RPS Alignment of Automotive Body Parts in Virtual Assembly and Deviation Analyses

Bibek Rai and Liu Shenglan

Abstract—Quality of products depends on various factors. The most important factors are inspection and measurement. The products have to be controlled in all phases of manufacturing. The production of automotive parts, medical devices, sport equipments or any other body parts has to be controlled in all phases of production. The most important usage is in sheet metal work-piece inspection. One of the latest invented techniques is a scanning method with cross scanning laser devices. This paper describes an accurate and efficient algorithm of point cloud registration. The algorithm contains two steps: initial registration and precise registration. We use the best-fit method to do the initial registration. Then, in this coordinate system, we can extract six nominal points from CAD module, then using corresponding measured point extraction algorithm to get the six measured points. According to the 3-2-1 alignment principle, alignment can be performed and also we can do adjustment alignment. Using line profile to evaluate the part condition, the profile tolerance of any line and surface have datum claim, by comparing and analyzing their definition, indication, tolerance zone ,etc. and regard them as position tolerances.

Keywords—automotive body, alignment, deviation, point clouds, RPS, virtual assembly, gap and flush

1 INTRODUCTION

Automobile product research is inseparable with the automobile body parts assembly quality. In the process of development and research, it usually needs to detect the deviation of the body assembly by build Aussen Meisterbock for the whole automobile body. But to build Aussen Meisterbock is a long period work and the detection speed of key dimensions is slow by the large scale coordinate measuring machine. Therefore, we can use the scanning and measuring equipment with which high measuring efficiency, measure the 3D shape of a part, and then, assemble the parts and detect the deviation under the virtual environment.

Aussen Meisterbock (also referred as, AMB) is a testing tool used for quality assurance in the automotive industry. It is also known as exterior master jig. Its task is to optimize and fine-tune dimensional fits on vehicle project before a production launch. This involves coordinating the fits of all parts that are visible on the exterior with one another. It is a kind of building support which is manufactured according to the RPS positioning principle of automotive sheet metal parts, used for installing side wall, doors, roof, fender, parts of the front and rear wall and other assembly parts, making systematic evaluation on parts appearance match on the premise of RPS adjustment, makes 3d coordinates testing reports of each assembly parts. The reports can be used for accurate analysis of matching defects, guiding parts matching optimization. We can contemplate our method as virtual assembly platform. It has the properties and can be used to perform RPS alignment and to identify and compare deviation of RPS corresponding points, assess RPS adjustment and contrast profiles of parts for further verification. It has some of the function and capabilities to match the work of AMB and it can be a lot cheaper, requires less physical structure in workplace, saves time due absence of installation of assembly parts, less work burden and can be economically more stable. And have lots of other advantages.

In this method proposed by Koch, a triangular mesh is generated from CAD-geometry. After points are moved inside the tolerance boundaries a visualization of the mesh can be presented. As the differences are usually very small, various visualization techniques can be used to visualize the deviations [2]. Barr proposes different transformations, like bending, twisting, and stretching for the deformation of solid objects. The methods are rather efficient, but the problem is that arbitrary deformations are not possible [3]. Another commonly used method is the free-form deformation [5]. Coquillart extended the method. Prismatic lattices with rational splines are used to deform the geometry in an intuitive manner. To enable customized deformations, a library of different lattices, which could also be enhanced by the user, was proposed [1]. The method can change the measurements of free-form surfaces by extending or shrinking the geometry in a certain direction. It can also be used to perform local deformations [4]. Chen, Brown, and Song (2000) and Gershon and Benady (2001) provide overviews of several non-contact measurement technologies [7][8]. Although the coordinate measurement technologies may differ, all systems share similarities in data acquisition and data post-processing or alignment methods. Verady, Martin, and Cox (1997) and Wolf, Roller, and Schafer (2000) summarize the application of non-contact measurement technology and how measurement results are generated [6][10]. ICP and related methods (Besl and McKay, 1992; Rusinkiewicz, 2001) use specifically selected features from the resolved geometry to align or register measured data against a nominal reference. The iterative

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alignment is essentially a best fit for a subset of interesting features among the thousands available in a large-volume measurement application [9][11]. Other tools, e.g. 3DCS Advanced Analyzer Optimizer which were developed from SOVA methodology can be used to set the tolerances accordingly to the designers specification [12]. One method to generate non-ideal visualizations is proposed by the VITAL project [13]. Different non-ideal views were generated and presented to different participants. The impact of different factors in percepting gap and flush measurements were then calculated by averaging the guessed values of each participant. The experiments showed that it is different and depending heavily on the used visualization. Gaps should be evaluated with a stereoscopic view combined with texture, while flush should be evaluated with a small distance to the gap [14]. Detailed discussions on sampling uncertainty in 3D measurement analysis and uncertainty of extreme fit evaluation can be found in [15][16]. The basic idea behind the algorithm is to use a closed form solution for the registration of corresponding points that has been described [17]. A description of a metrology system which is used for rapid inspection of critical dimensions in high volume production can be found in [18].

