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EXTRACTING SYMMETRY PLANE WHILE REVERSE ENGINEERING SYMMETRICAL PARTS

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ABSTRACT

This paper proposes a new method to find out the symmetrical axis in the reverse engineering models of symmetrical parts. It is based on an integrated use of Point Cloud Data (PCD) achieved from 3D scans of model and data achieved from Co-ordinate Measuring Machine. Different reference planes achieved from CMM merged with the PCD model are used to generate the symmetry plane. The result of the part modelled using the new technique was compared with the one modelled using conventional techniques with respect to their closeness the actual model. This method was found to be simpler and it assists in producing more accurate symmetrical plane and thus more accurate CAD models in the reverse engineering of symmetrical parts.

Keywords: *Symmetrical plane; Symmetry axis, Geometry, CAD modelling, Co-ordinate Measuring Machine, Point cloud data.*

1) INTRODUCTION

Typically a three dimensional (3D) Computer Aided Design (CAD) model is developed based on the functional requirements of a product. Whereas a reverse engineering approach for generating 3D CAD models uses a physical product which has already been manufactured (Kwan and Woo 2000; Várady et al. 1997; Xinmin et al. 2001; Yinling et al. 2006). Typically, reverse engineering involved the generation of the 3D point cloud data (PCD) models of parts through laser scanners or 3D photography. This is followed by a number of steps as shown in figure 1 to create the final 3D CAD model of parts. The flowchart in figure 1 elaborates the typical reverse engineering approach.

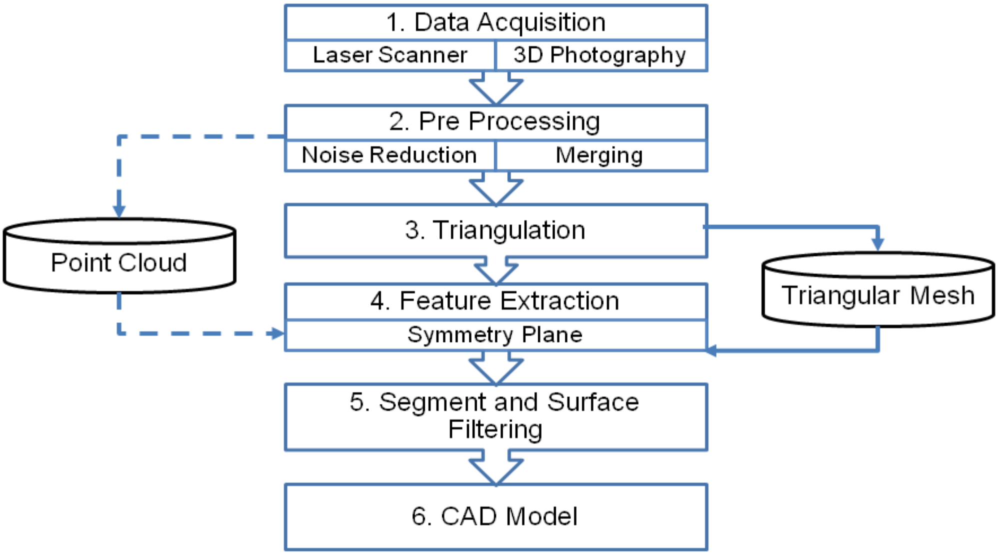

Figure 1: Typical Flow of Reverse Engineering adapted from (Chan and Park, 2008)

Segmenting & surface filtering are the most important steps in this process for creating an accurate model as close as possible to the actual part. In segmentation triangular meshes are split into sub-meshes which then can be filled with surfaces. This process and its refinement have direct impact on the quality of resulting CAD model.

Different features including sharp edges which can be used as references and the symmetry planes are of significant importance for generation of 3D-CAD models of parts from their PCDs. Symmetry plane is one of the most vital as well as critically important feature in segmentation of symmetrical parts (De Momi et al. 2006; Langbein et al. 2004; Tate and Jared 2003).

