A Study on Cutting Trajectory Planning for Windshield Reuse of ELV

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Abstract — **In the traditional process of disposal end of life vehicles, the windshield is treated just as waste material and break into pieces. In order to increase the reusing rate of old component after disassembly, the windshield be disassembly and resell in the second hand market. But the key problem is how to disassembly the windshield with high efficiency and low cost. This paper proposed a method for disassembly windshield of end of life vehicle. Firstly, the image of windshield is captured by camera. And then, the profile of windshield is calculated according to the image of windshield with a special algorithm. Next, a tracking method is proposed to create the cutting trajectory, it is planned according to the parameter of profile. In the end, an experimental equipment is fabricated and the result of cutting parameter with body of end of life vehicle is introduced. By this means, the cutting trajectory is planned automatically.**

Keywords* — *ELV, Windshield Recycling, Automatic disassembly, Trajectory planning

I. INSTRODUCTION

With increasing of automobile possession, the recycling and disposal of ELV (end of life vehicles) arouse great concern in the world [1-4]. The reasonable disassembly and treatment of ELV will not only decrease the potential pollution to the environment, but also bring us a large amount of renewable resources. Recently, many studies have been conducted in separation and reusing of disassembled materials of ELV [5]. In the process of disassembly and recycling of ELV, the reusing rate of material should be improved, and the economy of the disassembly also needs to be guaranteed [6]. Besides, many researches have been studying on the reutilizing and remanufacturing of component of ELV, such as engine and motor[7]. However, the current approach for treatment of windshield of ELV still in a simple way. The windshield of ELV usually is break into pieces and sent for landfill. Miroslav made a general analysis of recycling and utilization of glass of ELV, and proposed a model of its benefits [8]. Romain made a research on the optimization of glass recycling and logistics model of ELV in France. But this research was also based on the approach of breaking and utilizing the glass as raw materials [9, 10].

This issue of reusing windshield of ELV is so important either from the view of economy or environmental protection. The energy consumption of dismantling and recycling an ELV windshield is just one fifth to one fourth of the energy consumption of manufacturing a new one. By this means 70% of energy and 80% of raw material can be saved, compared with the manufacturing industry. Moreover it will reduce the impact on the environment, and reduce other investment cost at the same time. In fact, in the current automobile dismantling industry, the windshields are all buried as waste residue after destructive dismantling. The main reason is that the low efficiency of manual dismantling makes the value of dismantling of windshield can not compensate the disassembly cost. In addition, the destructive disassembly of windshield also reduces the purity of subsequent materials recycling, which will not only increase the difficulty of recovery, but also affect the effectiveness of reusing.

According to the development trend of China's automobile industry, under the increasing trend of car ownership, the demand of windshield in the automobile repairing market is a great number. If the windshields are dismantled from the ELV with non-destructive method, and then delivered into automobile maintenance enterprises through logistics network, it will be helpful for us to create a sustainable society.

II. FRAMEWORK OF WINDSHIELD CUTTING SYSTEM

Because the variation of the brand and the type of ELV, it is impossible to cutting windshield of ELV just like the method in the manufacturing technology of new car. The flexible and real time technology is needed for windshield cutting equipment. The framework of windshield cutting equipment for ELV is shown in Fig.1. The cutting tool is mounted on a 5 axis slider, the obliquity of the slider can be adjusted by the operator. Usually, after an ELV in pushed in the working station. The slider is adjusted to parallel the plane of windshield of ELV. On the preparing work, a calibration tag is pasted on the center of windshield. This tag is printed according to the predefined size and pattern, which is mainly used for the parameter calibration of position and size during the visual measuring process.

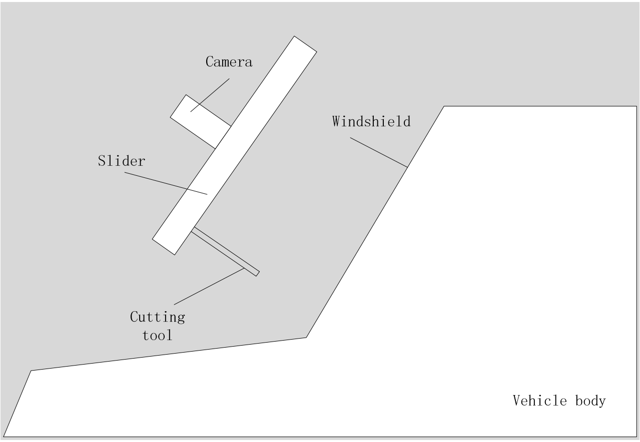

Figure 1. Framework of windshield cutting system.

