ANALYSIS OF OPTIMAL METHODOLOGY FOR GEOMETRY RECONSTRUCTION OF AN AIRBORNE LAUNCHER

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Abstract
An Airborne Launcher consists of subassemblies and components made of either regular, freeform or the combinations of both types of geometrical features. Geometry reconstruction of Launcher is required to study the feasibility of Launcher with Aircraft and missile and for the interface study of Launcher with Pylon. The optimal method provides minimum error in geometry reconstruction and preserves the design intend. In the present work various geometry reconstruction methods like Conventional measuring instruments, Coordinate Measuring Machine (CMM) and Laser scanner are considered. The effect of different methods adopted for capturing geometrical information and process of geometry reconstruction are analysed.

Keywords: Geometry Reconstruction, CMM, Laser Scanning, CAD modeling

1. Introduction

Generation of CAD database of a physical object needs several techniques for acquiring geometrical information of the object. The digitization of a physical object can be done either by a contact or non-contact method of measurement. Both the methods have their inherent characteristics which generate errors during geometry reconstruction. Regular geometrical features can be measured using conventional measuring instruments. In this case measurement accuracy is the given measurement-uncertainty value of the instrument [MussaMahmudaet al. (2011)] while measured in a controlled environment. If the same data is used for 3D modeling in CAD software, without further post-processing, the error in geometry reconstruction is same as the measurement-uncertainty. Freeform and complex surface profile needs the optical method of scanning for the geometry reconstruction. Since the optical method of scanning e.g. Laser scanning requires obtaining the cloud of points data and post-processing for geometry reconstruction [Krutch, and Kerstens (1998)], the error induced in the generated CAD model are due to cumulative effect of method of scanning and post processing of data [Deepak Giriet al. (2004)].

In present work various methods are analysed for geometry reconstruction of parts/assembly of an Airborne Launcher. Geometry reconstruction of Launcher is required for generation of 3D CAD model, which can be used for Computational Fluid Dynamics (CFD) study for feasibility of Launcher with Aircraft and missile. This requires capturing the outer aerodynamic shape of Launcher accurately. Geometrical information in the form of 3D CAD model is required for other sub-assemblies for the interface study of Launcher with Pylon. Typical assembly of Launcher with Missile and Pylon is illustrated in Fig.1 [http://en.wikipedia.org/].

Figure 1: Launcher Assembly

2. Problem Description

Although all parts can be scanned by Laser Scanner for geometry reconstruction, but if the part having regular feature are scanned and geometry is generated, it may produce higher measurement error and may lose the design intend hence an optimum method is required in geometry reconstruction process of different part of the launcher. The optimal method provides:

i. Minimum error in geometry reconstruction.
ii. Preserves the Design intend.
In the present work various geometry reconstruction methods are considered. Coordinate Measuring Machine (CMM) and Laser scanner are used to obtain surface data points. Followings are the objectives of the study:

- Comparison of errors generated in capturing the linear measurements of critical dimensions
- Error estimation and data comparisons in reconstruction of surface profile, using CMM data and Laser Scanner data.
- Comparison of errors generated in Geometry reconstruction of CAD model by different methods/software.
- Generation of CAD Models by optimal process.

3. Research Methodology

Various experiments are conducted for analysis and comparison of errors generated by different methods during geometry reconstruction. Post processing software like VX Element and Polyworks for laser scanning, Geomagic Studio and Design Direct for scanned data processing and generation of CAD model, Creo element and Solid Woks for CAD model editing and assembly are used. Following sections explain the research methodology adopted to solve the problem under consideration.

3.1. Minimisation of error in geometry reconstruction

The primary requirement in process of geometry reconstruction is the classification of the features in the individual components, based on the shape and size of the feature. Since the critical geometrical parameters of object need to be given first attention, they are measured with maximum precision compared to others. These parameters depend on the functional requirement of the part/assembly e.g. outer aerodynamic shape is more critical for aerospace component whereas the locations of joint are more critical in a mechanism.

3.1.1. Identification of the most critical geometrical parameter

In a mechanical assembly of a mechanism the relative locations of the joints are of utmost important, which defines the basic kinematics of the mechanism. Fig. 2 illustrates the release mechanism assembly of the Launcher.

To start with the geometry reconstruction processes of release mechanism the locations of joints of the different parts of the mechanism are identified. Here tactile probing of CMM or conventional measurement can give required dimensional parameters which can be used to generate 3D CAD model in design CAD software [A Seiler (1996)]. Since the joints’ locations are in three dimensional spaces CMM is used to find the location of the joints with respect to other joints. This approach provides more concentration on the most critical geometrical features of the object and set the datum of the measurements for the additional geometrical parameters of the other components of the Launcher. When most critical center distances are measured using laser scanner it produced certain amount of error [Susana Martínez et al (2010)], which is analysed experimentally.

3.1.2. Error estimation in measurement of centredistance by Laser Scanner

Following experiment is conducted to evaluate the error generated in measurement of centredistance by Laser scanner.