2 OUTLINE OF ESTABLISHING VIRTUAL ASSEMBLY PLATFORM

This section sums up the research work on virtual assembly and illustrates the ideas, routs and methods, key components are described and the results obtained are given. Then details this section from RPS registration principle and procedure, RPS point type analysis, RPS registration accuracy analysis, RPS correspondence point extraction method, RPS error range matching and other aspects are detailed.

The scanned data can be obtained as:

- Equipment installation and check calibration. Complete the installation of the tripod, measuring arm and laser scanning head. Locate the measurement equipment to ensure adequate scanning range.
- Measurement projection formulation. According to the characteristics of the parts and the focus of the measurement area, determine the location of the parts and the overall scanning program.
- Practical measurement. Focus on measurement of surface and edge data, pay attention to the measurement point of view.
- Data merging. Reduce the split error and ensure that two data sets have sufficient overlap region. Use the best-fitting data to the data object command, to complete the two measurement data set registration, and then to make triangulation.

2.1 RPS Registration Principle and Procedure

Assembly platform is a technology of RPS positioning that assemble vehicle side, door, cover, roof, fenders, front and rear panel for sheet metal parts with matched sample frame based on RPS registration principle and then evaluate the appearance matching of parts. RPS registration principle also known as RPS reference point system principle, is a positioning methods that defined some RPS points (usually has 6 points) on parts and build model coordinate system by 3-2-1 principle, so then restrict the model's six degree of freedom. The RPS datum points can make the parts design reference point, positioning and, reduce the deviation caused by the datum in the process of vehicle parts' machining and assembly, and ensure the quality stability of the automobile production process. When the measurement data are used to build the virtual assembly, the RPS points on the measured data are matched with the design of the RPS points, which is also called RPS registration.

RPS registration as shown in Figure 1, 6 RPS points in the graph are respectively controlled by the coordinate axes YYY-XX-Z. The RPS points in design nominal model denoted by Pi (i=1,2,…,6), coordinate value denoted by (xi,yi,zi), by using these 6 points, the theoretical coordinate system (OXYZ) can be constructed: where P1, P2, P3 to build Y coordinates, P4, P5 to build X coordinates and P6 to build Z coordinates. Correspondingly, there are RPS* points in the measurement data, denoted by Pi*(i=1,2,⋯,6) ,the measurement coordinate system is established O*X*Y*Z*. The nominal coordinate system OXYZ is coincident with the measurement coordinate system O*X*Y*Z* after the coordinate transformation, then rotation matrix R and translation T expressed as:

$$\begin{cases} \boldsymbol{R} = \begin{bmatrix} X & Y & Z \end{bmatrix} \cdot \begin{bmatrix} X^* & Y^* & Z^* \end{bmatrix}^T \\ \boldsymbol{T} = O - \boldsymbol{R} \cdot O^* \end{cases} \quad (1)$$

According to the principle shown in Figure 1, the specific implementation steps of RPS point registration method in 3d metrology software are as follows:

- Importing CAD model (REF), obtaining coordinate system OXYZ, and importing six RPS points' theoretical position;
- Importing measurement point cloud (DATA);
- Using Best-Fit method for initial alignment DATA with the REF, to obtain the initial Rotation matrix R0 and Translation vector T0;
- Extracting the corresponding points in the DATA with nominal of RPS point, obtaining RPS* point, and establishing measurement of coordinate system O*X*Y*Z*;
- Through the RPS* point with the RPS point alignment (Reference Targets→Align), obtaining the final Rotation matrix R and Translation vector T, and then the R and T is acting on DATA;
- Repeat steps (4),(5), until the DATA has a good matching with REF.

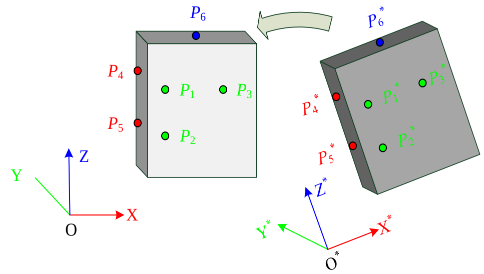


Fig.1. RPS point registration

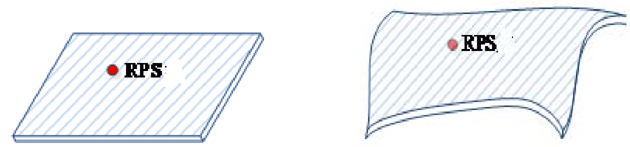
Theoretical RPS point is in the automotive parts structure design and it has been determined, including the information of a point position coordinates, control of the axis direction and tangent plane, etc. this information can be exported in the CAD file by the IGES general transformation format, and make appropriate settings in the metrology software. The measurement coordinate system and the design coordinate system are different. Thus the measurement data and the nominal CAD position are very far. The initial alignment is required to extract the corresponding RPS* points in the measurement data. Initial alignment can be manually specified by the matching points of the three or more points groups and can also be carried out using the best fit method. Point cloud data suggest that the latter approach, you can have a better alignment effect.

Fourth step is very critical, whether extraction of the corresponding point RPS* is accurate and reliable, will affect the measurement data and the accuracy of theoretical CAD matching. This is a key to build a virtual assembly platform. The project is based on the classification and analysis of the shape features of RPS points, and design algorithm to extract corresponding points. So improve the matching accuracy of measurement data and nominal CAD. For some parts with large deformation, when the initial alignment and re-alignment of the RPS extracted from the corresponding point position has a larger change, then the iterative idea is needed to carry out multiple RPS corresponding points extraction and RPS registration.

