

Automotive Sketch Processing in C++ with MATLAB Graphic Library

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1. Introduction

The purpose of automotive sketch processing is to separate the sketch into patches and extract the useful information and apply it to assist 2D to 3D transformation. How to extract the useful information depends on what the resources are, what kinds of information are needed, and what methods are applied. In sketches, the information may be extracted from features such as the geometry features, shading, colours and lighting. Geometry features are the most important because they contain the information to identify and distinguish between forms. For example, edges can be used to determine the shapes, and areas can be used to match the size.

This chapter introduces a way to make the automotive sketches ready for 2D to 3D transformation. Three aspects of problems are discussed including the pre-processing of sketches outside computer, the processing of pre-processed sketches inside computer, and the extraction of features. Some of sketch processing algorithms are implemented in C++ using the MATLAB image processing toolbox, Graphic Library and Math Library. Some have been developed from scratch. The work described in this chapter is concerned with the production of a feasible routine, from the point of view of application, which is capable of dealing with the real world characteristics of automotive sketches. There is no established method which provides a suitable starting point for the transformation of real automotive sketches. The combined algorithms, which are discussed in this chapter, have been found to be useful.

2. A glimpse of the 23D system

A brief set of requirements, from a usability point of view, for 2D to 3D tool can be summarised as follows:

- Can deal with 2D sketches and 3D models.
- Intuitive, simplified and robust.
- Flexible and expandable.
- Compatible with other CAD and CAM systems.

Following the above requirements, a prototype of 2D to 3D system, called "23D", has been implemented to support the novel method of transforming 2D automotive sketches quickly into 3D surface models.

2.1 The development environment

The main development language is Microsoft Visual C++® (Ladd, 1996; Seed, 1996; Smith, 1997; Schildt, 1998) with OpenGL® (Kilgard, 1996; Wright & Sweet, 1996; Fosner, 1997; Silverio et al., 1997; Chin et al., 1998; Segal & Akeley, 2001), MATLAB® C/C++ Math and Graphics Libraries (MathWorks, 2001). The basic functions and some algorithms are implemented based on the Open Geometry (Glaeser & Stachel, 1999), MATLAB optimisation toolbox (MathWorks, 2000), spline toolbox, and image processing toolbox (MathWorks, 2001), Image Analysis Pro (iaePro) (Matthews, 2002) and Microsoft VisSDK (The Vision Technology Group, 2000).

2.2 Multiple working modes

The system needs to deal with 2D sketches and 3D surface models, and transformation from 2D to 3D as well. Therefore, the working modes should be easily exchanged between 2D and 3D. In the system, the multiple working modes have been implemented for 2D and 3D manipulations. It is easy to switch the modes, see Fig. 1. 2D sketch is considered as the background in 3D space. Therefore, the 2D working mode is that the background plane containing the sketch is displayed without the 3D models, see Fig. 1a; the 3D working mode is that the 3D models are displayed without the background, see Fig. 1b; and the mixed working mode is that both the 3D models and the 2D background are displayed at the same time, see Fig. 1c. The 2D sketch background is not affected by any 3D manipulations.

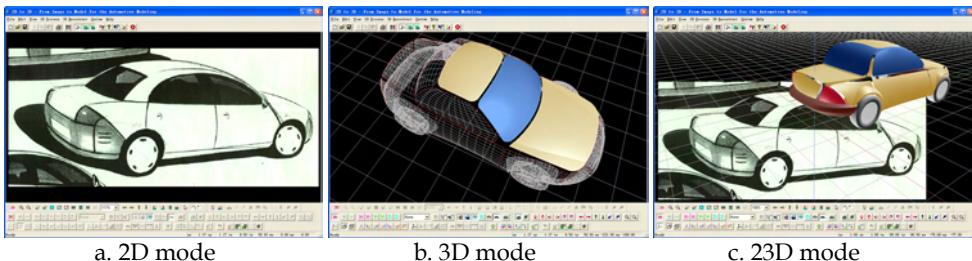


Fig. 1. Three working modes

3. The pre-processing of a sketch

The sketches are not realistic images. The forms and shadings may contain many inconsistencies compared with a true projection of a possible real object. In addition, the reverse transformations from 2D to 3D are rather complicated and contain possible ambiguities, in that a 2D shape may represent many possible shapes in 3D. Therefore, some assumptions have to be made in order to simplify the problem. The fundamental assumptions made here include:

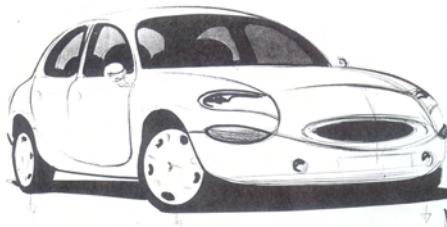
- The scanned sketches will be pre-processed to reduce the inconsistencies in them. The end result of the pre-processing will be that boundaries are complete and are all closed contours or silhouettes. Any key lines will be clear and without ambiguities so as to give enough information for further processing. With these conditions satisfied, the sketch can be separated into patches which can be represented by parametric models.

- Shadings of sketches may be ignored initially, since many techniques of the representations in sketches are not realistic and exact. To derive meaning from them requires psychological interpretation of the intention of the designer, which is beyond the scope of this project.
- Any side, front, rear or top view of automotive model in the sketches is considered to be orthographic projection, others such as front or rear $\frac{3}{4}$ perspective views are considered to be perspective projection.
- Minor details are ignored and allowing concentration on the major ones which establish the essential 3D geometry. It is possible that these could be restored after the basic form has been determined, perhaps using parts from a parts library.
- There is a limit to the exaggeration of forms in a sketch that can be used. Designers often do use exaggerated geometry to achieve a desired mood. If translated into 3-D, the resultant model will also contain exaggerated geometry.
- No attempt is made to correct ambiguities of the reverse transformation automatically. These functions are best left for user intervention. The user is likely to be the stylist, who is in a good position to judge which of a number of possibilities best represents the intended vehicle.