With image processing technology, the profile of windshield can be obtained. And then, with the vectorization algorithm, the parameter of 2D profile of windshield can be created. Since the edge of windshield is a 3D curve, a tracking method is proposed for this purpose. With tracking of the windshield edge by tracking sensor installed at the end of 5 axial cutting equipment, the 3D geometric parameters of windshield profile is obtained, after post process, the cutting trajectory can be created for controller modular. After windshield is removed from the body of vehicle, the residue metal attached on the windshield is cleaned with special tool. At last, by checking the boundary stress of windshield, qualified windshield can be sent to the second market for reuse.

III. CUTTING TRAJECTORY PLANNING APPROACH FOR WINDSHIELD

A. *Contour extraction from windshield image*

The original image of windshield is captured by a camera mounted on the equipment. Due to the system error of lens and imaging system, the original image is distorted. Thus, General correction algorithm is applied to correct the original image for eliminating the distortion of image. And then, several image processing method are used to transform the original image in to a binary image, furthermore, the contour of image is extracted as shown in Fig.2. At the mean time, the contour of tag also extracted (rectangle ABCD in Fig.2). Here, a most common used algorithm, Hough transformation is used to extract the parameter of pixel of point A, B, C and D [11].

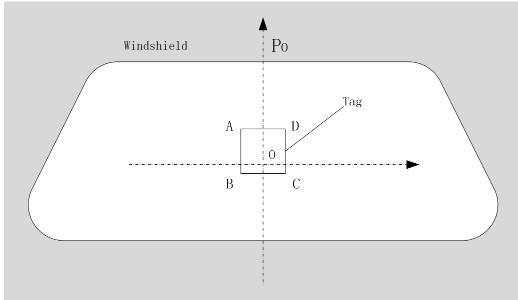

Figure 2. Principle of image process for windshield profile.

Since the parameter of tag is predefined, that is, the length of AB is given, and assumed as the m. According to the Eq.1 and Eq.2, two coefficients can be determined.

$$kh = \frac{D_i - A_i}{m} \tag{1}$$

$$kv = \frac{A_j - B_j}{m} \tag{2}$$

Where Di is the column number of pixel D, Ai is the column number of pixel A. similarly, A_j is the row number of pixel A, and B_j is the row number of pixel B. Point O is the center of image. Thus, according to the two coefficients, each pixel in the image can be transformed to an actual parameter.

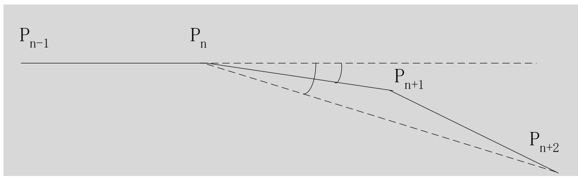

Figure 3. Vectorization of profile of windshield.

The principle of vectorization is demonstrated in the Fig.3. Assume that P_{n-1}, P_n, P_{n+1} and P_{n+2} are the point on the profile of windshield in Fig.2. The coordinate of this point can be determined by the following method. Assume that the row number and column number of P are i and j, respectively. Also assume that x, y are the coordinate of P.

$$x = \frac{P_i - O_i}{kh} \tag{3}$$

$$y = \frac{P_j - O_j}{kv} \tag{4}$$

In order to vectorize the profile of windshield, not all the pixel in the profile is used. Only small number of pixels is used to represent the profile of windshield. Following algorithm is used to extract the feature point. Firstly, assume that P_{n-1} and P_n have been vectorized, the next point

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is on searching. As shown in Fig.3, there are point Pn+1 and P_{n+2} on the profile of image. Assume that the angle between $P_{n-1}P_n$ and P_nP_{n+1} is θ_1, the angle between $P_{n-1}P_n$ and P_nP_{n+2} is θ_2. A threshold value is set for searching the next point. Each pixel on the profile is judged by the threshold. If θ_1 less than threshold while θ_2 greater than threshold, then P_{n+1} is selected as the next point. According to the Eq.(3) and Eq.(4) , the coordinates of P_n can be determined. Continue this method, until all the pixel on the profile have been judged.