3 RPS CORRESPONDING POINT EXTRACTION

3.1 RPS Point Type Analysis

According to the characteristics situation of the RPS point in local range (usually consider a range of 4 * 4 mm2) in typical automobile sheet metal parts, RPS point can be divided into three categories: surface RPS point, profile RPS point and structure RPS point. For different types of RPS points, we will use different methods to extract RPS corresponding points. RPS point is located in sheet metal surface or flange surface. It can be divided into planar point and surface point, as shown in figure 2. Because it is difficult to extract surface RPS point accurately when surface curvature is large, it is designed to place RPS point on a flat area. Based on that, in the subsequent algorithm design in this project, the surface RPS point will be treated as planar point.

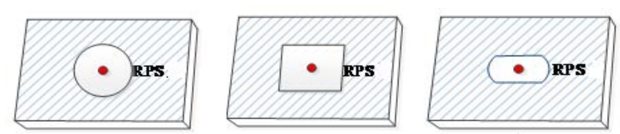


(a) Plane RPS point (b) Surface RPS point
Fig.2.The diagrammatic sketch of surface of the RPS points

Profile RPS point is located on the side edge of the sheet metal parts. It can be divided as trimming point and flanging point, as shown in figure 3. Part of the trimming point is narrow long plane. Plane width is very narrow, as the thickness of the plank is only a few mm.

(a) Trimming RPS point (b) Flanging RPS point
Fig.3.profile (contour edge) RPS points

Structure RPS point is difficult to directly measure and need to use local features to generate the measurement points. Depending on the difference in the characteristics of shape, it can be divided into hole center RPS point and geometric constraints RPS point. Hole center RPS point are divided into round hole center, rectangular hole center, slots hole center, waist shape hole center and so on, and geometric constraints RPS point has center of symmetry and midpoint, as shown in figure 4.



(a) (b) (c)

(d) (e)

Fig.4. Schematic structures of RPS points (a) round hole center RPS point (b) rectangular hole center RPS point (c) slots hole center RPS point (d) waist shape hole center RPS point (e) center of symmetry RPS point

By using 3d metrology software features (Features - Points) to represent RPS point, according to the features of whether they are attached to other features can be divided into basic point (Primitive) and derived point (Dependency), Moreover the software offers a variety of method to create the

Features-Points. Primitive can be used for surface RPS point and profile RPS point. They can be imported by IGES file. Dependency can be used for structure RPS Point. For example, the round hole center of derived type is Circle Center, rectangular hole center of derived type is Rectangle Center, slots hole center of derived type is Slot Center, waist shape hole center of derived type is Ellipse Center, the Center of symmetry can be derived by Average of Points.

3.2 RPS Registration Accuracy Analysis

RPS registration accuracy is affected by the precision of the parts manufacturing, scanning measurement accuracy, RPS corresponding point extraction accuracy and other factors. The manufacturing, measurement or extraction methods themselves will have the limit of accuracy. The accuracy of these methods is also affected by the local shape characteristics of RPS points. According to the latter, the method can be put forward or selected based on the analysis of the influence of the shape characteristics. For example, for the precision of parts manufacturing, when the sheet metal parts have a larger deformation, the iterative method can be used to extract the RPS corresponding point and have RPS registration many times. So make RPS corresponding points gradually close to the theoretical point and improve the accuracy of registration. The effect of the local shape features of RPS points on the extraction accuracy of RPS points is analyzed in detail. Mainly considering the surface RPS points and contour edge RPS points, RPS is constructed by the extraction and surface contour edge is generated.

On the surface RPS point, the information of design definition contains the point position coordinates, control of the axis direction and the tangent plane. Take the RPSFy1 point of the left front door of a certain car as an example, the information of the surface RPS point is: Position coordinates (411.37,-843.55,535.00), control of the axis of the direction is the Y direction, and the normal vector is (0.021,0.977,-0.212) as shown in figure 5. Usually, a RPS point controls only one coordinate axis direction. So as long as the position coordinates value of the coordinate axis which is controlled by the control system can be extracted accurately. The RPS points shown in the figure, As long as the y value -843.55 can be extracted accurately, the X and Z coordinate values are not required. Therefore, RPS points on the surface, in the local tangent plane to find the corresponding point RPS*, can have a better accuracy and stability of the algorithm. Because the coordinates of all points in the tangent plane are equal, and is the normal method of corresponding point extraction.