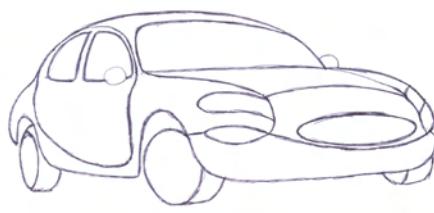
As known, not all the sketches are suitable for 3D modelling by the 23D system, but many do contain the required characteristics. There are many different styles in automotive sketching, according to the stylist's personal practice. The information contained varies at the different conceptual design stages, and is not exactly correct in geometry shape and projection, because the sketches are not real-world images. Humans can easily interpret the shape through adding additional information, in the form of prior knowledge of automotive forms to the sketches and ignoring the faults according to this knowledge. However, the computer is not as agile as the human. It must have available enough information to create the shape, which can come from various sources. One approach is to establish a powerful knowledge database to support the object recognition; another approach is to add the information before image processing. The former needs larger investment and longer time to train the computer, and the later needs less investment and is easy to realize. Two examples of the use of an original sketch as a basis for two well established edge detection algorithms are shown in Fig. 2c and 2d. The results show that they are difficult to be interpreted, even by a human. If the results are to be interpretable by a computer program, significantly more sophisticated processing will be required. Therefore, it is necessary and feasible to establish some input requirements for the sketches that will be used for 3D modelling by the method proposed in 23D system, and will form the requirements for the pre-processing stage. The requirements are relative. The more powerful the pre-processing method is, the lower the requirements for the interpretive program are. The original sketches are drawn by stylist, as shown in Fig. 2a and 2e. The results after pre-processing are shown in Fig. 2b and 2f.

The aim of the pre-processing of sketches is to allow the requirements for the interpretive program to be met by a greater variety of original sketches. Essentially, the pre-processing emphasises useful features in the sketches and eliminates useless ones. According to the analysis of Tingyong Pan (Pan, 2002), the form-lines and form-shadings should be enhanced and kept, and the non-form-lines and non-form-shadings should be ignored. The vehicle components should be simplified in details and ambiguities removed. One of the important

requirements is that the input sketches should have completed and closed contours or silhouettes. Any key form-lines should be clear to give enough information to the further processing. For example, the original sketches (Fig. 2a and 2e) leave some missing and unclear contours or silhouettes to give an imaginary space. These should be redrawn by stylists, see the sketches in Fig. 2b and 2f. All the silhouettes are closed and clear. Some details are ignored such as small lights, highlights, and shadings. The shading information can be separated from the contour or silhouette information. If the shading information is important and near realistic, and is within the closed contours, it can be kept. Otherwise, it should be ignored or further processed to a suitable form. The shadows of the vehicles are deleted, and the completed silhouettes of wheels are added, which are very important for the determination of the 3D coordinates. Side elevations, front and rear $\frac{3}{4}$ perspective views are the best starting point for system processing.

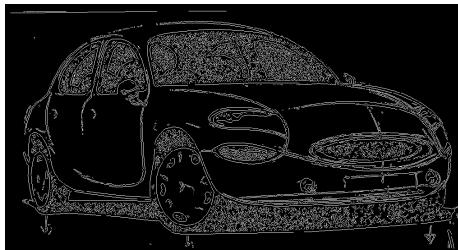


a. The original sketch

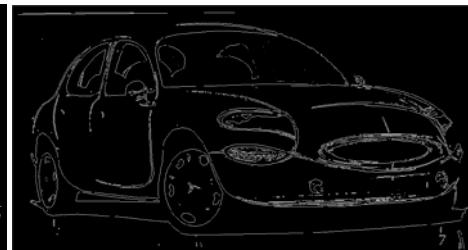


b. The pre-processed sketch

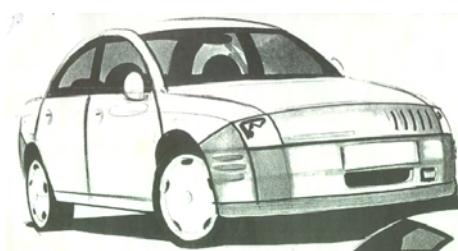
(Both sketches by courtesy of Tingyong Pan)



c. Canny method

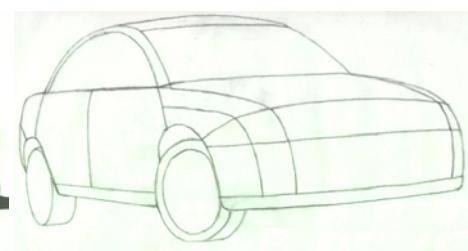


d. Sobel method



e. Canny method

(Both sketches by courtesy of Tingyong Pan)



f. Sobel method

Fig. 2. The pre-processing of the sketch

It is also important to produce pre-processed sketches with simple patches, which can be represented using existing parametric models.

Because the features extracted from sketches are currently pixel-based in order to keep the balance between the speed of processing and the precision of calculation, the suitable size of input sketches should be carefully considered.

4. Sketch processing

Even though the sketches have been pre-processed before scanning, they also need to be subject to further image processing before transforming them into 3D. Some basic functions - such as the adjustment of lightness, hue, and saturation, the exchange from colour to grey scale and B&W, the erasure of unnecessary areas in the sketch, the separation of form from non-form line and shading - are used before edge detection and segmentation. To decrease the size of the dataset and smooth the boundaries, B-spline or NURBS curve fitting to the outlines are applied. These form-lines are disassembled into spline segments and are used to build up the patches, which represent the whole surface model.

The original sketches (if applicable) or pre-processed sketches still need to be processed further in order to obtain a sketch with single pixel edges and closed boundaries, and this sketch is separated into patches for the downstream processes. Therefore, it is necessary to investigate a set of efficient image processing algorithms for this application.

4.1 Image mode selection

There are many modes for the different purposes of raster image processing including colour and non-colour ones. Some typical colour modes such as RGB (red, green and blue), HSV (hue, saturation and value), HLS (hue, lightness and saturation), and CYMK (cyan, yellow, magenta and black) have been described in the books (Foley et al., 1996; Salomon, 1999). The Adobe Photoshop 6.0 supports colour modes such as RGB, CYMK, Lab (lightness, green-red axis and blue-yellow axis), Indexed Colour, and HSB (hue, saturation and brightness), and non-colour modes such as Greyscale, Multi-channel, Bitmap and Duotone.