B. Cutting trajectory planning with tracking approach

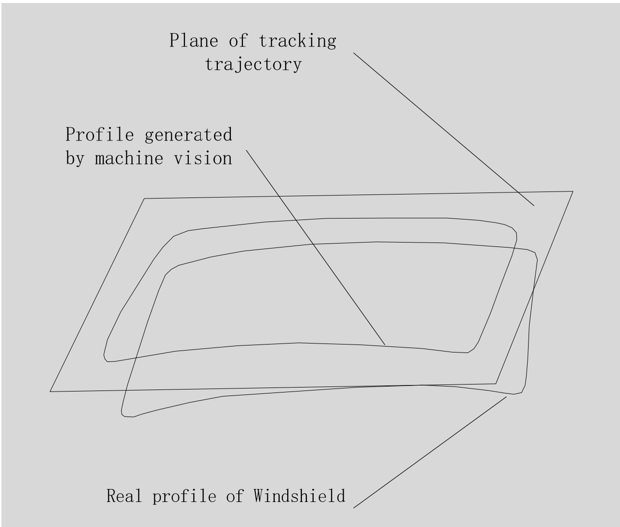

Figure 4. 2D profile of and the 3D profile of windshield.

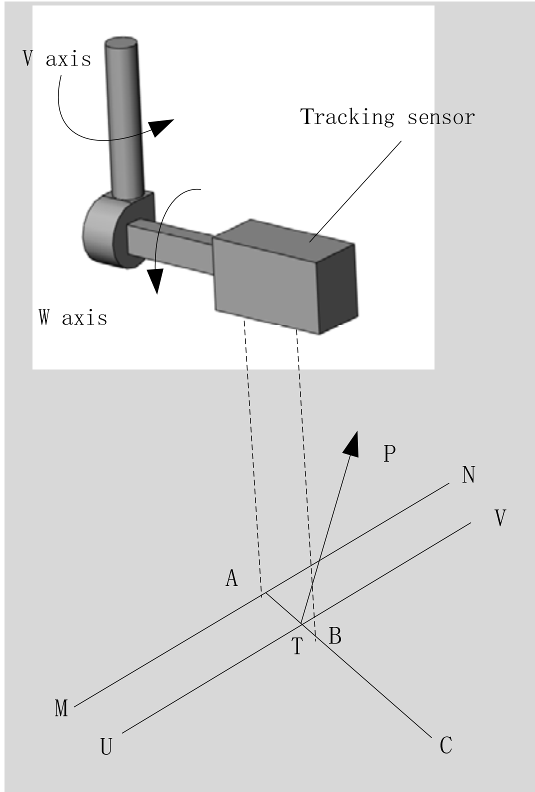

Figure 5. Tracking method for trajectory planning.

With image processing and vectorization approach, the planar contour of windshield is obtained as the coordinates format, which is equivalent to the projection of windshield perpendicular to its vertical direction. However, as shown in Fig.4, the actual windshield profile is a 3D enclosed curve. In order to obtain the actual profile curve of windshield, which is used for generating the cutting trajectory, the secondary tracking is needed based on the planar profile. Then the trajectory of plasma cutting will be calculated according to the tracking data.

As shown in Fig.5, a tracking sensor is mounted at the end of the W axis. This tracking sensor composed of two laser displacement sensors. In the tracking process, axis of W keep the state of perpendicular with the segment of 2D profile of windshield. For example, MN is the partial line segment of planar profile of windshield. The point A and point B located on the surface of vehicle body, point A locates on the line of MN, while point B locates outside of MN. These two points are come from the tracking sensor. In other words, the distance between tracking sensor and the point A, the distance between tracking sensor and the point B, can be measured by the tracking sensor automatic and send to the computer in real time. Thus the vector AC can be determined. By searching a point T on the vector AC, the line segment of cutting trajectory is calculated. Where distance AT is a predefined parameter used to guarantee the increase of temperature cause by the plasma cutting will not affecting the edge of windshield. In the end, by connecting all the cutting vectors UV, the trajectory data for plasma cutting can be determined.

