Study on Wiped Area Measurement Method Based on 3D Scanning

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Abstract. The coverage rate of wiped area is a critical index for designing the windshield wiper system and driver forward field of view in particular. SAE Recommended Practice clearly define the minimum requirements for wiped area that must be met before a passenger car can be sold. The challenge is to develop measurement methods which transfer wiper pattern extracted from the windshield glazing surface to the data that can be calculated. In this paper, we apply hand-held laser scanners to produce the point clouds of wiper pattern, convert them into computer-aided design model, and then trim areas A, B, and C according to the edge feature of wiper pattern, finally calculate the percentages of areas A, B, and C that are wiped. Compared with traditional photography-based measurement method, the application result showed that scanning-based method possess better accuracy performance for wiped area test.

1. Introduction
The function of windshield wiper system is to sweep away the rain, snow and dust on the exterior vehicle windshield glazing surface. When the wiped area is too small, it will cause to narrow the scope of vision, increase the risk of driving safety. 50 years ago, SAE Recommended Practice has clearly defined the minimum requirements for the wiped area and the general test method.

At present, in most case automotive manufacturers apply traditional photography-based method to measure the size of windshield wiped area before sending the vehicle to OVSC laboratory who conducts compliance tests. In order to transfer full-size unwrapped view with wipe pattern and areas A, B, and C to 2D images and calculate the percentages of areas that are wiped, digital camera and image processing will be most in use. With the traditional method, it is very convenient for engineers to measure the percentages and verify the rationality of the design. However, the downside of the traditional method is, obviously, lack of accuracy where it is required.

Here we describe a method which precisely generates a digital model of the exterior windshield surface and wipe pattern, using a 3D scanner, and completes the calculation in CAD software. We have successfully applied this method to several vehicles for verification and achieved beneficial results.

There are three common types of wipe pattern, tandem, opposed and single arm pattern, as shown in Figure 1. In this paper, we choose tandem pattern as the study object. To the other two patterns, the scanning-based method is also applicable.
2. **Motor vehicle safety standard of United States about wiped area**

Society of Automotive Engineers (SAE) J903a has described three specific areas A, B, C on the exterior windshield glazing surface as vision areas.[1] Each area has been established using four planes. Two of them are tangent to the upper and lower edges of the SAE eyellipse in the side view and fixed at an angle to the horizontal plane. The other two planes are tangent to the left and right edges of the SAE eyellipse in the plan view and fixed at an angle to the vertical plane. The parts of vision areas which are not within the area bounded by a perimeter line on the glazing surface 25 millimeters from the edge of the daylight opening should be crossed out. Figure 2 shows the division of areas A, B, C.

Federal Motor Vehicle Safety Standards (FMVSSs) No.104 has clearly defined the angles of four planes according to the overall width of passenger cars.[2] For example, for the cars of 1730 or more millimeters in overall width, Areas A, B, and C shall be established using the angles specified in Table 1. The actual wiped areas, as commonly called as wiped areas, should include accessorial sweep fields which are generated due to the high speed operation on the wet windshield surface and the air flow, as shown in Figure 3. Wiped areas should cover at least 80% of area A, 95% of area B and 99% of area C.

### Table 1. Specified Angles for Cars of 1730 or More Millimeters in Overall Width.

| Area | Minimum percent to be wiped | Driver eyellipse, percent | Angles, degrees |
|------|-----------------------------|---------------------------|-----------------|
|      |                             |                           | Left  | Right | Up  | Down |
| A    | 80                          | 95                        | 18    | 56    | 10  | 5    |
| B    | 95                          | 95                        | 14    | 53    | 5   | 3    |
| C    | 99                          | 95                        | 10    | 15    | 5   | 1    |

3. **General procedure for wiped area test**

Measuring environmental requirements: a water spray system with 2 nozzles, with 50 ~ 100 cubic inches per minute flow, and accuracy of ± 2.5 cubic inches per minute. Water hardness is less than 12 grains per gallon. Environmental temperature remains between 50 and 100° F, with wind speed not exceed 1 meter per hour.
3.1. Preparation
Clean the exterior and interior surfaces of the windshield with a nonabrasive type cleaner to make the surface grease free. Print the outlines of areas A, B and C on a clean vellum. Position the test vehicle in an area containing the water spray system.