There are four modes for image displaying and processing supported by the 23D system: RGB colour, 256 greyscale, 16 greyscale, and black and white (B&W). The internal format is RGBA colour; therefore the modes can be changed reversibly. The algorithms of greyscale are different. For example, the Image Analysis Explorer Pro (iaePro) supports three methods to obtain a greyscale as follows.

$$A_{ij} = \begin{cases} 0.2125R_{ij} + 0.7154G_{ij} + 0.0721B_{ij} & \text{Greyscale BT709} \\ 0.299R_{ij} + 0.587G_{ij} + 0.114B_{ij} & \text{Greyscale Y} \\ 0.5R_{ij} + 0.419G_{ij} + 0.081B_{ij} & \text{Greyscale RMY} \end{cases} \quad (1)$$

However, for simplification, the transformation from RGB to 256 greyscale used here is an average algorithm of the colour RGB values (Jain, 1995, pp. 281).

$$A1_{ij} \Big|_{\substack{i=0, \dots, BmpBgr_w-1 \\ j=0, \dots, BmpBgr_h-1}} = \frac{1}{3}(R_{ij} + G_{ij} + B_{ij}) \quad (2)$$

Where $A1_{ij}$ is the greyscale value of a point in image including three components R_{ij} , G_{ij} and B_{ij} ; $BmpBgr_w$ and $BmpBgr_h$ are the width and the height of sketch in pixels, respectively. In B&W mode, the two levels are obtained from a point between 0 and 255 to bisect the whole range. A similar function is used in Adobe Photoshop 6.0 (Adobe, 2000).

$$A2_{ij} \Big|_{\substack{i=0, \dots, BmpBgr_w-1 \\ j=0, \dots, BmpBgr_h-1}} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 255 \end{bmatrix} \quad \begin{array}{l} 0 \leq A1_{ij} < D_L \\ D_L \leq A1_{ij} \leq 255 \end{array} \quad (3)$$

Where $A2_{ij}$ is determined by $A1_{ij}$, and D_L is a threshold to determine a dividing level. The default of D_L is 192, and can be adjusted. The change from 256 greyscale to 16 greyscale is obtained according to the average rule. A coding scheme proposed in 23D system is that the values of 16 intervals are increased through adding the value 17 for smoothness and keeping it spanning to the two ends (0 and 255).

An example is shown in Fig. 3 for the four modes of processing allowed by the system.

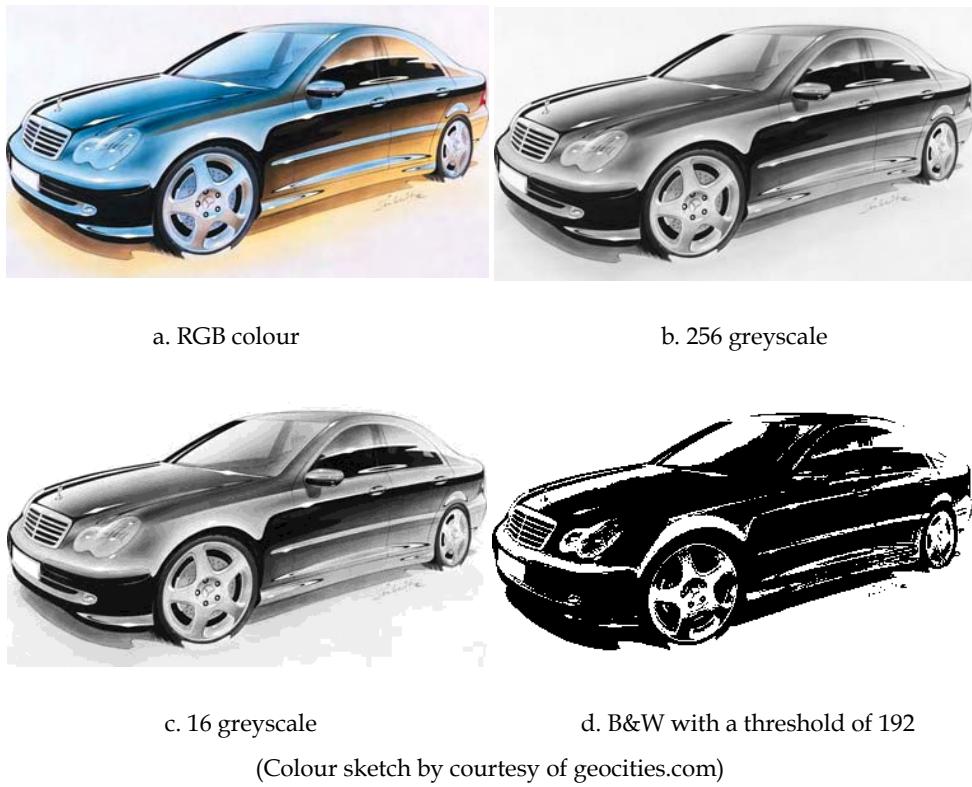


Fig. 3. The four display modes of the system

$$A3_{ij} \Big|_{\substack{i=0, \dots, BmpBgr_w-1 \\ j=0, \dots, BmpBgr_h-1}} = \begin{bmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \\ 13 \\ 14 \\ 15 \end{bmatrix} = \begin{bmatrix} 0 \\ 17 \\ 34 \\ 51 \\ 68 \\ 85 \\ 102 \\ 119 \\ 136 \\ 153 \\ 170 \\ 187 \\ 204 \\ 221 \\ 238 \\ 255 \end{bmatrix} \quad \begin{array}{l} 0 \leq A1_{ij} < 16 \\ 16 \leq A1_{ij} < 32 \\ 32 \leq A1_{ij} < 48 \\ 48 \leq A1_{ij} < 64 \\ 64 \leq A1_{ij} < 80 \\ 80 \leq A1_{ij} < 96 \\ 96 \leq A1_{ij} < 112 \\ 112 \leq A1_{ij} < 128 \\ 128 \leq A1_{ij} < 144 \\ 144 \leq A1_{ij} < 160 \\ 160 \leq A1_{ij} < 176 \\ 176 \leq A1_{ij} < 192 \\ 192 \leq A1_{ij} < 208 \\ 208 \leq A1_{ij} < 224 \\ 224 \leq A1_{ij} < 240 \\ 240 \leq A1_{ij} \leq 255 \end{array} \quad (4)$$