2) PREVIOUS WORK

The issue of determination the symmetry of part models has been investigated by researchers for many years (Jiang and Bunke 1992; Sugihara 1984; Wolter et al. 1985). Researchers have revealed, the possibilities to find polyhedral symmetry in 3D models in time (n x logarithm(n), where n: No. of vertices), using symbolic categorization/ sorting algorithms (Sugihara 1984). For determining the exact symmetry, algorithms require the capability to notify locally if a point can be mapped to the other, which cannot be true for a PCD with a range of noise and absence of exact reference points or surfaces. Therefore, exact symmetry determining algorithms cannot be practical for the approximate cases. Even though, PCDs of symmetric parts do not have accurate symmetry planes from mathematical point of view, it usually carries enough information for reverse engineering the symmetry. Extracting approximate symmetries is required to meet the functional and aesthetic requirements of parts. Researchers have been determining approximate symmetry planes by different methods.

Fukushima and Kikuchi (Fukushima and Kikuchi 2006) developed a method based on artificial neural networks to extract symmetry plane from the visual patterns. An interesting aspect of this proposal was the use of blur to extract a symmetry plane in order to decrease computational cost. An algorithm was proposed by Tuzikov, Colliot, & Bloch (Tuzikov et al. 2003) to identify the most suitable symmetrical plane in 3-D magnetic reverberation brain illustrations. Process is initiated by obtaining a plane through main inertial axes and optimizing it with the down-hill simplex methodology. This algorithm was found steady regarding the noise and non-uniformity of concentration. However, it was responsive to the location of primary plane during optimization process.

Mills, et al proposed a two-step algorithm for determining symmetry plane (Mills et al. 2001). First step replaced specific clusters of points with their respective centroids. Next step determined the nearly symmetrical plane based on the left over collection of points. Yingling, et al (Yinling et al. 2006) also successfully developed an algorithm for the extraction of an approximate symmetry plane from PCD.

Chang and Sang proposed a method for extracting the approximate symmetry plane from PCD during the reverse engineering of symmetric parts (Chang and Park 2008). In order to enhance the computational competence of the proposed approach, registration of PCD has been tailored by using the inherent characteristics of the problem: (1) the PCD may contain noise and (2) PCD can possibly partially lack symmetry. The proposed methodology proved to be sufficiently competent in managing quite large data sets consisting of millions of unit (either points or triangles) after experimental investigation.

3) METHODOLOGY FOR EXTRACTING THE SYMMETRY PLANE

The methodology adopted for the research is described in figure 2 which is partially based on the guidelines provided by Chang and Park (Chang and Park 2008).

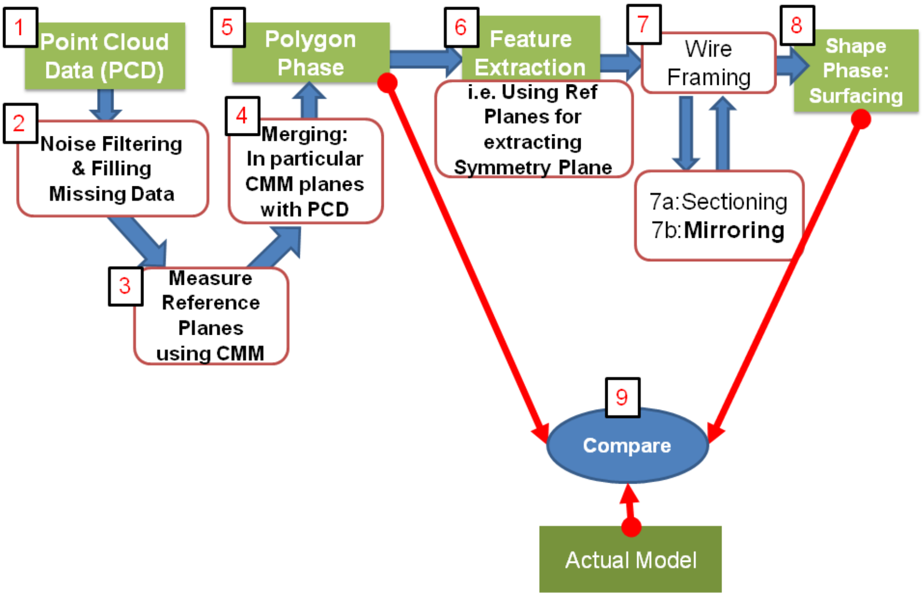

Figure 2: Methodology for investigating the novel symmetry plane extraction technique