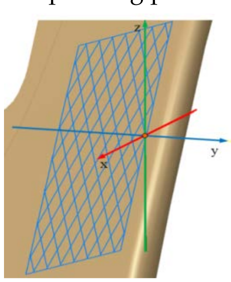


Fig.5. Left front door Fy1 RPS point

But, if the tangent plane is not parallel to the axis of the control direction, the normal coordinates of all points in the plane are not equal so there is the error between the measured point and the nominal point in the direction of the coordinate axis. This is the case with the Fy RPS point shown in Figure 6. This point control Y direction. The normal vector Y' is not parallel to the Y axis of the coordinate system, the θ angle between the two Y and Y'. The nominal point for RPS, the green point shown in the figure, its value of coordinate is (x,y,z). The search for the corresponding point is RPS*, the red point shown in the figure. The value of coordinate is (x*,y*,z*). The distance between RPS* and RPS is d. The RPS* is on the local part tangent plane X'Z', but not on the XZ plane relevant to coordinate axes. y is coordinate value of point RPS and y* is coordinate value of point RPS*. The deviation between y* and y, as:

$$\delta = y^* - y = d \sin\theta \quad (2)$$

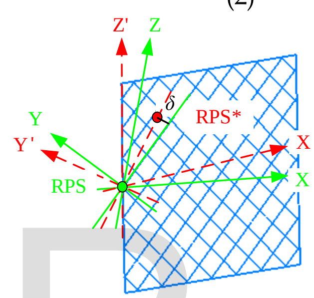


Fig. 6 Registration error of surface RPS points

Some RPS points on the covering parts, the angle cannot be ignored. For example, some of Fy on the door can reach 12 degrees or even greater. If the distance D is 1mm, then the error can be up to 0.2mm (0.208mm = 1mm*sin12). In the design of the corresponding point RPS* search algorithm should try to reduce the value of D, that is, to minimize deviation between the corresponding point and the nominal value.

As for the points on the contour edge, the information that is defined in the nominal design includes the position coordinates of the point, the direction of the control axis, and the tangent line. The local tangent plane is changed into local tangent line. When the vertical axis direction and the tangent are not parallel, the tangential deviation can cause the deviation in the control direction. Based on the above analysis, the extraction accuracy of the corresponding point RPS* is affected by the local shape feature. When the normal of tangent plane is not parallel with the direction of axis control, deviation between RPS* and nominal value will cause the deviation of coordinate control direction. Therefore, during design of RPS* extraction method, consider the impact of tangential deviation.

3.3 RPS Corresponding Point Extraction Algorithm on the Surface

As for the corresponding point extraction of RPS points on the surface, in this project, the automatic extraction method of 3d metrology software and Inspection GOM software is analyzed, and a kind of plane fitting projection method is proposed. The following three algorithms are introduced as.

(I) Adjacent Point Average Method in 3d Metrology Software

As for the feature of the points, an automatic extraction method of the corresponding points in 3d metrology software is presented (Extract Measured). It can be called adjacent average method. The average value of all the measured data points in a given distance range is the average of corresponding point as shown in Figure 7. Triangle point represents nominal point, adjacent dots represent points within a given distance, and large dots indicate extracting corresponding measured points. Based on the average method, the result of the calculation is affected by the point cloud distribution, i.e., the corresponding point is close to the area with large density. Thus, there is a tangential deviation from the nominal point. The upper left part of the point cloud distribution is dense and the lower right part of the point cloud distribution is sparse, so there is extraction of corresponding points near the left upper part.

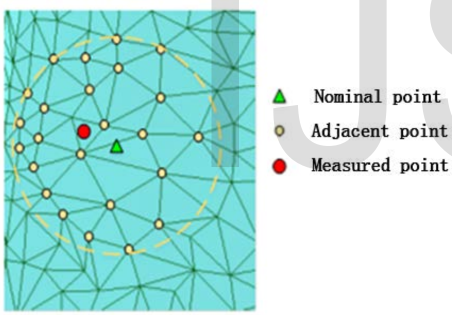


Fig.7. The corresponding point extraction: based on the adjacent point average

(II) Normal Vector Projection Method in Inspection GOM Software

As for the Inspection GOM software, a method for automatic extraction of corresponding points based on normal projection is presented, that is, the normal vector of the nominal RPS point, along the normal direction of the nominal point to make projection to point cloud, the intersection point is the corresponding point. As shown in Figure 8, Triangle represents nominal point, with the arrow line as the normal vector, and large dots indicate corresponding measured point.

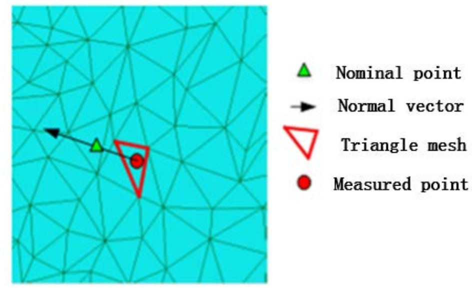


Fig.8. The corresponding point extraction: based on the normal projection

Based on the corresponding point extraction method of point projection, the tangential deviation can be eliminated. However, the extraction method is easily affected by the local situation of the triangular patch where the projection point is located, that is to say, if the local noise is caused by the measurement, the extraction result of the corresponding point is affected.

(III) The Plane Fitting Projection Method Presented in this Project

The extraction method of the corresponding points is as follows: to give the nominal point and nominal tangent plane and get the measured point in a range. The least square method to fit a plane, and then the nominal point to the fitting plane projection, the projected point is the corresponding point. As shown in Figure 9. Triangle point represents nominal point, small dots represent adjacent points, quadrilateral plane represent fitted plane, with arrows for normal vector, and large dot indicate corresponding measured point.

