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Study on a Scan-to-CAD Workflow and Geometric Deviation Assessment of an Automotive Lower Control Arm

Tran Hoang Xuan Thang[1]

[1]Vinh Long University of Technology Education

Abstract

This paper presents a case study on a scan-to-CAD workflow and geometric deviation assessment of a lower control arm in a double-wishbone suspension system. The component was digitized using an industrial blue-light optical scanning system, and the acquired data were processed in GOM Software and Geomagic Design X 19.2 to generate a mesh, clean the data, remove non-corresponding regions, and compare the scan with a reconstructed parametric CAD model in STEP format. Since the scan included the ball-joint stud whereas the reference CAD model did not, the comparison domain was trimmed before alignment and deviation analysis. Global geometric deviation was visualized by a color map with an in-tolerance range of ±0.5 mm, while three circular functional features, including two rubber bushing holes and one ball-joint mounting hole, were locally inspected on corresponding cross-sections. The results indicate that the main corresponding surfaces of the control arm body show good visual agreement, whereas larger deviations are mainly concentrated at boundary edges, curvature transition regions, and incompletely corresponding domains. For the three circular functional features, the displayed scan and CAD values coincide within the software display resolution: the two rubber bushing holes have diameters of approximately 17.000 mm, and the ball-joint mounting hole has a diameter of approximately 27.443 mm. These results confirm that the proposed workflow is suitable for digitizing, CAD reconstruction, and geometric inspection of suspension-arm-type mechanical components when the original CAD model is unavailable.

Keywords: reverse engineering; scan-to-CAD; blue-light 3D scanning; lower control arm; double-wishbone suspension; geometric deviation assessment.

1. Introduction

In modern manufacturing engineering, three-dimensional CAD models are essential for design, CAE simulation, CAM machining, dimensional inspection, and product lifecycle management. However, in practical production and operation, many mechanical components no longer have original drawings or CAD models, while others may undergo geometric changes due to manufacturing, repair, wear, or long-term use. These issues create difficulties in restoration, replacement, design improvement, and quality inspection.

Reverse engineering provides an effective approach for reconstructing digital models from physical components. A typical reverse engineering process includes 3D geometric data acquisition, point cloud or mesh processing, geometric analysis, CAD reconstruction, and deviation inspection between measured data and a reference model [1–3]. For complex mechanical components, parametric CAD models are more valuable than simple surface models because they can preserve design intent, support modification, and facilitate subsequent engineering applications [4–8].

Among 3D data acquisition methods, blue-light optical scanning enables rapid, non-contact acquisition of high-density surface data. When combined with specialized software such as GOM Software and Geomagic Design X, the scanned data can be used to establish a scan-to-CAD workflow involving mesh processing, alignment, CAD reconstruction, and geometric deviation assessment. This approach is particularly suitable for automotive components with complex shapes, curved surfaces, reinforcing ribs, and precise assembly features [9,10].

The lower control arm of a double-wishbone suspension system connects the vehicle frame to the hub/wheel assembly and affects the working geometric relationship of the wheel during vehicle motion [11]. Because this component contains transition fillets, reinforcing ribs, rubber bushing holes, and a ball-joint mounting hole, it is a suitable object for investigating digitization, CAD reconstruction, and geometric deviation assessment, especially when the original CAD model is unavailable.

Previous studies have addressed reverse engineering, surface reconstruction, and geometric deviation inspection. However, practical reports covering the complete workflow from 3D scanning, data processing, comparison-domain standardization, scan–CAD alignment, to local assessment of functional features remain useful for complex automotive components [12]. In addition, when the reference CAD model is reconstructed from scanned data, the comparison results should be interpreted as an assessment of the scan-to-CAD workflow and the preservation of functional features, rather than as an inspection of absolute manufacturing errors against the original design.

Based on these considerations, this paper presents a case study on a scan-to-CAD workflow and geometric deviation assessment of a lower control arm in a double-wishbone suspension system. The study aims to establish a workflow including 3D scanning, mesh processing, removal of non-corresponding regions, alignment with a parametric CAD model, and assessment of both global and local geometric deviations. The main contribution is to systematize a scan-to-CAD workflow for complex automotive mechanical components and demonstrate the combination of global deviation maps with dimensional inspection at important functional features.

2. Scan-to-CAD Workflow and Assessment Method

2.1. Research Object and 3D Scanning System

The research object is the lower control arm of a double-wishbone suspension system in an automobile. This component is responsible for connecting the vehicle frame to the hub/wheel assembly, while also contributing to maintaining the working geometric relationship of the wheel during vehicle motion. In terms of geometry, the lower control arm consists of two rubber bushing mounting positions on the frame side, one ball-joint mounting position on the hub side, together with many curved surfaces, reinforcing ribs, and transition fillet regions. Therefore, this is a suitable object for investigating the scan-to-CAD workflow because it has both complex geometry and functional features that can be quantitatively inspected.