The first two steps are usual reverse engineering steps of getting the PCD model of the part and then reducing the noise (unwanted points) in that PCD. The 3rd step involved the measurement of reference planes from the CMM. These reference planes are actually sets of point which are then merged with the PCD model in step 4. This provides accurate reference planes in the model from which the mid plane can be generated later. Then in 5th step, points are converted to polygons or triangles creating a polygon mesh. The polygon model is saved for comparison with the model generated using symmetry plane. Then in 6th step the CMM references planes are used to generate mid plane by simple geometric method of finding the mid plane between two selected reference planes. Step 7 consists of mirroring the half with less noise and gaps about mid plane before surfacing of the polygons is done to generate the final parametric model in step 8. In the end the models generated using CMM and without CMM are compared with the exact part model to investigate the accuracy in step 9.

In this research a novel aspect involves the inclusion of Co-ordinate Measuring Machine (CMM). The most accurate method of measuring other than calibration methods using instruments e.g. Ball Bar testing equipment and Laser calibration equipment etc. The symmetry axis generated is finally validated by measuring the produced part on the CMM, therefore, why not to include the data from the CMM in the PCD to generate a more accurate symmetry plane. A model of part can be developed the PCD using conventional algorithms to find symmetry. A similar model can be developed where symmetry of the part was found by integrating CMM data with PCD. Both the models can then be compared to the actual model to determine the accuracy of the model.

4) EXPERIMENTATION

4.1) Design of the experimental system

The design of experimental system includes the selection of part, the software tools used for parametric and non-parametric modeling and the co-ordinate measuring machine (CMM).

The part selected had to be a symmetrical one in order to fulfill the requirements of the proposed research work. Although there are various symmetrical parts available which could have been taken up for this research work but, it was desired to select a part which had the wide application and is produced in mass numbers. This is because the whole process of reverse engineering is economically justified for mass produced parts. Reverse engineering of non-mass production parts is not justified as it involves high cost in terms of expensive equipment, software, skills, man hours etc. The part selected was 'Horn Pad' or 'Driver Side Air Bag Cover' as shown in figure 3. This part was selected due to its wide application and mass production.

Figure 3: Air bag cover disassembled from steering

In order to get the scan the Air Bag Cover to get a PCD model, a hand held laser scanner (Two Eyed Z-Scan 600) was used. This was outsourced from a company specializing in generating 3D scans.

The software tools and the equipment used were specified by the Manufacturing Technologies Development Centre (MTDC) who funded this research work.

The software used for the non-parametric modeling and handling the point cloud data was 'GeoMagic Version 7.0'. The software used for the parametric modeling was ''DELCAM Power shape Version 6.0' CMM used is manually operated.

4.2) Procedure

The new technique being proposed to find out the best possible symmetry axis which are nearest to the actual model here is the integrated use of; the CMM, parametric modeling software and non-parametric modeling software. The process is explained below.

Step 1: The scanned data was being achieved from the hand held laser scanner and a non parametric model was developed as shown in figure 4.