Based on the plane fitting projection of the corresponding point method, can solve the above two shortcomings of tangential deviation and local noise. This is because: fitting plane projection eliminates the tangential deviation, the projection surface is through the adjacent point fitting plane, rather than isolated triangle, eliminated the local noise.

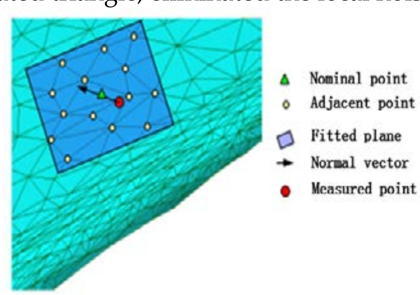


Fig.9. Corresponding point extraction -based on plane fitting projection

Plane fitting projection method can be implemented in 3d metrology software through the macro program, and the key functions are as follows:

(1) Extraction of neighboring points in a given range

TREEVIEW FEATURE PROPERTIES AUTO_EXTRACT MAX_DISTANCE(2.0)

MEASURE EXTRACT MEASURED

ISSN 2229-5518

SELECT DATA_POINTS MEASURED_DATA_POINTS

(2) Least square fitting

TREEVIEW FEATURE PROPERTIES MEASUREMENT_METHOD ("Extract")

TREEVIEW FEATURE PROPERTIES EXTRACT MEASURED MAX_ANGLE (15.0)

TREEVIEW FEATURE PROPERTIES EXTRACT MEASURED REJECT_OUTLIERS METHOD ("Percentage")

TREEVIEW FEATURE PROPERTIES EXTRACT MEASURED FIT_TYPE ("Best-fit")

FEATURE PRIMITIVE FIT TRIM_USING_REFERENCE_OBJECT_ELEMENTS ("On")

FEATURE PRIMITIVE PLANE FIT_SELECTED_ELEMENTS

FEATURE PRIMITIVE PLANE FROM_POINTS

(3) Nominal point to plane projection

FEATURE PRIMITIVE POINT CREATE

TREEVIEW FEATURE MEASURED SELECT

FEATURE OPTIONS CREATE_DEPENDENCIES ("Off")

FEATURE PRIMITIVE POINT FROM_PROJECTION_ONTO_PLANE

4 RPS ALIGNMENTS WITH AND WITHOUT TOLERANCE

4.1 RPS Corresponding Point on the Surface Extraction Methods Comparative Experiment

RPS process is the transformation of the coordinate system, the measurement point cloud data, translation and rotation transformation to the nominal model coordinates. According to the 3-2-1 rule, the coordinate system (taking YYY-XX-Z) is established by using six points in space. Three control Y direction of the function point to determine the Y plane, two X function point to determine the Z axis and Z function point to determine the coordinate system origin. As shown in Figure 10, the left front door of the RPSFy3 as an example of corresponding point extraction method, preliminary alignment of Best-Fit after the corresponding point extraction. Adjacent point average method takes two kinds of distance 2mm and 4mm. The plane fitting projection method proposed in this project, the plane size is 3*3mm2. Table 1 shows the nominal point coordinate values and the results of each method. Since this point controls the Y direction, the focus is on the deviation of the Y coordinate values. The tangential deviation (i.e., x, z coordinate value is not zero) exists in the 2mm adjacent average method. The corresponding points extracted by the average method of 4mm have large deviations which indicate that the adjacent range is too large to affect the extraction accuracy of RPS points.

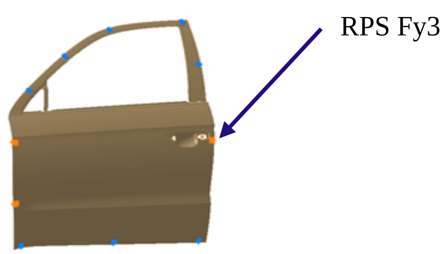


Fig.10. Left front door RPSFy3 point

TABLE 1

RPS CORRESPONDING POINT DEVIATION COMPARISON

projection	Nominal points	Adjacent point average		Normal projection	Plane fitted projection
		(2mm)	(4mm)		
x,y,z coordinates	1453.36 -849.68 535.00	1453.56 -849.46 534.74	1454.44 -849.25 534.68	1453.35 -849.47 534.97	1453.35 -849.44 534.96
Deviation with theory		0.20 0.21 -0.26	1.08 -0.43 -0.32	-0.01 0.21 -0.03	-0.01 0.24 -0.04

4.2 RPS Error Range Alignment Under Given Tolerance

Within the RPS error tolerance range, -0.2mm ~ +0.2mm, adjust the nominal RPS point function value. Measurement data is based on the RPS adjustment around the X, Y, Z coordinate translation and rotation, can optimize the RPS matching, optimization of profile between adjacent parts assembly space, get a better matching state. RPS match within the error range, the key is to get the amount of rotation and translation measurement data, manually adjust the way through the SDK program implementation.

4.3 Profile Calculation

After the RPS alignment, we use the profile Modular to calculate the edge profile error. The profile type using “One radius only =180”, especially we can define the flush and gap caculation. The flush (Normal Dist) = Distance Point-to-Vector Signed(A1 Proj, TgVectA1[R], SignA1) and the gap (TgVect Dist) = DistancePoint-to-Point Directional Signed(A Highest Pt[R],A Highest Pt[D], TgVectA1[R], SignA1), schematic diagram as shown in Figure 11. The creation method selecting “along curve-from the reference objects”, click a part of curve or a whole curve and determine the sampling interval value. Create the cross-sections and modify the their directions, which the height (normal) direction points to the outside of the part and the wide (tangent) direction points to the non-material side.