The geometric data of the component were acquired using an ATOS Compact Scan optical 3D scanner based on blue-light technology, in combination with a rotary table and GOM Software 2021. During the scanning process, the component was placed on the rotary table, and data were acquired from multiple viewpoints to reduce occluded regions and increase surface coverage. The scanned data were then registered, merged, and preliminarily processed to generate a triangular mesh model for the subsequent processing steps. Figure 1 presents the ATOS Compact Scan 3D scanning system and the data acquisition process, including the arrangement of the scanning device, rotary table, control computer, component under blue light, and the GOM Software 2021 interface.

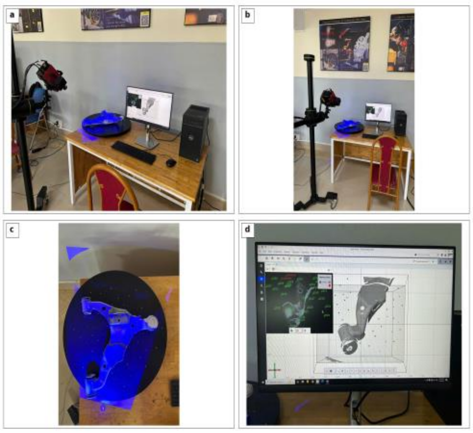

Figure 1. ATOS Compact Scan 3D scanning system and data acquisition process: (a) overall system arrangement; (b) another view of the scanner head–rotary table–computer setup; (c) component placed on the rotary table under blue light; (d) GOM Software 2021 interface during data acquisition and registration.

2.2. Preprocessing of Scanned Data and Standardization of the Comparison Domain

After data acquisition using the ATOS Compact Scan 3D scanner, the scanned data from multiple viewpoints were registered and merged in GOM Software 2021 to generate the initial triangular mesh model of the component. This model was preliminarily checked to remove noise and isolated components that did not belong to the part, while ensuring an appropriate level of surface coverage for the subsequent processing steps.

The merged mesh was imported into Geomagic Design X 19.2 for preprocessing to support the scan-to-CAD workflow. The main operations included repairing mesh errors using the Healing Wizard, checking normal directions, removing redundant data, cleaning boundary regions, and preparing the working mesh for alignment with the reference CAD model. The quality of the preprocessed mesh directly affects the stability of the alignment process and the results of geometric deviation assessment.

In the initial scanned data, the protruding ball-joint stud was still present, whereas the reference CAD model did not include this geometric domain. If a direct comparison were performed, the non-corresponding region would generate outlier deviation values and distort the assessment of the geometric agreement of the lower control arm body. Therefore, the ball-joint stud was removed from the mesh before alignment and deviation analysis to ensure that the scanned mesh and the CAD model were compared within the same geometric domain. Figure 2 presents the standardization process of the scanned data comparison domain before and after removing the non-corresponding region.

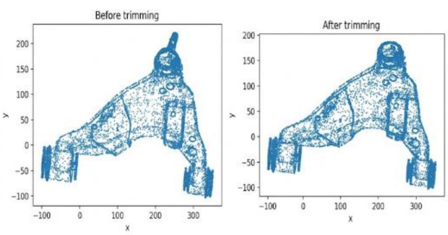

Figure 2. Standardization of the scanned data comparison domain: (a) initial scanned mesh containing the ball-joint stud; (b) mesh after removing the region that does not correspond to the reference CAD model.

2.3. Reference CAD Model, Alignment, and Geometric Deviation Assessment

After the scanned data were preprocessed and the comparison domain was standardized, the mesh was used as the basis for reconstructing the parametric CAD model of the lower control arm. The reconstruction process prioritized preserving the overall shape of the control arm body and the main functional features, such as the two rubber bushing holes and the ball-joint mounting hole. The reconstructed CAD model was exported in STEP format to support the comparison with the scanned data.

In this study, the reconstructed CAD model was considered the reference model, while the scanned mesh after removing the non-corresponding region was considered the measured model. Since the reference CAD model was not the original CAD model from the manufacturer, the scan–CAD comparison results were interpreted to assess the suitability of the reconstruction workflow and the preservation of the main geometric features, rather than as an evaluation of absolute manufacturing errors.

The scan–CAD alignment process was performed in Geomagic Design X 19.2 using the Quick Fit and Best Fit sequence. After alignment, the two models were brought into the same coordinate system for geometric deviation analysis. The overlapping state between the scanned mesh and the reference CAD model after alignment is illustrated in Figure 3.