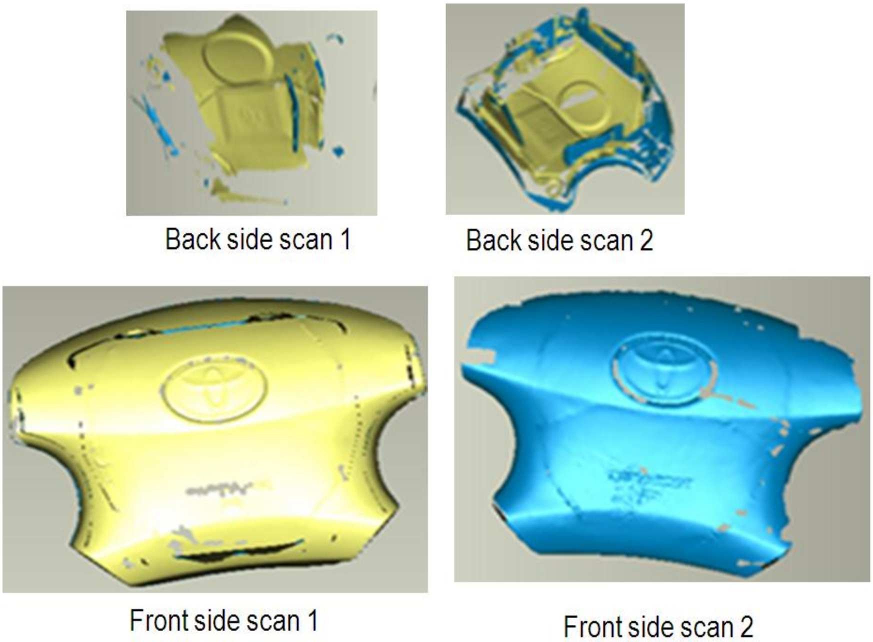

Figure 4: Various scans of Horn Pad/Air Bag Cove

Step 2: The unwanted points were erased from the PCD using the GeoMagic non parametric software.

Step 3: Involved the use of the CMM to measure reference planes on the actual part which can later be used as for extracting the mid plane. Figure 5 shows the selected reference surfaces on the actual being measured using the CMM.

Figure 5: Measuring the four plan sides of air bag cover on CMM

Step 4: The four reference planes measured using the CMM were re-created and generated in a format that could be taken into a CAD modeling environment. Figure 6(a) shows the four reference planes being generated for a CAD environment. Those planes were then merged with the PCD model of the part as shown in figure 6(b). The planes were merged with PCD where most points of PCD were matching with the CMM reference plane point. This step thus ensured maximum positional accuracy of the PCD and by providing a reference geometry taken from the CMM.

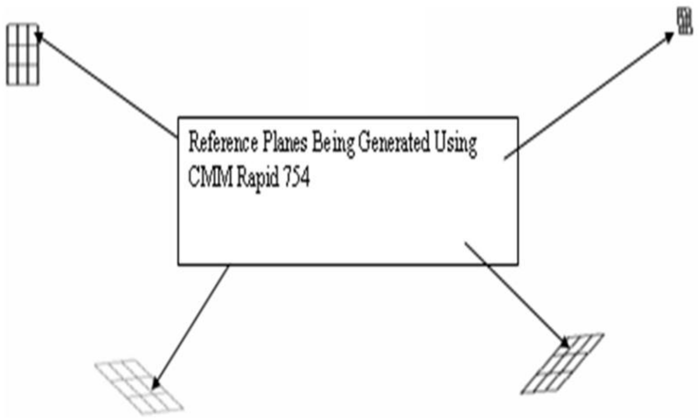

Figure 6 (a): The Four Reference Planes being generated using the CMM data

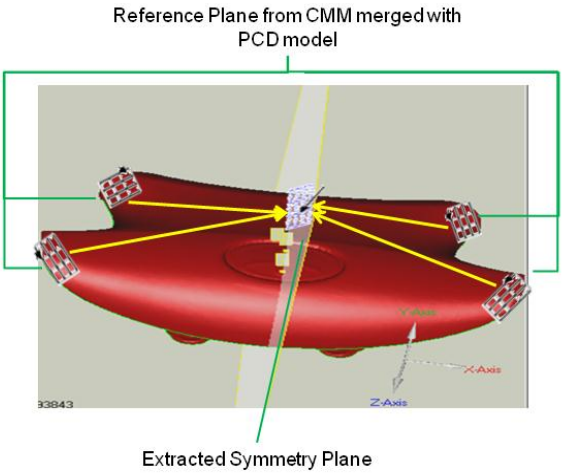

Figure 6 (b): Merging CMM planes with PCD and generating the mid plane using them.

Step 5: The PCD was converted into a triangular mess by collecting the points into interconnected triangles. As a result a 3D model made of triangular mesh was created as shown in figure 7.