ISSN 2229-5518

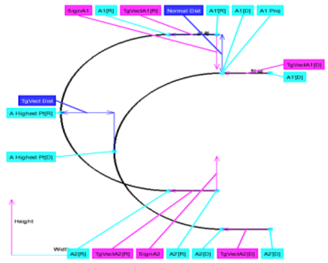


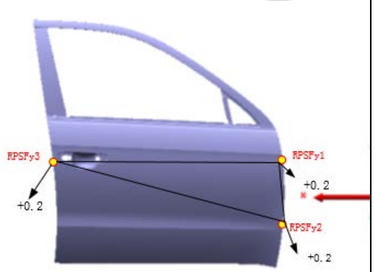
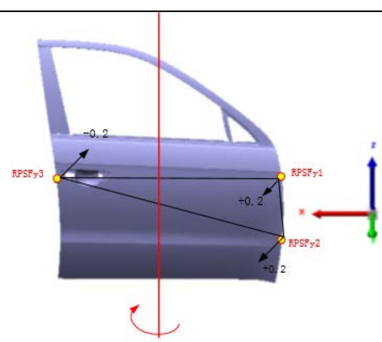
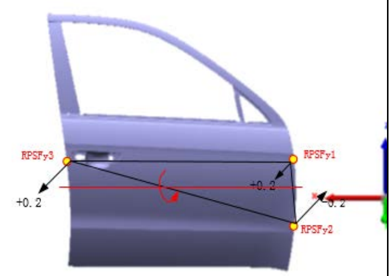
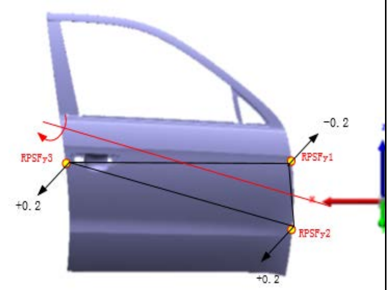
Fig.11. Profile calculation

4.4 RPS Adjustment

According to the findings, points RPSFy1, RPSFy2, RPSFy3 to adjust the flush in the y direction. Point RPSHz to adjust the gap in the Z direction. And using points RPSFx1, RPSFx2 to adjust the gap in the X direction. The point RPSFy changes in a range of (-0.2 - +0.2), to take the adjustment for example, that is the point RPSFy changes +0.2 or -0.2, then we can have eight kinds of situations, as table 2 shown. The point RPSHz changes in a range of (-0.2 - +0.2), the most bias values of Z directional gap is 0.2mm. The point RPSFx varies in the range (-0.2 - +0.2), taking the adjustment RPSFx1 to -0.2, RPSFx2 to +0.2 of left front door, the results shown in the table 3. Totally, the whole body has turn 0.2mm anticlockwise, the down left part has nearly 1.0mm variation. The upper right part has almost 1.0mm variation and the curvature of both sides of the region will have 0.2mm Z directional variation.

TABLE 2

RPSFY ADJUSTMENT

Adjustment	Sketch Map	Remark
Fy1 +0.2(-0.2) Fy2 +0.2(-0.2) Fy3 +0.2(-0.2)		Totally 0.2mm inside(outside) translation
Fy1 +0.2(-0.2) Fy2 +0.2(-0.2) Fy3 -0.2(+0.2)		In the middle, Δ_{vary} = 0 The left side, Δ_{vary} = -0.2 The right side, Δ_{vary} = 0.2; Vice versa
Fy1 +0.2(-0.2) Fy2 -0.2(+0.2) Fy3 +0.2(-0.2)		The upper max variation Δ_{vary} = +1.0 The down Δ_{vary} = -0.4; Vice versa
Fy1 -0.2(+0.2) Fy2 +0.2(-0.2) Fy3 +0.2(-0.2)		The left upper corner Δ_{vary} = +0.4 The left down corner Δ_{vary} = -0.6