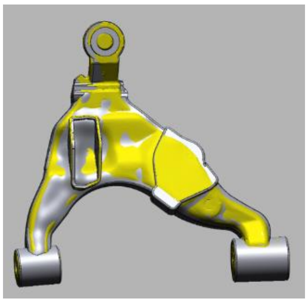

Figure 3. Overlapping state between the scanned mesh and the reference CAD model after the scan–CAD alignment process in Geomagic Design X.

The global geometric deviation was evaluated using the Deviation for Body tool in the Accuracy Analyzer group, with an in-tolerance range of ±0.5 mm. The results were represented by a color map to identify the regions with good agreement and the regions with local deviations between the scanned mesh and the CAD model.

In addition to the global assessment, three circular functional features, including two rubber bushing holes and one ball-joint mounting hole, were locally inspected on the corresponding cross-sections. The diameter of each feature was determined as D = 2R, while the diameter difference was calculated as $\Delta D = D_{scan} - D_{CAD}$. The case of ΔD = 0.0000 mm was understood as no observable difference at the displayed digit level of the software, rather than as an absolute zero physical error.

3. Results and Discussion

3.1. Global Geometric Matching Results

The global geometric deviation map between the reference CAD model and the scanned mesh after alignment is presented in Figure 4. With an in-tolerance range of ±0.5 mm, most of the main surfaces of the lower control arm body appear in green and cyan, indicating relatively good agreement between the reconstructed CAD model and the scanned data. In the front view shown in Figure 4a, the main body region and large surfaces exhibit a relatively stable color distribution, while yellow/orange regions are more concentrated around hole edges, reinforcing ribs, and curvature transition regions.

On the opposite side shown in Figure 4b, the large plate surface of the control arm is mainly within the green region, indicating that the overall morphology of this surface was fairly well preserved after CAD reconstruction. However, yellow bands appear along the outer edges and fillet regions, reflecting local deviations at positions with open boundaries or strongly varying curvature. The side view in Figure 4c and the spatial view in Figure 4d further show that large deviations are not distributed over the entire component but are mainly concentrated at boundary edges, fillet/chamfer regions, and secondary geometric features.

This result is consistent with common characteristics in reverse engineering, where extrema on deviation maps can be affected by outliers, open boundaries, trimmed regions, or domains that do not fully correspond between the mesh and the CAD model [6,9,10]. Therefore, the global deviation map should be combined with local assessment at functional features such as the rubber bushing holes and the ball-joint mounting hole to provide a more accurate evaluation of the quality of the scan-to-CAD workflow.

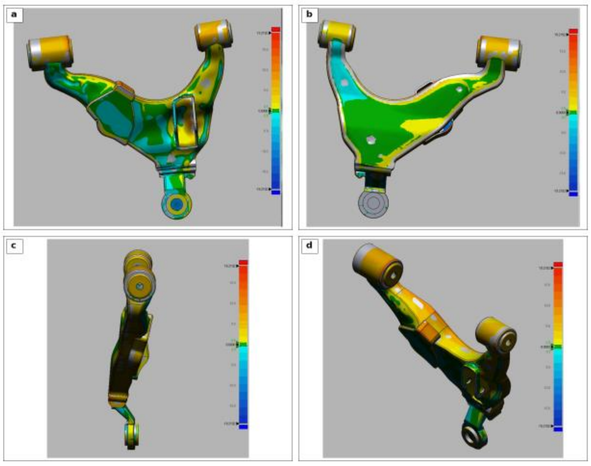

Figure 4. Global geometric deviation map between the reference CAD model and the scanned mesh after alignment: (a) front/main view; (b) opposite side; (c) side view; (d) spatial view. The in-tolerance range was set to ±0.5 mm; the overall color scale was automatically extended to approximately ±19.2192 mm due to the influence of local outliers.

3.2. Local Assessment Results of Circular Functional Features

To supplement the global deviation assessment results, the study further performed local inspection of three circular functional features, including two rubber bushing holes and one ball-joint mounting hole. These positions are important for the assembly and positioning of the lower control arm in the suspension system. The measured results are presented in Table 1 and illustrated on the cross-sections in Figure 5.

Table 1 shows that rubber bushing hole 1 has a diameter of 17.0002 mm, rubber bushing hole 2 has a diameter of 17.0000 mm, and the ball-joint mounting hole has a diameter of 27.4430 mm. The diameter values determined from the scanned data and the CAD model coincide within the displayed digit range of the software, with ΔD = 0.0000 mm for all three features. This result indicates that the reconstructed CAD model has well preserved the dimensions of the main assembly regions.