4.2 Brightness and contrast adjustment

The adjustments of brightness and contrast supply the basic means of image enhancement, which compensate for the losses caused by imperfect scanning methods. The algorithm from MATLAB (MathWorks, 2001) *imadjust* function was used to control the values of RGB components directly. The brightness f_b can be adjusted as follows.

$$f_b = \begin{cases} f_{b0}(255-b)/100 & t \geq b \\ f_{b0}(255-t)/100 & t < b \end{cases} \quad f_{b0} \geq 0 \quad f_b \in [0, 255] \quad (5)$$

$$f_b = \begin{cases} f_{b0}t/100 & t \geq b \\ f_{b0}b/100 & t < b \end{cases} \quad f_{b0} < 0$$

Where f_{b0} is the original value of brightness; t and b are the top and the bottom values of brightness. They are adjusted by f_b , $t = t + f_b$ and $b = b + f_b$; h and l are the highest and the lowest values among the values of RGB. The differences are defined as $dx = h - l$, $dy = t - b$. They are limited within 0~255.

$$\begin{cases} h = l + (255-b)dx/dy, t = 255 & t > 255 \\ h = l - bdx/dy, t = 0 & t < 0 \\ l = h - tdx/dy, b = 0 & b < 0 \\ l = h - (t-255)dx/dy, b = 255 & b > 255 \end{cases} \quad (6)$$

If the original value $f_{c0} \geq 0$, the contrast f_c can be adjusted as

$$f_c = f_{c0} dx / 200 \quad f_c \in [0, 255] \quad (7)$$

Then h and l should be adjusted as $h = h - f_c$ and $l = l + f_c$. Otherwise, the image is not enhanced. The boundaries should be adjusted again.

$$\begin{cases} h = x_0 + 0.5dy / k & y_1 \geq t \\ h = 255; t = y_1 & y_1 < t \\ l = x_0 - 0.5dy / k & y_2 \leq b \\ l = 0; b = y_2 & y_2 > b \end{cases} \quad \text{where} \quad \begin{cases} k = \text{tg}[\text{arctg}(dy / dx)(100 + f_c)] \\ x_0 = 0.5(h + l), y_0 = 0.5(t + b) \\ y_1 = y_0 + k(255 - x_0) \\ y_2 = y_0 - kx_0 \end{cases} \quad (8)$$

The Gamma value f_γ is adjusted according to the original value $f_{\gamma0}$ as follow.

$$f_\gamma = (f_{\gamma0} / 5)^{1.2} \quad f_\gamma \in [1, 10] \quad (9)$$

Therefore, the RGB values of each pixel can be calculated as follow.

$$\begin{bmatrix} R_{ij} \\ G_{ij} \\ B_{ij} \end{bmatrix} = \begin{bmatrix} b + (t-b)(C_\gamma)^{(R_{ij}-l)/(h-l)} \\ b + (t-b)(C_\gamma)^{(G_{ij}-l)/(h-l)} \\ b + (t-b)(C_\gamma)^{(B_{ij}-l)/(h-l)} \end{bmatrix} \quad \begin{matrix} i = 0, \dots, \text{BmpBgr_w-1} \\ j = 0, \dots, \text{BmpBgr_h-1} \end{matrix} \quad (10)$$

The dialog window and examples are shown in Fig. 4. The range of the sliders is ± 100 .

4.3 Edge detection

Many algorithms for edge detection have been developed for different image resources. Because the sketches are not the real-world images and can be pre-processed before imported into the system, the edge detection is just a simple routine to quickly find the necessary points for the further processing. Therefore some basic and common algorithms are implemented into the system including *Sobel*, *Prewitt*, *Roberts*, *Canny*, *Zerocross*, *Direct* and *Sobel+*. The system was built using the MATLAB C++ Math Library and the Graphics Library (MathWorks, 2000). The dialog window is shown in Fig.5, which is similar to the MATLAB find edges function.

Some examples are shown in Fig. 6 and Fig. 7. In most cases, the algorithms from the MATLAB edge functions can give good results for original sketches, shown in Fig. 6. However, they give poor results on pre-processed sketches, shown in Fig. 7b and Fig. 7d. The pre-processed sketches are composed of sets of dense and thick strokes coming from a quick expression of the edges according to the original sketches. Therefore, a hybrid algorithm, *Direct*, is proposed to deal with such styled sketches.

The idea comes from a demo – *Region Labelling of Steel Grains* – in the MATLAB image processing toolbox. Two binary images are obtained from pre-processed sketches by using low and high thresholds. The edge points from low threshold image are used to delete the same points from high threshold image. The left edge points from the high threshold image are considered as the edges. In this way minor regions caused by strokes are deleted. The result is shown in Fig. 7c produce from a thick edge image.