IV. EXPERIMENT OF WINDSHIELD CUTTING FOR ELV

A. *Structure of experiment equipment*

Experiment set-up for this work is design and fabricated as shown in Fig.6. A five-axis slider is installed on a double-column lifting machine. A mechanism is designed in order to adjust the angle of inclination of slider. The data of inclination angle is also fed back to the control system with an angle sensor. Meanwhile, the height of five-axis slider also is adjustable. For the task of disassembly windshield of coach, the working surface of slider can be adjusted to parallel the in front face of windshield of coach. For the task of disassembly windshield of a small old car, the working surface of slider will be adjusted with a small inclination angle.

All the axis are driven by servo motors, which controlled by an industry computer. Two image capturing card, a motion controlling card, and a data acquisition card are installed in the computer. A controlling program is developed with Microsoft Visual Basic and several SDK (Software Development Kit) tools.

Figure 6. Experiment set-up of windshield of ELV.

B. *Cutting trajectory planning*

The original image captured by the camera is as shown in Fig. 7. After process of contrast adjustment with image, the binarization method is applied on the image. that is, each pixel in the image is set as 0 or 255. Considering there are similar characteristic on the whole profile of windshield in the image, the global binary algorithm is used for image process in this work. As shown in Fig.8, excepting for the enclosed area where windshield locates, there are some irregular regions. Each region is an independent pixel region. Among all these regions, the connected region where the windshield locates is the largest one. Thus, by searching and comparing these connected regions, the largest one can be found. After denoising processing with the edge of the largest connected region, the entire profile image of windshield is obtained.

Figure 7. Windshield image captured by camera.

Figure 8. Image of windshield after binarization.

According to the approach mentioned in the 3.1 section, the parameters of outer contour of windshield in the image can be calculated according to the proportion relation between the corrected calibration tag and the image of the profile of windshield. After extracting the contour of windshield, a closed curve of image is created. And then, with vectorization algorithm, a closed contour which composed by multiple segment of line is produced. With the tracking method, the cutting trajectory can be created with the planning program. The snapshot of program is shown in Fig.9.

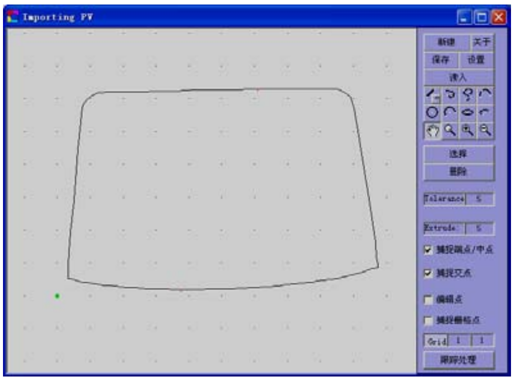

Figure 9. Snapshot of vectorization program.

The data format of plasma cutting trajectory is listed in the table 1. Each data segment composed of three coordinate points parameters and two angle parameters. The coordinate data and angle data are used to determine the space position and the posture of the plasma cutting head. Control word is used for describing the working state of power. S represents ignition, E represents turn-off and H represents the initial working point. The velocity of the plasma cutting head during the cutting procedure is uniformly controlled and set by control program.

TABLE 1. DATA FORMAT OF CUTTING TRAJECTORY OF WINDSHIELD.

Link Number	X	Y	Z	Angle of V axis	Angle of V axis	Control word
5	418.5	100	56	15.8	38.7	S

C. Experiment Result and Discussion

A simple ELV body is used for experiment in this work as shown in Fig.6. After ELV body pushed into the working unit, the trajectory planning system begins to capture the image of windshield, and process the image according to above mentioned approach. And then create the trajectory for plasma cutting. It takes 23 second for all this work. And then, the industry computer starts the cutting program to execute plasma cutting performance. The cutting speed is 6.8m/min. After all the cutting performance are finished. The edge outside the windshield is checked with electric torch. We found that a little fraction of metal body is not cut off since there is some marl on the surface of body, which means that the cutting technology and cutting parameter need to be improved.

V. CONCLUSIONS

There is important meaning with reusing windshield of ELV. To disassembly the windshield of ELV with low cost, the equipment with high efficiency and intelligent function is significant. The Above mentioned approach will help to .create the real time cutting trajectory within ELV disassembly. But there are still some problems need to be resolved. During plasma cutting, a lot of smoke and noise is caused by the cutting point. So, the better cutting approach needs to be developed for a good working condition. In our research team, an innovative cutting tool driven by ultrasonic technique is on the way and will be used to instead of the plasma cutting tool.

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