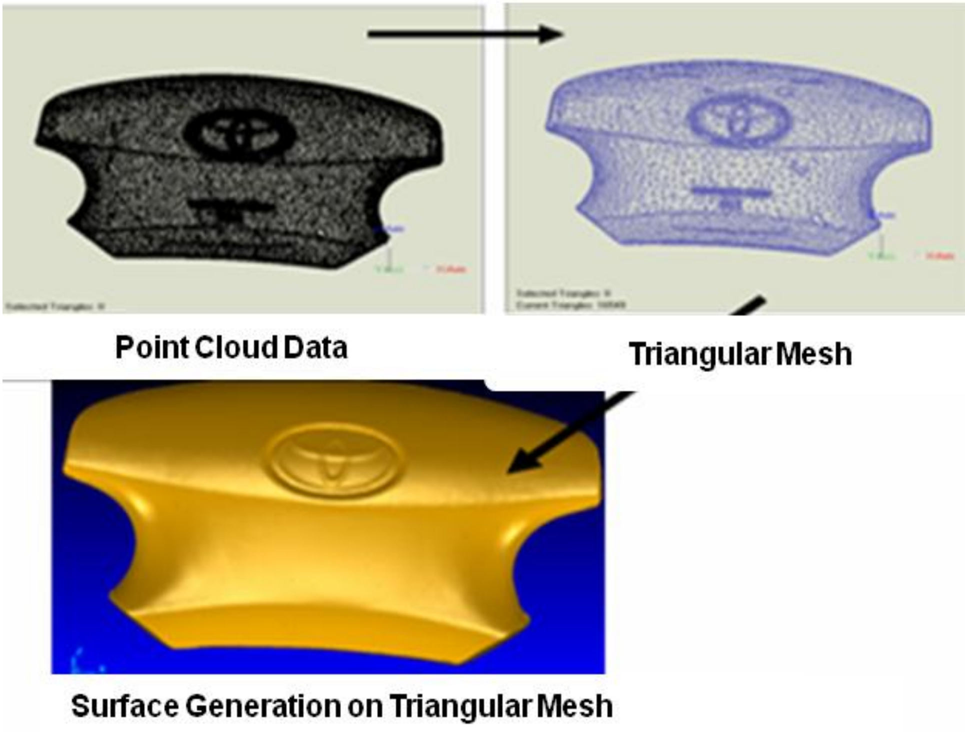

Figure 7: From PCD to triangular mesh to surfaced model

Step 6: Then the triangular mesh model and the four reference planes generated using the CMM were taken to the parametric modelling software i.e. DELCAM-Power shape. The four planes were then used as reference for creating the mid plane for the mesh model as shown in figure 6(b).

Step 7 & 8: Created the wire frame and then surfaces were developed on that wire frame. Only half of the part was modelled and the rest was mirrored about the generated symmetry plane. Figure 7 shows the final CAD model generated using the symmetry plane generated with the novel method.

Step 9: The results of models obtained through this technique were compared against the model generated using conventional reverse engineering technique in terms of their accuracy with respect to the actual mode.

The dimensions of the actual CAD model cannot be shown to avoid publishing of any information that is sensitive to the company. Therefore, the actual numbers have been replaced with "xx" in the table 1 (the values in table 1 have been rounded off to third decimal place). However, the numbers followed by the decimal placed have been shown in table 1 to present the results.

As shown in table 1, the actual model required absolute symmetry of the mid plane with respect to the left and right hand side planes. This shown by the equal distances of the plane being from both left and right hand side of the plane (Colum 1 of table 1). However, the exact symmetry has not been achieved by either the conventional reverse engineering method or the method proposed in this research (Columns 2 and 3 and table 1). However, if a comparison is made between columns 2 and 3 of table 1, it is evident that the results obtained through the proposed method have made it possible to achieve a relatively more accurate symmetry plane. For example, the distance of the symmetry plane extracted using proposed method is xx.415 and xx.395 respectively from left and right hand side upper reference planes whereas, these values are xx.425 and xx.385 for the symmetry plane generated using conventional reserves engineering approach.

Table 1: Comparison of symmetry plane generated using proposed method with the one generated using conventional method

Mid Planes Positions / Reference Planes	Actual position of the Mid Plane	Position of the Mid Plane generated using CMM and PCD	Position of the Mid Plane using conventional reverse engineering method
Distance from upper L.H.S Reference Plane	xx.405	xx.415	xx.425
Distance from upper R.H.S Reference Plane	xx.405	xx.395	xx.385
Distance from lower L.H.S Reference Plane	xx.810	xx.818	xx.973
Distance from lower R.H.S Reference Plane	xx.810	xx.802	xx.827

The results have shown that the symmetry plane generated using the proposed method of reverse engineering is more accurate and closer to the required symmetry of the part than the plane generated using conventional reverse engineering method.