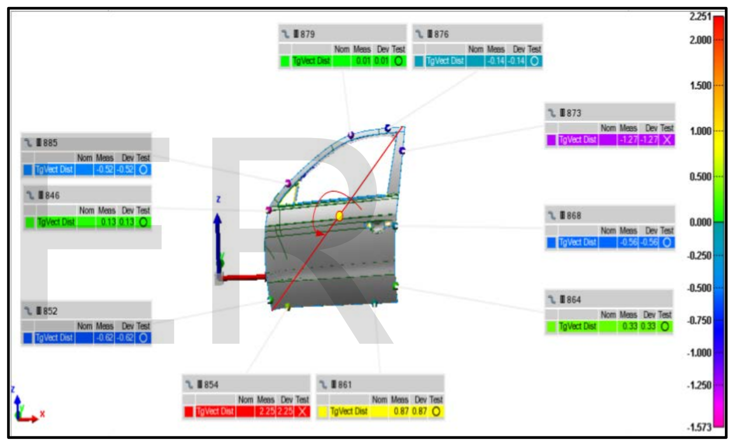


Fig.12. X- directional gap adjustment

TABLE 3

RPSFX ADJUSTMENT

Region	Profile	Initial Gap	Adjusted Gap	Variation
Left	Profile 846	0.08	0.12	0.04
	Profile 852	-0.44	-0.62	-0.18
Right	Profile 873	-0.48	-1.27	-0.79
	Profile 868	-0.34	-0.56	-0.22
	Profile 864	0.01	0.33	0.32
Down	Profile 854	1.17	2.25	1.08
	Profile 861	0.72	0.87	0.15
Upper	Profile 876	-0.21	-0.14	0.07
	Profile 879	0.05	0.02	-0.03
	Profile 885	-0.27	-0.52	-0.25

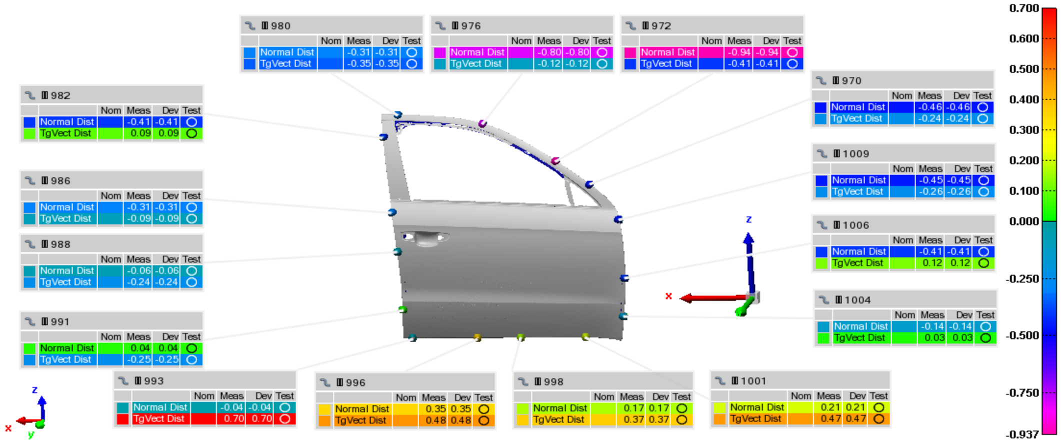


Fig.13. Flush and gap value of right front door

TABLE 4
FLUSH AND GAP VALUE OF RIGHT FRONT DOOR

Profile region	profile	Calculation value (initial)		standard value		Calculation value(after adjustment)	
		flush	gap	flush	gap	flush	gap
Upper	970	-0.46	-0.24	-0.20	-0.20	0.07	-0.27
	972	-0.94	-0.41	-0.30	-0.60	-0.28	-0.55
	976	-0.80	-0.12	0.10	-0.20	0.07	-0.33
	980	-0.31	-0.35	0.70	-0.40	0.62	-0.58
Down	993	-0.04	0.70	-0.20	0.50	-0.41	0.68
	996	0.35	0.48	0.10	0.30	-0.06	0.47
	998	0.17	0.37	-0.20	0.10	-0.24	0.36
	1001	0.21	0.47	-0.10	0.30	-0.20	0.44
Left	982	-0.41	0.09	0.40	0.00	0.42	0.10
	986	-0.31	-0.09	0.10	-0.10	0.06	-0.08
	988	-0.06	-0.24	0.00	-0.10	0.08	-0.25
	991	0.04	-0.25	-0.20	-0.10	-0.17	-0.25
Right	1004	-0.14	0.03	-0.10	0.00	-0.41	0.00
	1006	-0.41	0.12	-0.50	0.10	-0.44	0.12
	1009	-0.45	-0.26	-0.40	-0.10	-0.13	-0.28

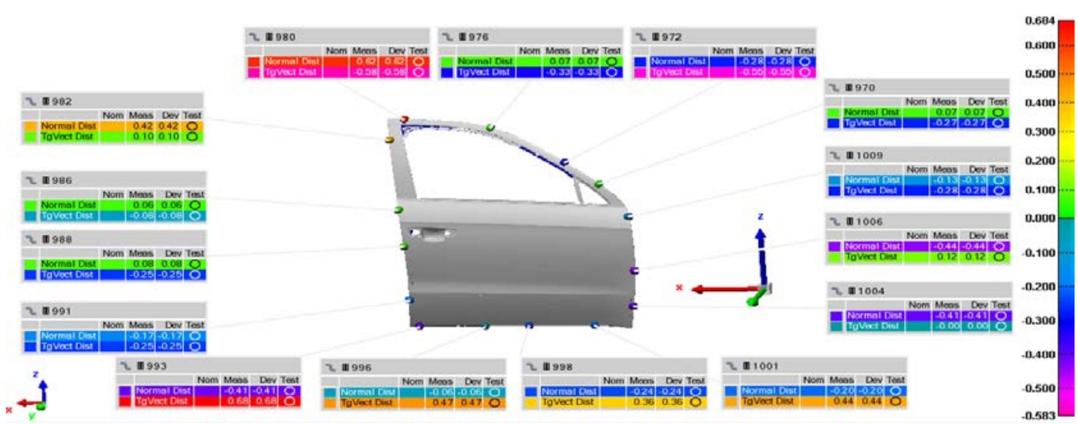


Fig.14. Flush and gap value of right front door (after adjustment)

Comparing with the results, we can get the part's status. The flush: the upper and the upper left sides tend to be generally smaller while the downside and the lower right side tend to be larger. The gap: the upper side is usually smaller and the downside is usually larger. According to the existing status, make the change of points RPSFy1, RPSFy2, RPSFy3 to +0.2, -0.15, +0.2 and make the point RPSFz to +0.1 then we can get the more standard results as shown in table 4, calculation value after adjustment.

