps are preparing the residual limb surface, fixing registration marks, 3D scanning, cloud registration & alignment, data filtering, segmentation, curve fitting to build wire frame geometry and building of surface model. These steps thoroughly applied with few innovative techniques and modification to the traditional techniques in use. Each subsequent transformation, like cloud points to curve and curves to surface are analyzed and modified iteratively, to obtain a final shape with minimum possible error. This process supplements traditional method of manufacturing artificial limb with more quantitative techniques for rectification of residual limb socket development [5].

II. DIGITIZATION

Digitization of an object for modeling purpose can be done by contact and non contact 3D scanner. Contact scanners are having touch probes and are best suited for rigid shapes with lot of holes and bosses. Non contact digitizers are best suited for digitizing non rigid objects having complex geometry full of regular/irregular contours like different human organs. In this work white light scanner (Steinbichler) has been used to obtain 3D cloud points of residual limb. Since, the white light scanner is available at CMERI, Durgapur, scanning work is carried out there only to get the cloud points. Further work for development of surface form cloud points have been done at BIT, Mesra, Ranchi (INDIA). An intensive care is to be taken while digitizing a live human body part as they are made of soft tissues and muscles covered with skin for which contour is changing from one position to other. This causes errors while recording process and post processing it to cloud points. The errors can only be prevented by reducing the recording time [1] and arrangement of fixture for stabilizing of the limb under scanning. A fixture is arranged at the scanning site for fixation of residual limb i.e. amputees leg. The scanning process is pre evaluated for ease of movements of a standard white light scanner available before actual scanning. The actual scanning of the artificial limb is performed within 10 minutes.

The room temperature needs to be controlled for the scanner to be operated, which is a pre requisite for the available white light scanner to work. Refractive index of air changes with temperature thereby affecting the optical characteristics of the air. Overall room temperature maintained at 25^{o}C.

The surface preparation also has a very large impact on the resultant cloud point generation and ease of registration process. The surface of residual limb can be made white using a Non toxic white spray or by a standard talcum powder. The surface can now have a better fringe generated over it by the scanner. The quality of the fringes captured also increases.

Registration marks are also placed at suitable places. These marks are placed so that it can be viewed from at least two scans locations. These help in identifying any particular location on cloud points. A group of three marks are placed at any particular location and at least one such group is visible from any particular scanning location.

Fig 1: Scanning of Residual Limb of Amputee at CMERI, Durgapur

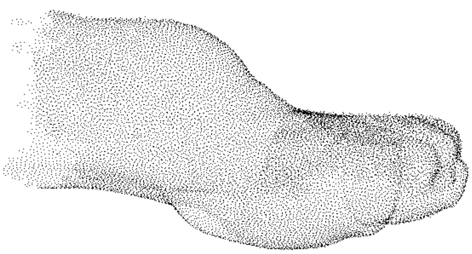

Fig 2: Cloud Data obtained after scanning.

III. METHODOLOGY FOR SURFACE PREPARATION

A. Scan Data Alignment and Sampling

The cloud points can be grouped in patches, which are aligned by dedicated software (IMAlign) with the Steinbichler white light scanner. All the patches are aligned and registered to same coordinate system, with common points in two different scans with different coordinate systems. The common points are the registration marks placed before scanning on the amputee's leg.

Once the data are aligned and exported to the data processing package (Imageware® 12.0) the excess of clouds are filtered using space sampling method which requires the minimum distance between the points to be specified. Chordal deviation method for data reduction and filtering method followed next for further smoothening of the data. The cloud data are polygonized for proper visualization and pre planning.

B. CLOUD SEGMENTATION

Feature based segmentation is adopted for cloud segmentation. All the approximate cylindrical data are classified to a single group which is to be surface fitted like a tube. Remaining surfaces are divided based on their geometry like a dome shape, conical shape and the transition shape. Each of them is to be fitted with Sweep surface, Loft Surface and Curve bounded surface.