3.2. Testing
Operate the test vehicle engine at manufacturer's recommended idle speed with transmission in neutral. Actuate the windshield wiper control to the high speed position with an approximately equal distribution of water spray over the entire windshield surface. Place the clean vellum containing outlines of areas A, B, C on the exterior windshield surface. Using a grease pencil to outline the windshield patterns that are cleanly wiped by the wiper blades and the accessorial sweep fields on the vellum.

3.3. Calculation
Take a photograph of a full-size unwrapped view of the vellum and transfer it into a digital image data. Use an image processing software to calculate the percentages of areas A, B, and C that are wiped.

4. Measurement method based on 3D scanning technology
Differ from the traditional method, this paper used 3D scanning technology to obtain a higher accuracy. The main difference is, instead of outlining the wipe patterns on a clean vellum placed on the exterior windshield surface, we use a 3D scanner to produce point clouds of the patterns and transferred them into a 3D model. This 3D model consists of the geometric features of the windshield glazing surface and the boundaries of the areas A, B, C. It is very convenient and precise to reconstruct the windshield surface and divide it into pieces for calculation with the professional CAD software.

The procedures of this measurement method based on 3D scanning is mainly divided into the following steps: point clouds scanning, data pretreatment, surface reconstruction and error adjustment, areas division and calculation.

4.1. Point cloud scanning
Point clouds can be produced by two ways: contact and non-contact scanning.[3] The contact way has its disadvantages of low efficiency and needs for radius compensation, while the non-contact one has the advantages of high efficiency and no need for radius compensation, but it is easily affected by the small amounts of vibration of the measured work piece surface.[4]

In need of scanning the entire windshield surface and A-pillar surrounding features, we used a hand-held laser scanner. When sampling frequency is more than 200 points per second, the scanning process is progressive along the direction of feature extension and no part will be left behind.[5] If necessary, the scanning angle should be adjusted to eliminate the blind area until the scanning is completed, as shown in Figure 4. The point clouds data directly collected is based on an independent coordinate system relative to the origin of measurement. Subsequently, label points shall be attached on pillar A or a part of the front fender to align the point clouds coordinate with the vehicle design data, so as to ensure the error of point clouds data within a reasonable range.

![Figure 4. Point clouds data acquisition.](image_url)
4.2. Data pre-treatment

No matter what point clouds data acquisition method is used, data errors will inevitably be introduced in the process of scanning. The existence of errors affects the subsequent curve and surface reconstruction process. Therefore, some necessary processing should be carried out on point clouds data to make them good enough for surface reconstruction.

There are many powerful reverse solver software on the market, such as Imageware and Geomagic Studio. With the application of specialized reverse engineering software, the point clouds data can be smoothed, sampled and filtered according to the curvature, section and boundaries of the geometrical objects, and its characteristic position can be extracted to eliminate the redundant point clouds, so as to facilitate the reconstruction of CAD model of wipe pattern.[6] The abnormal data points usually include singular points, noise points and other data, which should be removed in the pretreatment.

Common point clouds data preprocessing methods include: removing abnormal data, filling in the missing points, data smoothing, filtering and de-noising, merging of multi-views clouds or redundant data and feature extraction. Satisfactory point clouds can be obtained after data simplification, as shown in Figure 5.

4.3. Surface reconstruction and error adjustment

Surface reconstruction is to use the pre-processed point clouds data to construct an approximate model close to the windshield surface through differencing or fitting methods. With the functions of rapid construction of freedom surface modeling and surface editing tools, specialized reverse engineering software on the market allow users to dynamically adjust the surface until requirements are met. The real-time surface detection tool can detect the error and continuity between surface and point clouds, so that users can conveniently construct a high quality surface.