5) CONCLUSIONS

Numbers of useful conclusions are drawn from the experimentation. Some of the results are right up to the expectations either good or bad whereas, some results differ a little from what was expected.

1) There is no need for the lengthy mathematical calculations & algorithms in this method for the location and extractions of the symmetry axis or symmetry plane.
2) The symmetry plane is created using CMM machine which is the final yard stick to measure the accuracy & precision of the reverse engineered part. The symmetry plane created or extracted using CMM was found to be more accurate than the one extracted using complex mathematical algorithms.
3) The advantages of the use of symmetry plane are obviously involved there as only one of the two symmetrical halves of the symmetrical product can be modelled and the other half can be created through mirroring.
4) This method of symmetry plane extraction is fairly lengthy and time taking so this is one of the drawbacks.
5) The shape of the object i.e. symmetrical one needs to be studied very carefully in order to locate the mid points or reference points for the mid plane on the CMM.
6) This method requires very little mathematical algorithms involved and is mainly skill & expertise based is using the modeling softwares both parametric as well as non parametric and the Co-ordinate Measuring Machine.
7) As compared to the effort and time required in the modeling of whole of the part and particularly the noise reduction and gap filling steps involved in full part's PCD handling all symmetrical axis methods are advantageous and so is this one but with an increased accuracy.

REFERENCES

Chang, Minho and Sang C Park. 2008. "Reverse engineering of a symmetric object". Pergamon Press, Inc.

De Momi, E., J. Chapuis, I. Pappas, G. Ferrigno, W. Hallermann, A. Schramm and M. Caversaccio. 2006. "Automatic extraction of the mid-facial plane for cranio-maxillofacial surgery planning". International Journal of Oral and Maxillofacial Surgery 35(7):636-642.

Fukushima, Kunihiko and Masayuki Kikuchi. 2006. "Symmetry axis extraction by a neural network". Neurocomputing 69(16-18):1827-1836.

Jiang, X. Y. and H. Bunke. 1992. "A simple and efficient algorithm for determining the symmetries of polyhedra". Academic Press, Inc.

Kwan, H. Lee and H. Woo. 2000. "Direct integration of reverse engineering and rapid prototyping". Pergamon Press, Inc.

Langbein, F. C., A. D. Marshall and R. R. Martin. 2004. "Choosing consistent constraints for beautification of reverse engineered geometric models". Computer-Aided Design 36(3):261-278.

Mills, B. I., F. C. Langbein, A. D. Marshall and R. R. Martin. 2001. "Approximate symmetry detection for reverse engineering". In Proceedings of the sixth ACM symposium on Solid modeling and applications. Ann Arbor, Michigan, United States: ACM.

Sugihara, Kokichi. 1984. "An n log n algorithm for determining the congruity of polyhedra". Journal of Computer and System Sciences 29(1):36-47.

Tate, S. J. and G. E. M. Jared. 2003. "Recognising symmetry in solid models". Computer-Aided Design 35(7):673-692.

Tuzikov, Alexander V., Olivier Colliot and Isabelle Bloch. 2003. "Evaluation of the symmetry plane in 3D MR brain images". Pattern Recognition Letters 24(14):2219-2233.

Várady, Tamás, Ralph R. Martin and Jordan Cox. 1997. "Reverse engineering of geometric models--an introduction". Computer-Aided Design 29(4):255-268.

Wolter, Jan D., Tony C. Woo and Richard A. Volz. 1985. "Optimal algorithms for symmetry detection in two and three dimensions". The Visual Computer 1(1):37-48.

Xinmin, Lai, Lin Zhongqin, Huang tian and Zeng Ziping. 2001. "A study of a reverse engineering system based on vision sensor for free-form surfaces". Computers & Industrial Engineering 40(3):215-227.

Yinling, Ke, Fan Shuqian, Zhu Weidong, Li An, Liu Fengshan and Shi Xiquan. 2006. "Feature-based reverse modeling strategies". Butterworth-Heinemann.