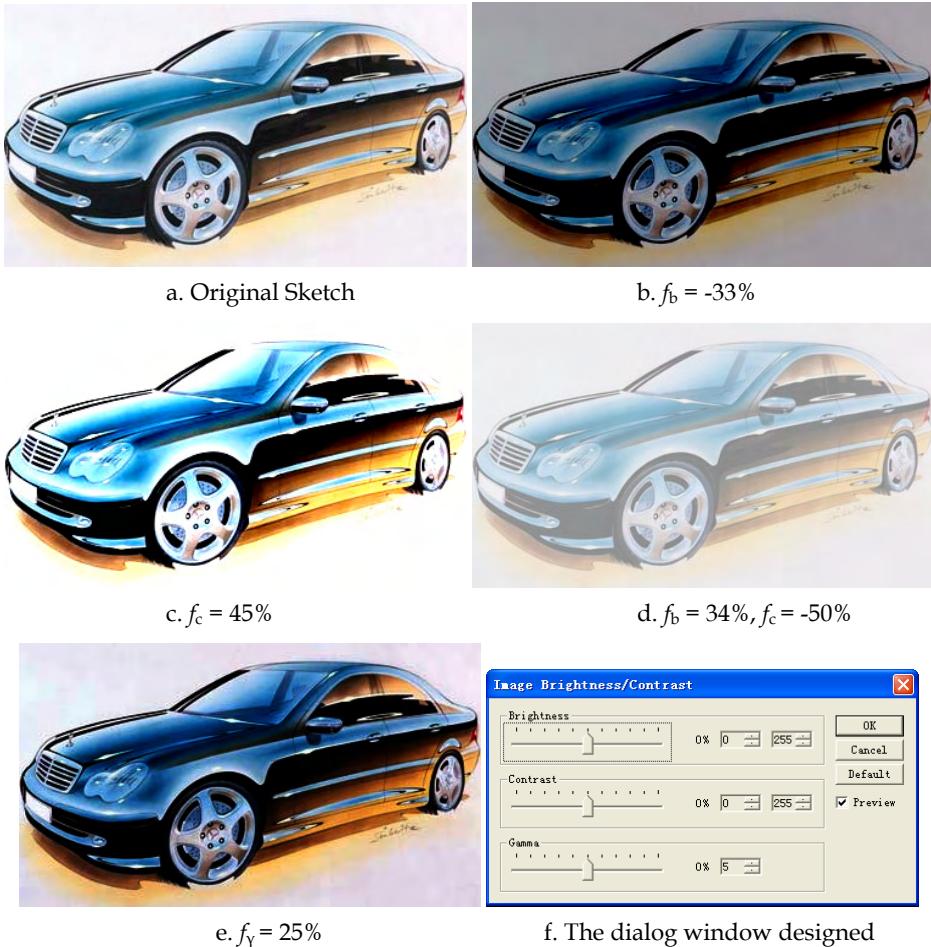
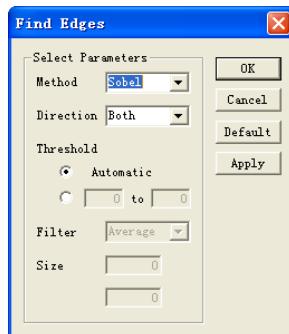
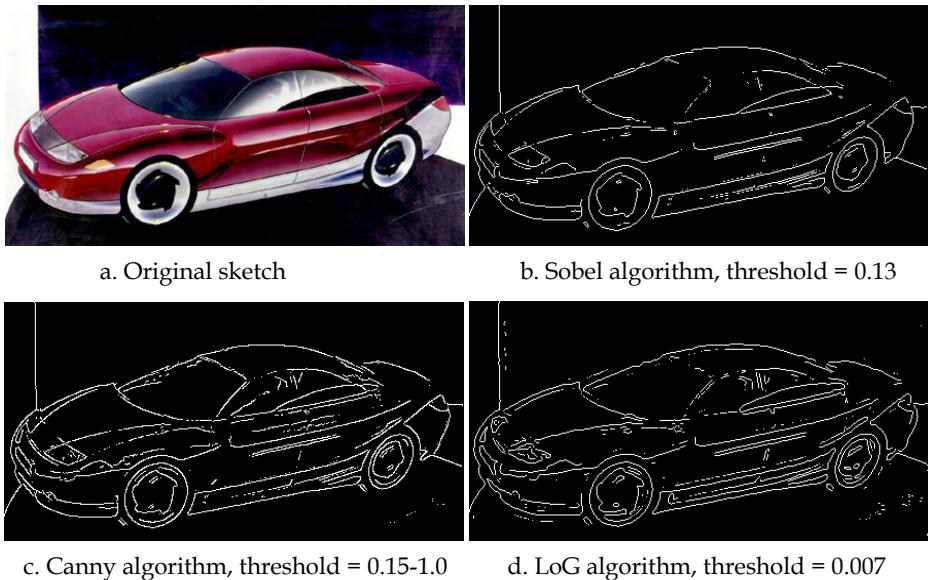


Fig. 4. The samples of the brightness and contrast adjustment

Fig. 5. The dialog window of *Find Edges* function



(Original sketch by courtesy of Cor Steenstra, Foresee Car Design)

Fig. 6. Edge detection of the original colour sketch with the different algorithms

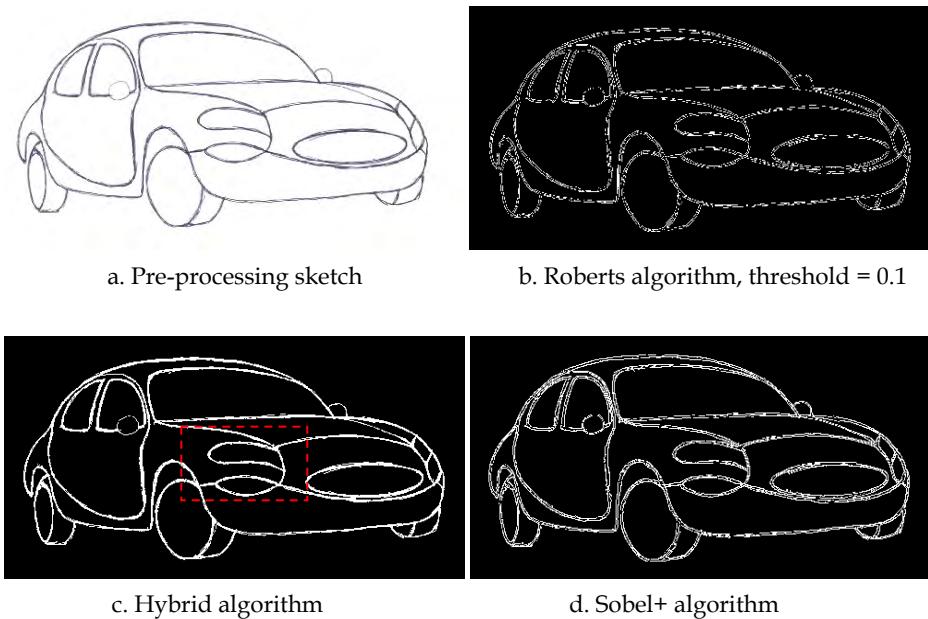


Fig. 7. Edge detection of the pre-processed sketch

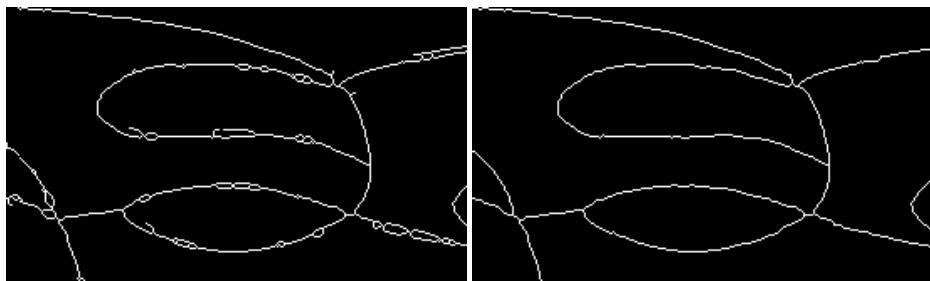
To obtain a satisfactory result, it is crucial to select a suitable threshold for edge detection. However, some problems are still left such as thick edges, double edges and broken edges which cause unclosed boundaries, and small 'spurs' or 'prickles'. Therefore, further processing is needed to eliminate these problems.