After surface being modeled and reconstructed, it is necessary to check surface precision, curvature and continuity. The difference between the reconstructed windshield surface and the point cloud can be viewed intuitively by using the error checking tool of professional software. Throughout the error of the model analysis, as shown in Figure 6, the maximum error is 0.35 millimeters, the standard deviation is 0.099 millimeters. The error does not meet the accuracy requirement, so it is need to improve the precision and smoothness of reconstruction in the further adjustment. After optimization, the reconstruction is relatively satisfied, as shown in Figure 7, the maximum error is less than 0.15 millimeters and standard deviation is 0.035 millimeters.

Figure 5. Point clouds simplification

Figure 6. Error analysis of point clouds before optimization.
Figure 7. Error analysis of point clouds after optimization.

The curved surface we reconstructed is modeled as many small flat pieces. Connecting adjacent points to create a continuous surface with straight lines always distort the whole windshield surface model, and the curvature of windshield surface model has an important impact on the measurement result. All surfaces with large errors are adjusted through the cyclic process of adjusting control points- error analysis- re-parameterizing the control points until the ideal model finally obtained. The analysis of minimum curvature as is shown in figure 8 and figure 9.

Figure 8. Curvature analysis before optimization.

Figure 9. Curvature analysis after optimization.
4.4. Areas division and calculation

The boundary features on the point clouds are captured and the reconstructed windshield surface model is trimmed to obtain the wiped area covering area A and B, as shown in Figure 10 and Figure 11. The percentages of areas A, B, and C that are wiped can be easily calculated by professional software. Visually, area C has been completely covered, so the coverage rate of area C is 100%, and no additional calculation by the software is required. If it is needed to calculate area C, please refer to the calculation method of area A and B.

![Figure 10. Area A be wiped.](image1)

![Figure 11. Area B be wiped.](image2)

4.5. Effect

The above measurement method has been successfully used to measure three test vehicles U, V and W, among which U is a 5-seats sport utility vehicle with a width of 1839 millimeters, V is a 5-seats sedan with a width of 1854 millimeters, and W is a 7-seats sport utility vehicle with a width of 1868 millimeters. Compared with the traditional measurement method, the measurement method based on 3D scanning can reflect the design target more accurately. The measurement results are shown in Table 2.

| Test vehicle | Area | Design value | Cloud | Relative error to design value | Image | Relative error to design value |
|--------------|------|--------------|-------|--------------------------------|-------|-------------------------------|
| U            | A    | 90.5         | 89.6  | -0.99                          | 89.1  | -1.55                         |
|              | B    | 96.5         | 95.3  | -1.24                          | 94.5  | -2.07                         |
|              | C    | 100          | 100   | 0                              | 100   | 0                             |
| V            | A    | 92.0         | 91.4  | -0.65                          | 90.0  | -2.17                         |
|              | B    | 97.5         | 96.9  | -0.62                          | 95.7  | -1.85                         |
|              | C    | 100          | 100   | 0                              | 100   | 0                             |
| W            | A    | 90.5         | 89.4  | -1.22                          | 88.7  | -1.99                         |
|              | B    | 95.5         | 94.9  | -0.63                          | 94.3  | -1.26                         |
|              | C    | 100          | 100   | 0                              | 100   | 0                             |
5. Conclusion

Although traditional photography-based measurement method meet requirements of United States safety standards and regulations on the vehicle wiped area, it is usually affected by the camera angle, image resolution and other factors in the actual measurement process. Measurement results deviate greatly from the design target. This paper puts forward a kind of innovative measurement method based on 3D scanning and point clouds data processing technology. By using a hand-held scanner to precisely obtain the wipe pattern point clouds data and specialized reverse engineering software to conduct data preprocessing, surface reconstruction, error adjustment, areas division and finally the accurate calculation of the percentages of areas A, B, and C that are wiped. According to the comparative test, it shows measurement method based on 3D scanning has better characteristics of high precision and strong maneuverability over traditional method and worth using for reference.

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