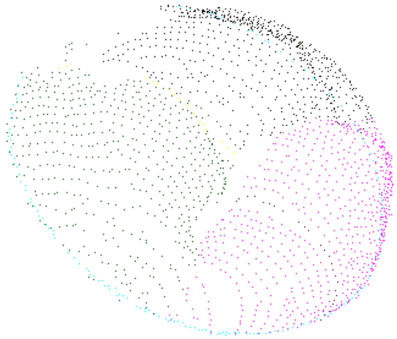

Fig 3: Segmented cloud points

C. CURVE FITTING AND ANALYSIS

A centerline longitudinal section is taken along the length of the tubular part of the leg scan, the section plane being parallel to the saggital plane of the body. A curve is then fitted to the sectioned cloud thus obtained. Now, complete scan data is sectioned in 30 sections, the sectioning planes is aligned perpendicular to the curve generated in the previous step and the extents of the sectioning planes are sufficient to cover the cloud data. This gives a set of circular cloud sections.

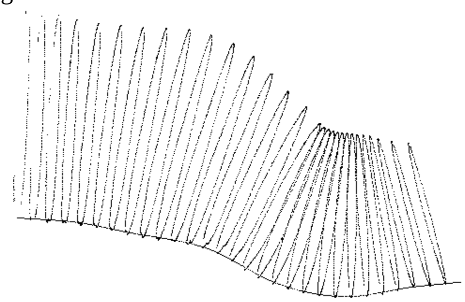

Fig 4: Sectioned Cloud Points

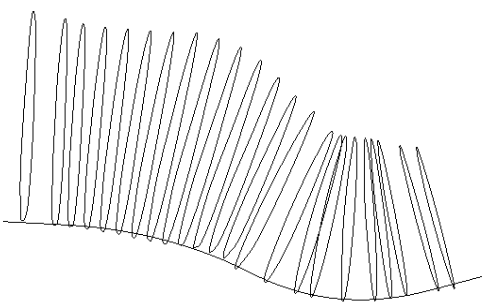

Fig 5: Set of closed B-Spline curves fitted over sectioned cloud points.

A set of B-Spline curve is fitted to these sets of sectioned cloud. These curves are compared to the original cloud and modified with their control points for best fitting.

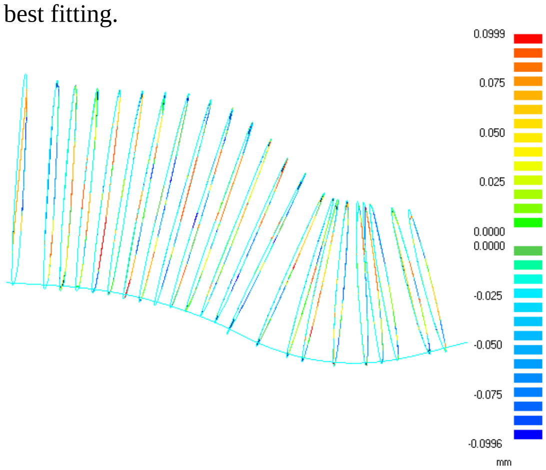

Fig 6: Curve to cloud difference analysis

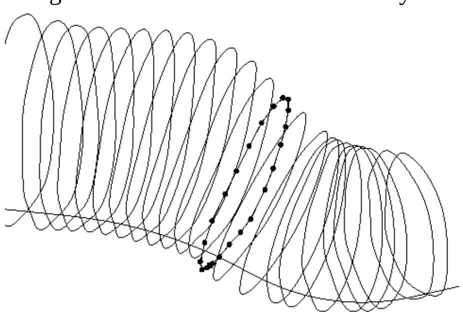

Fig 7: Curve modification using control points

The start points of all the curves are aligned and curves parameters are made to flow in same direction. The unnecessary control points are removed to a certain tolerance and the knots are redistributed uniformly along the length of the curve.