4.4 Edge morphing

Edge morphing can further refine the image obtained from edge detection. This function is implemented using the MATLAB *bwmorph* function including the method *Bothat*, *Bridge*, *Clean*, *Close*, *Diag*, *Dilate*, *Erode*, *Fill*, *Hbreak*, *Majority*, *Open*, *Remove*, *Shrink*, *Skel*, *Spur*, *Thicken*, *Thin* and *Tophat*, as shown in Fig. 8. It can apply specific morphological operations to the binary image. Repeated application of these operations may be necessary. *Infinite* means that *Times* are determined by the methods automatically.



Fig. 8. The dialog window of *Edge Morphing* function



a. Thin operation (Times = 7)

b. Debubble algorithm

Fig. 9. Edge thins and debubbles (Please refer to Fig. 7c)

When the edges are not single pixels such as the ones shown in Fig. 7c, edge morphing should be applied. The result after the seven applications of the thin operation is shown in Fig. 9a. The edges become the single pixels, but with some small holes and spurs. This is still not a satisfactory starting point for the transformation. The bubbles and spurs must be eliminated.

4.5 Debubble – a hybrid algorithm

It has not proved to be possible to obtain the required result using a single method. Different hybrid methods have been applied to achieve a good result. Here is a hybrid algorithm proposed in this research to perform an operation of deleting the small holes and spurs, such as shown in Fig. 9a. The algorithm entitled *Debubble*, shown in Fig. 10, applies

firstly the *Bwlabel* algorithm in MATLAB to find the small bubbles (holes), which are determined by the bubble size parameter. Once the small bubbles are found, they are filled into solid areas. Then the *Skel* and *Spur* algorithms are applied to obtain the single pixel edges. The actual bubble size is the percentage of the maximum size in pixels, which is compared with the image size in pixels. For example, to obtain the result in Fig. 9b, the actual bubble size is 165, and the image size is 524288 (1024×512). This is just 0.0315% of the image size – very small bubbles! In this case, all the bubbles those are smaller than 165 are deleted. The result shown in Fig. 9b is quite acceptable. Using the *Direct*, *Thin*, and *Debubble* algorithms for the pre-processed sketches can give a good result.

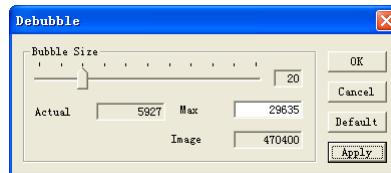


Fig. 10. The dialog window of *Debubble* function

4.6 Edge refinement

Once satisfactory edges are obtained, the image is ready for segmentation. However, there are still anomalies that must be handled. For example, see the case in Fig. 11a, the crossing point of the three patches is not unique. This produces three crossing points. In order to delete this small error, the edge points must be checked and refined.

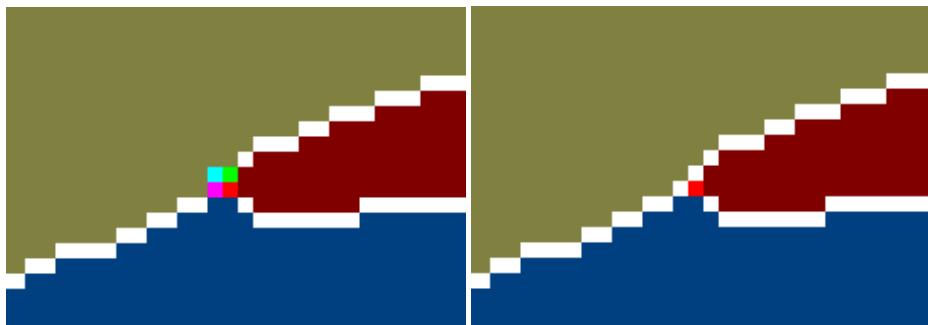


Fig. 11. Crossing point searching

An algorithm is proposed here to perform this operation. It is described as follow:

- Every point is checked in the whole image.
- If it is an edge point, a counter is set with initial value of zero. The point is the current point.
- The eight neighbours of the current point are checked one by one from 0 to 7, see Fig. 12a.
- Once a neighbour point is edge point, the counter is increased by one.
- The current neighbour point is anomaly point, once the counter reaches three within the eight neighbours.

- The last current neighbour is deleted.

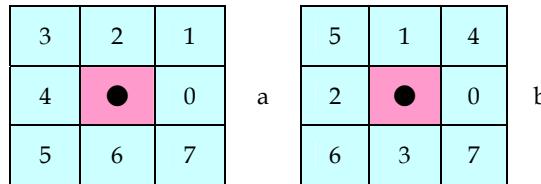


Fig. 12. Eight-neighbour graph

The result is shown in Fig. 11b. Now the three patches share the same single pixel boundaries and have a unique crossing point.

4.7 Patch segmentation with colours

It is easy to separate an image with closed boundaries into patches by applying the MATLAB *Bwlabel* function, and it can then be displayed with the different colour maps. The *Pseudo Colormap* includes *Autumn*, *Bone*, *Colorcube*, *Cool*, *Copper*, *Flag*, *Gray*, *Hot*, *HSV*, *Jet*, *Lines*, *Pink*, *Prism*, *Spring*, *Summer*, *White* and *Winter*, as shown in Fig. 13. The label 0 is assigned to the boundaries between the patches. Label 1 is assigned to the background and used as the silhouette of the whole vehicle. From label 2 onwards, they are assigned to the patches which form the surfaces of the vehicle. After labelling, a pseudo colour map is added for separating the patches. The labelled image is shown in Fig. 14.