5 CONCLUSION

RPS registration principle also known as reference point system principle is a positioning methods that define RPS points on parts and build coordinate system by 3-2-1 principle. Whether extraction of the RPS corresponding point is accurate and reliable, will affect the measurement data and the accuracy of nominal CAD matching. RPS points are categorized as: surface RPS point, profile RPS point and structure RPS point, different methods are performed to extract RPS corresponding points. Based on the analysis, the extraction accuracy of the corresponding point is affected by the local shape feature. The conclusion, based on the plane fitting projection of the corresponding point method, can solve the above two shortcomings of tangential deviation and local noise. RPS tuning or adjustment is considered to be a kind of optimization method of RPS alignment, within a range, we can use our expertise to make the adjustment. And also, we use the experiment to do the quantitative analysis to help us make the modification. When we do the RPS corresponding point extraction, there are many factors such as the scan data's accuracy and others, influencing the accuracy of the measured points. So, RPS tuning has the important function. Considered and tackled together, the issues outlined in this paper could provide us with the opportunity to make the most out of its optimization potential.

REFERENCES

[1] Coquillart, S., "Extended Free-Form Deformation: A Sculpturing Tool for 3D Geometric Modelling", Computer Graphics, Vol.24, No. 4, 1990, pp. 187-196

[2] Koch, A., Meerkamm, H., "TolVis – visualization of possible shape variations resulting from shape and position tolerances", Proceedings of 15th International Conference on Engineering Design (ICED 05), Melbourne, 2005, pp. 311-312 (full paper on CD)

[3] Barr, A.H., "Global and local deformation of solid primitives", Computer Graphics, Vol. 18, No. 3, 1984, pp.21-30

[4] Guillet, S., Leon, J.C., "Parametrically deformed free-form surfaces as part of a variational model", Computer Aided Design, Vol. 30, No. 8, 1998, pp. 621-630

[5] Sederberg, T.W., Parry, S.R., "Free-Form Deformation of Solid Geometric Models", SIGGRAPH, Vol. 20,1986, pp.151-160

[6] Verady, T., Martin, R. and Cox, J. (1997) "Reverse engineering of geometric models: an introduction," Computer-Aided Design, Vol. 29, No. 4, pp. 255-268.

[7] Chen, F., Brown, G.M., and Song, M. 2000. Overview of three-dimensional shape measurement using optical methods. Society of Photo-Optical Instrumentation Engineers.

[8] Gershon R. and Benady M., (2001). "Non-contact 3-D Measurement Technology Enters a New Era," Quality Digest, September.

[9] Besl P. J., and McKay N. D. (1992). A method for registration of 3d shapes. In IEEE Transactions on PAMI vol. 14, pp. 239–256.

[10] Wolf, K., Roller, D., and Schafer D., (2000). "An approach to computer-aided quality control based on 3D coordinate metrology," Journal of Materials Processing Technology, Volume 107, Issues 1-3, Pages 96-110

[11] Rusinkiewicz, S. and Levoy, M., (2001). "Efficient variants of the ICP algorithm," Third International Conference on 3D Digital Imaging and Modeling.

[12] Ceglarek,D., Huang, W., Zhou, S., Ding, Y., Kumar R., Zhou Y., "Time-based competition in manufacturing stream-of-variation analysis(SOVA) methodology–review", Internaltional Journal for Flexible Manufacuring Systems, Vol. 16, No.1, 2004, pp. 11–44

[13] Maxfield, J., Dew, P., Zhao, J., Juster, N., Fitchie, M., "A Virtual Environment for Aesthetic Quality Assessment of Flexible Assemblies in the Automotive Design Process", SAE 2002 World Congress, Detroit, 2002, pp 209-217

[14] Wickman, C., Söderberg, R., "Perception of gap and flush in virtual environments", Journal of Engineerig Design, Vol. 18, No. 2, 2007, pp. 175-193.

[15] W. Choi, T.R. Kurfess, J. Cagan, Sampling uncertainty in coordinate measurement data analysis, Prec. Eng. 22 (1998) 153-163.

[16] W. Choi, T.R. Kurfess, Uncertainty of extreme fit evaluation for three-dimensional measurement data analysis, Computer-aided Des. 30 (7) (1998) 549-557.

[17] B.K.P. Horn, Closed-form solution of absolute orientation using unit quaternions, J. Opt. Soc. Am. 4 (4) (1987) 629-642.

[18] T. Gallagher, T.R. Kurfess, Design and implementation of a system for rapid inspection of critical dimensions in high volume production, Mechatronics 87 (7) (1998) 413-425.