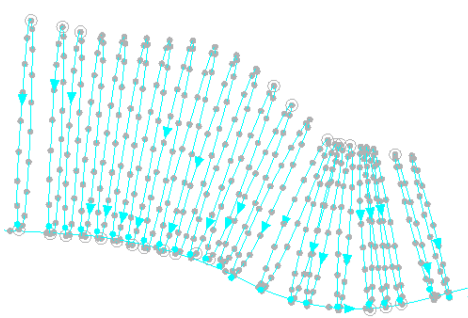

Fig 8: Curve Re-parameterization

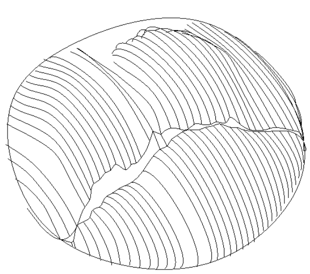

Fig 9: Curve fitting over top surface.

The segmented dome parts of the original scan, each of them are considered separately and processed in a similar fashion as that of the tubular part only the cloud sections gave the open uniform B-Splines. A set of bounded curved are generated for remaining parts of the transition segments. Other curve operations include extending the curves to the edges and trimming the protruding curves.

D. SURFACE FITTING

A lofted surface is generated over the sets of curves. These surfaces are again inspected with respect to the original cloud for deviation, and modified with their control points. A shaded display of the surface is generated for proper visualization. Normals to the surface are reversed for uniform shading, if required. The transition surfaces are generated with the bounding set of curves.

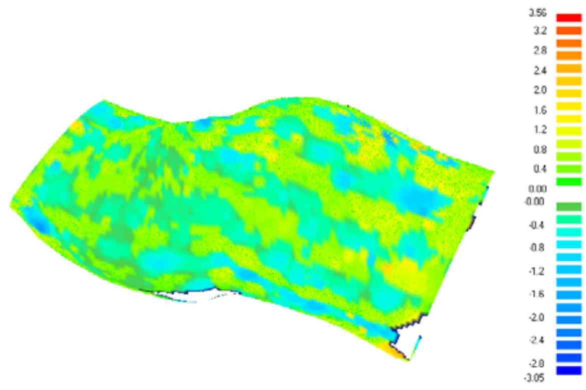

Fig 10: Surface to cloud difference analysis.

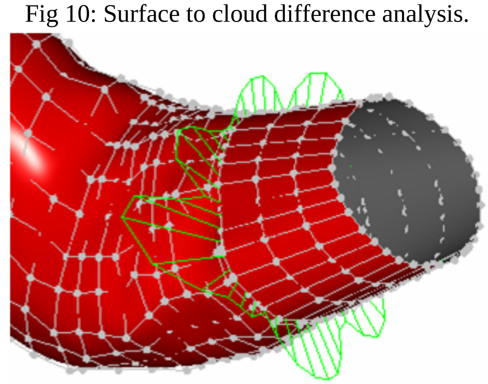

Fig 11: Continuity check at the joining of two surfaces.

Fig 12: Completed Surface Model.

Any joining of the surfaces is made continuous by making first order derivative (slope) and second order derivate i.e. curvature (if required) should be same across each side of the joining surfaces. Any holes in the cloud are patched with suitable B-Spline surface patch and made continuous with the joining surfaces.

IV. RESULTS AND DISCUSSION

All the surfaces are matched to the original cloud obtained after scanning and 90% of the surfaces are within the ±3.0 mm of deviation. A slope variation between the surfaces joined below 5^o are accepted. A maximum gap of 0.05 mm existed between the surface joints. The surface prepared with this accuracy can be very well exported to any Rapid prototyping machine for creating positive mould.

The current work is intended for supplementing the existing manual method. So a further scanning of manual Plaster of Paris (POP) cast prepared for the same amputee is to be scanned and fitted with surfaces. A POP cast surface and live human limb scanned surface difference is to be taken after aligning both the surfaces together. A difference plot will be created which will help in modification of the manually prepared POP cast. Artificial limb is to be prepared based on this modified cast for better fit.

V. ACKNOWLEDGEMENT

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