A master block, of spheres mounted at known locations is measured by CMM (Fig. 3 a) and then it is scanned by Laser Scanner (Fig. 3 b). Scanned data is processed to fit spheres (Fig. 3 c). Measurement is taken fordiameters of spheres Sphere1 (S1), Sphere2 (S2) and Sphere3 (S3), and distances between them i.e. S1-S2, S2-S3, and S3-S1 are measured (Fig. 3 d).

![Figure 3 a: Measurement in CMM](image1)

![Figure 3 b: Measurement using Laser Scanner](image2)

![Figure 3 c: Generation of best fit sphere](image3)
The above experiment shows that error in measurement of centre distances using laser scanner is more in comparison to CMM measurement. The error in the measurement of centre distances of two holes or spheres is also due to the fact that to measure the centre distance first feature is created then its centre is located in the 3D space and then centre distance is measured as shown in fig. 3d. The more the error in generating the feature higher is the value of error generated during measurement.

3.2. Considerations for Optimisation in post processing of scanned data of laser scanner:

Launcher is scanned by a Laser Scanner for capturing freeform surface data (Fig. 4).

During post processing of the captured laser scan data (Fig. 4) following processes are analysed:

3.2.1. Mesh Optimisation:

A poorly formed polygon mesh can be very difficult to surface (Fig. 5a). An optimized mesh is essential for surfacing operations and will yield more predictable results than a uniform mesh.

An optimized mesh has a higher ratio of triangles in areas of high curvature to low curvature. The mesh is optimized to increase the density of triangles in areas of high curvature (Fig. 5b).

3.2.2. Decimation:

Meshes that have undergone extensive repairs or which are very dense (Fig. 6a), they need to be decimated. In this process numbers of triangles are reduced (Fig. 6b).

Curvature protection is taken care, especially on the areas of high curvature.

3.2.3. Combination of measurement and scanning:

The distinct advantages of all measuring instruments and data capturing system along with data processing software has to be combined together for optimum method of geometry reconstruction. Hence the components which are having large regular features and also contains irregular profiles, combination of measurement data obtained by Laser scanning system (Fig. 4) and other precision measuring instruments is used to create CAD model as shown in fig. 7.
4. Generation of Parametric Surfaces

A region of a polygon may or may not be planar or cylindrical. A parametric surface applied to such a region would be perfectly flat or cylindrical. Design intent may be created by classifying regions as planes, cones, cylinders, spheres, lofts, extrusions, freeform and swept surfaces [Chang and Chen (2011)]. Rapidform and Geomagic software is used to generate feature tree based CAD model from scanned data of Laser Scanner. Certain amount of error is produced in capturing of surface points by Laser Scanner and post processing of scanned data for CAD data generation.

4.1. Error estimation and data comparisons in reconstruction of surface profile

The following experiment is conducted to estimate the amount of error generated in generation of parametric CAD surface:

For error estimation CMM measurement data is taken as nominal dimensions of the component (Fig 8a). The component is scanned and offline measurement is done to evaluate the accuracy of captured cloud of points data (Fig. 8b). Then the scanned data is processed and CAD model is generated. Dimensions are measured again. Each dimensions value is compared against CMM value. Radius at different stations in the CAD model is taken by sectioning the CAD model at different stations.

![Figure 8 a: CMM Measurement](image)

![Figure 8 b: Laser Scanning and Sectioned CAD Model](image)

Data obtained are compared which shows that certain amount of error is added while generating CAD model from scanned data. Also this amount of error may vary from one software to another.

5. Results and Discussions

Table 1 shows the comparison of data obtained from CMM and Laser scanner in measurement of sphere-centre distances.

<table>
<thead>
<tr>
<th>Actual value (Ac) (mm)</th>
<th>CMM value (mm)</th>
<th>Laser Scanner value(mm)</th>
<th>δe - δl</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured (Am)</td>
<td>Measured (Al)</td>
<td>(δe) Ac-Am</td>
</tr>
<tr>
<td>Ø S1 = 25.39</td>
<td>25.395</td>
<td>25.434</td>
<td>0.005</td>
</tr>
<tr>
<td>Ø S2 = 25.39</td>
<td>25.396</td>
<td>25.416</td>
<td>0.006</td>
</tr>
<tr>
<td>Ø S3 = 25.39</td>
<td>25.389</td>
<td>25.336</td>
<td>0.001</td>
</tr>
<tr>
<td>S1-S2= 121.1</td>
<td>121.116</td>
<td>121.091</td>
<td>0.016</td>
</tr>
<tr>
<td>S2-S3= 163.3</td>
<td>163.316</td>
<td>163.279</td>
<td>0.016</td>
</tr>
<tr>
<td>S3-S1= 121.1</td>
<td>121.116</td>
<td>121.159</td>
<td>0.016</td>
</tr>
</tbody>
</table>

The above experiment shows that error in measurement of centre distance using laser scanner is from 25μ to 43μ in comparison to CMM measurement of 16μ.

Table 2 shows the comparison between Data obtained by CMM, Polygon data by Laser
Scanner, and measured value in generated CAD model.