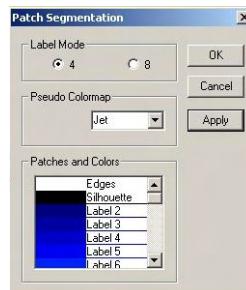
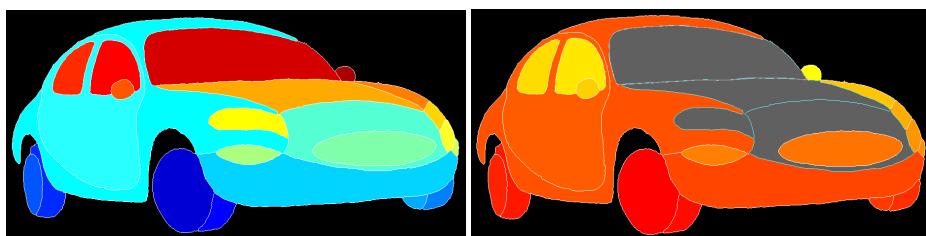


Fig. 13. The dialog window of *Patch Segmentation* function



a. Labelled sketch

b. Multiple Selection of patches

Fig. 14. The sketch after segmentation

As well as the labelling and colour mapping, some other tasks are performed at the same time, such as finding out the start points of each patch on the boundary and the maximum rectangles containing each patch, initialising the boundary node data and searching all the sequential nodes and the crossing points on the boundary of each patch, and calculating the areas and centres of patches.

4.8 Curve fitting

After the segmentation, the sketch is separated into small patches with zigzag boundaries. In most cases, the shape does not vary largely compared with the original sketch. However, at some corners which contain crossing points, the shape may look strange. The use of spline curve fitting can smooth the zigzag boundaries and provide modification of the shapes if necessary.

The patches are selected by the user, shown in Fig. 15b, for performing the curve fitting. The basic functions are implemented from the MATLAB *Splinetool* function in the spline toolbox [THEM01c]. The similar dialog window, as shown in Fig. 16, was designed. An example is given to demonstrate the curve fitting process, shown in Fig. 15 (refer to the area in Fig. 7c). Comparing the areas from Fig. 15a and Fig. 15d, the boundary of the light is smooth and its shape has been improved.

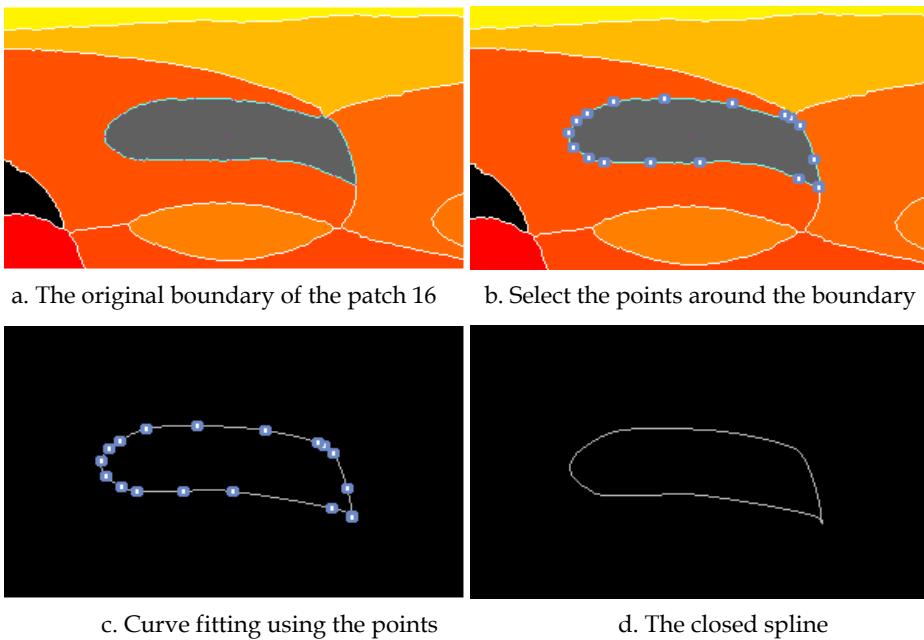


Fig. 15. The curve-fitting and shape modification

5. Feature extraction

The features include the point, curve and patch features extracted from the sketch, which are put into a data structure.

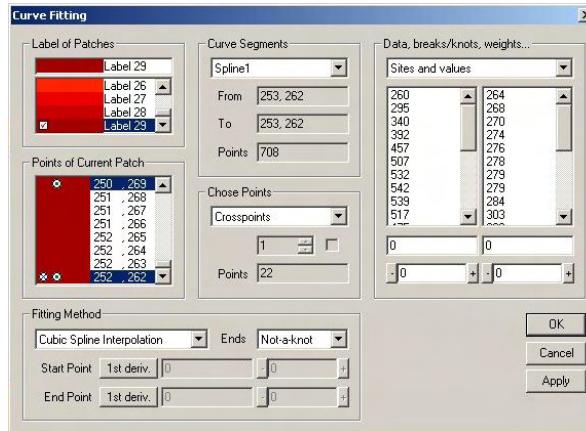


Fig. 16. The dialog window of *Curve Fitting* function

5.1 Data structure for sketch

The points after labelling contain a lot of information for further processing and analysis. Therefore, it is important to establish an efficient data management system. A proposed sketch structure is shown in Fig. 17. The basic unit is a single point, a set of points presents a curve, a close curve or several curves stands for a patch, all the patches make a vehicle.