Observation of Figure 5 also shows that the circle fitted from the scanned data and the corresponding circle on the CAD model have good overlap on the cross-section. This further confirms that the important functional features of the component were reconstructed more stably than some boundary edge regions or transition regions observed on the global deviation map. Therefore, combining the global deviation map with local inspection is necessary to more comprehensively evaluate the quality of the scan-to-CAD workflow [6,9,10].

Table 1. Local comparison of circular functional features between the scanned data and the CAD model.

Feature	Rubber bushing hole 1	Rubber bushing hole 2	Ball-joint mounting hole
R_{scan} (mm)	8.5001	8.5000	13.7215
D_{scan} (mm)	17.0002	17.0000	27.4430
R_{CAD} (mm)	8.5001	8.5000	13.7215
D_{CAD} (mm)	17.0002	17.0000	27.4430
ΔD (mm)	0.0000*	0.0000*	0.0000*

*ΔD = 0.0000 mm is understood as indicating that no difference was observed at the displayed digit level of the software at the time of measurement; this is not a statement of an absolute zero physical error.

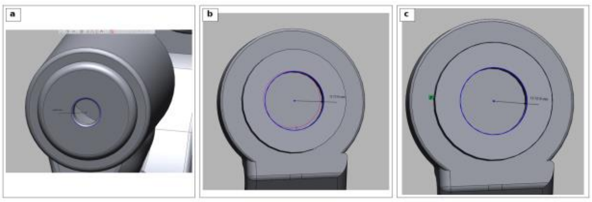

Figure 5. Local inspection of functional features on cross-sections: (a) representative rubber bushing hole; (b) ball-joint mounting hole with an overlay between the fitted circle from the scanned data and the CAD circle; (c) CAD circle of the ball-joint mounting hole on the corresponding cross-section.

3.3. Discussion

The global matching results and local inspection results show that the scan-to-CAD workflow in this study is capable of relatively good reconstruction of the geometry of the lower control arm. The deviation map in Figure 4 shows that the main surfaces of the control arm body have good agreement between the scanned mesh and the CAD model, while larger deviations are mainly concentrated at boundary edges, fillet/chamfer regions, and geometric transition positions. This is a common phenomenon in reverse engineering, as open boundary regions, trimmed regions, or surfaces with strongly varying curvature are easily affected by mesh processing, alignment, and geometric idealization [6,9,10].

The results in Table 1 and Figure 5 show that the main functional features, including the two rubber bushing holes and the ball-joint mounting hole, are well preserved in the reconstructed CAD model. Since these features are directly related to the assembly, positioning, and operation of the component in the suspension system, local inspection has greater technical significance than relying only on the global deviation map. This indicates that the quality assessment of a scan-to-CAD model should combine overall deviation analysis with inspection at important assembly regions.

It should be noted that the CAD model in this study was reconstructed from scanned data and was not the original CAD model from the manufacturer. Therefore, the scan–CAD comparison results reflect the suitability of the reconstruction workflow and the ability to preserve geometry at the main features, and should not be interpreted as absolute manufacturing errors. The present study is limited to a specific case and has not yet evaluated repeatability across multiple scanning trials, global deviation indices such as RMSE and the 95th percentile, or the integration of the CAD model with CAE analysis. These are directions that can be developed in future studies.

4. Conclusion

The study presented a scan-to-CAD workflow and geometric deviation assessment for the lower control arm of a double-wishbone suspension system. The workflow consists of the main steps: 3D scanning using the ATOS Compact Scan system, processing the scanned data in GOM Software 2021, mesh preprocessing, reconstructing a parametric CAD model using Geomagic Design X 19.2, scan–CAD alignment, and geometric deviation analysis.

The global assessment results show that the main surfaces of the lower control arm body have relatively good agreement between the scanned mesh and the reconstructed CAD model within the tolerance range of ±0.5 mm. Larger deviations are mainly concentrated at boundary edges, fillet/chamfer regions, curvature transition regions, and domains that do not fully correspond. The local inspection results show that the two rubber bushing holes have diameters of approximately 17.000 mm, and the ball-joint mounting hole has a diameter of approximately 27.443 mm; the diameter values from the scanned data and the CAD model coincide within the displayed digit range of the software.

From the above results, it can be seen that the proposed scan-to-CAD workflow is capable of supporting digitization, CAD reconstruction, and preliminary geometric inspection of automotive mechanical components with complex shapes when original drawings or CAD models are no longer available. In future research, the workflow can be extended by evaluating the repeatability of the scanning process, adding global deviation indices such as RMSE or the 95th percentile, and linking the reconstructed CAD model with CAE analysis or suspension kinematic assessment.

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