Table 2: Data comparison of CMM, Polygon data by Laser Scanner, and CAD model

<table>
<thead>
<tr>
<th>Stn</th>
<th>Radius (Rc)</th>
<th>Radius (Rs)</th>
<th>Deviation (Rc-Rs)</th>
<th>Deviation wrtCMM</th>
<th>Software A</th>
<th>Software B</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>107.463</td>
<td>107.457</td>
<td>0.005</td>
<td>0.022</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>105.793</td>
<td>105.791</td>
<td>0.002</td>
<td>0.023</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>103.873</td>
<td>103.868</td>
<td>0.005</td>
<td>0.013</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>101.728</td>
<td>101.727</td>
<td>0.000</td>
<td>0.017</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>99.335</td>
<td>99.338</td>
<td>-0.003</td>
<td>0.025</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>96.708</td>
<td>96.720</td>
<td>-0.013</td>
<td>0.027</td>
<td>0.014</td>
<td></td>
</tr>
<tr>
<td>220</td>
<td>93.823</td>
<td>93.845</td>
<td>-0.023</td>
<td>0.022</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>90.718</td>
<td>90.725</td>
<td>-0.008</td>
<td>0.047</td>
<td>0.011</td>
<td></td>
</tr>
<tr>
<td>260</td>
<td>87.353</td>
<td>87.365</td>
<td>-0.013</td>
<td>0.052</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>280</td>
<td>83.738</td>
<td>83.747</td>
<td>-0.010</td>
<td>0.057</td>
<td>0.014</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>79.885</td>
<td>79.893</td>
<td>-0.008</td>
<td>0.075</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>320</td>
<td>75.778</td>
<td>75.782</td>
<td>-0.004</td>
<td>0.088</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>340</td>
<td>71.418</td>
<td>71.417</td>
<td>0.001</td>
<td>0.108</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>360</td>
<td>66.803</td>
<td>66.796</td>
<td>0.007</td>
<td>0.113</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>380</td>
<td>61.933</td>
<td>61.924</td>
<td>0.009</td>
<td>0.133</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>56.800</td>
<td>56.790</td>
<td>0.010</td>
<td>0.150</td>
<td>0.014</td>
<td></td>
</tr>
<tr>
<td>420</td>
<td>51.408</td>
<td>51.402</td>
<td>0.005</td>
<td>0.167</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>440</td>
<td>45.750</td>
<td>45.734</td>
<td>0.016</td>
<td>0.180</td>
<td>0.019</td>
<td></td>
</tr>
<tr>
<td>460</td>
<td>39.825</td>
<td>39.828</td>
<td>-0.003</td>
<td>0.195</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>480</td>
<td>33.618</td>
<td>33.634</td>
<td>-0.017</td>
<td>0.197</td>
<td>0.011</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>27.160</td>
<td>27.143</td>
<td>0.017</td>
<td>0.230</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>520</td>
<td>20.420</td>
<td>20.422</td>
<td>-0.002</td>
<td>0.250</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>540</td>
<td>13.398</td>
<td>13.364</td>
<td>0.034</td>
<td>0.278</td>
<td>0.031</td>
<td></td>
</tr>
</tbody>
</table>

Maximum Maximum Maximum
-0.023 0.278 0.011
Average Average Average
-0.001 0.107 0.015

5.1 Process flow for optimum geometry reconstruction

Based on the study carried out a general process flow chart (Fig.10) is given for the optimum geometry reconstruction. In this process first the objective of Geometry Reconstruction is defined. The generated CAD data may be used to represent the actual geometry of the object (e.g. eroded or deformed surface) or it can be used for product development using certain geometrical information of the existing part. Most critical geometrical features and surface with regular geometries are measured with precision measuring instruments and CMM. Freeform complex surfaces are scanned using Laser Scanner System. Geometrical information are obtained and combined together for generation of CAD data. For metrology application, the NURBS surfaces are directly exported and dimensions are measured from generated CAD model. For product development the design intend / modifications are included and an editable feature based parametric CAD model [William Bet et al. (1999)] with complete feature tree is generated, which can be used for downstream activities such as extraction of detail manufacturing drawing, Structural Analysis or Dynamic analysis [Yu Zhang(2003)].

Figure 10: General process flow chart for optimum geometry reconstruction

Figure 11: Components of Launcher and the generated CAD models
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Figure 12: Launcher Frame assembly with Release Mechanism

This procedure is used for generation of CAD models from Launcher components (Fig. 11) and the Assembly of Launcher is generated (Fig. 12)

6. Conclusions

For optimal geometry reconstruction regular feature and linear parameters are measured using conventional measuring instruments. CAD model is generated based on measurement data. CMM is used for scanning 2D curve data and other dimensional and geometrical parameters. Laser scanners are found suitable for acquiring freeform surface geometry. Combining the capabilities of data capturing techniques are used for optimal geometry reconstruction.

Critical parameters are measured using CMM, which produced lesser measurement error in comparison to laser scanning method.

Correctness of reconstructed surface also depends on the method of post processing.

Since the optimal method has to preserve the design intent an editable CAD model with feature tree is generated. The Geomagic software is used for scanned data processing and to generate editable 3D CAD model. This method provides flexibilities to the designer for further product development on the existing hardware.

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References