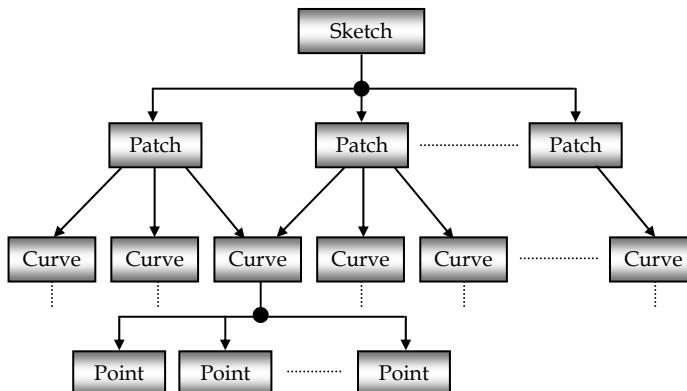


Fig. 17. Sketch data structure

5.2 Point features

After labelling, the sketch becomes a two-dimensional integer array. Zero stands for boundaries as known, but it is necessary to find out which patch it belongs to. They are just the separate edge points with the value of zero at the moment, nothing else. They should be reorganised to useful data.

As the basic unit from data structure, 2D point contains three basic features – the coordinates {x, y}, attributes (crosspoint, selected, breakpoint), and links (previous point, next point).

After labelling, each boundary point has at least two different neighbours. If more than two, the point is a crosspoint. If the point is selected for spline fitting, the selected attribute is true. If the point is used for breaking whole boundary into pieces, the breakpoint attribute is true. The links like a chain join the separated points into a sequential structure. The extraction of point features follows the other feature calculations.

A simple algorithm searching related neighbours is developed as follows

- Assume that the current point is an edge point. The eight neighbours of the current point are checked one by one from 0 to 7, see Fig. 12a.
- Once a neighbour is not an edge point, the first related neighbour is found and saved.
- Carry on searching, any different neighbour will be saved until all neighbours are checked. Return the number of related neighbours and an array containing the different neighbours.
- If the number of related neighbours is greater than two, the current point is a breakpoint.

5.3 Curve features

A set of edge points around a patch make a closed curve. Each closed boundary may have more than one curve segments, i.e., each segment has its own point set. The point sets may be sparse for curve fitting in order to reduce the size of data and obtain a precise representation of the sketch. The following features need to be extracted in a curve:

- Number of points, and the coordinates of each point (values)
- Number of breakpoints if a closed boundary is broken down to several segments.
- The first point and the last point, if the last point is equal to the first point, it is a closed boundary.
- Curve type, either the outer silhouette curve or the internal curve

If using spline fitting to present a curve, the following features need to be extracted.

- Number of selected points for curve fitting
- Fitting method selected.
- End conditions.
- If the point doesn't belong to the original boundary point, a changed tag is given.
- If displaying a spline, a view tag is given.
- If displaying marks on each node, a mark tag is given.

A searching algorithm of boundary curve point setting is based on single pixel has been developed as follows.

- If a point is an edge point and one of its neighbours is the patch, the edge point belongs to the patch.
- The first edge point is the start point of boundary curve, and it becomes the current point, previous point 1 and previous point 2.
- Check the eight neighbours of the current point using the graph in Fig. 12b.
- Once a neighbour point is the edge point and it belongs to the patch, and it is not the previous point 1 and 2, it is a new edge point. Add it to the curve.
- The new edge point becomes the current point. Repeat the same procedure from beginning, until the point is equal to the first point.

In the algorithm, two previous points are used to determine the direction of processing. Using the neighbour graph in Fig. 12b will obtain slightly smoother curves than using the one in Fig. 12a.

5.4 Patch features

Several curve segments are joined together into a closed curve to form a patch. The following features can be extracted.

- The patch serial number, i.e. the label number
- The colour and the title of patch
- If selected for display or processing, a selected tag is given
- The minimum rectangle containing the patch
- The area and centre of the area of patch, the area value is the number of points within the patch. The centre is the sum of coordinates divided by the area.

5.5 Sketch features

When a sketch is separated into patches, the features such as the number of patches and each patch features will be obtained. The neighbourhood will be established. Each patch has the number of neighbours, the shared boundaries with the neighbours. A boundary with one neighbour is the outer silhouette, with two is the inter boundary. The features directly derived from the sketch are shown in Fig. 18.

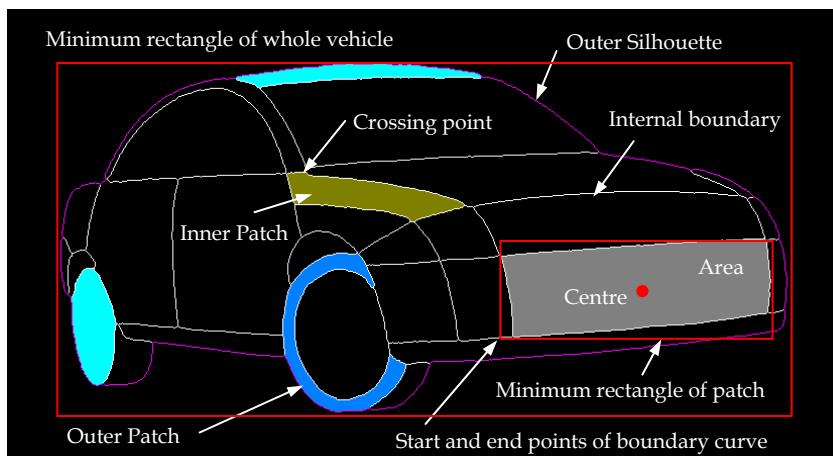


Fig. 18. Features in sketch

Currently, the features directly used for the 2D to 3D transformation are the area and centre of patch. However, more features can be extracted from the points and basic features for further application. It is easy for humans to distinguish where the patch belongs to, what size it is, and where the characteristic points are located. The use of human recognition of patches can help provide a direct and interactive transformation from 2D to 3D, without the need for sophisticated recognition methods. For example, the features such as the position of patch, size and curvature can be used to determine which part of surface it belongs to; the features such as the principal axis of ellipse, size and position can be used for determine the position and tangent points of wheels for coordinate system determination; and features such as symmetric points from breakpoints and the curve between the them, and shading features can be used to determine the curvature of surface, the difference of the areas of 2D patch and its corresponding 3D surface can be used for the adjustment of coordinates. This

can all be done in a straightforward manner so long as the patch is correctly identified, which is most readily done by human intervention (although an automated, possibly artificial intelligence based method for this may be feasible, but is outside the scope of this research).

6. Implementation of MATLAB functions

As mentioned above, the 23D system has been implemented the MATLAB functions. Differing from the proposed method of MATLAB implementation, our method was to apply directly the kernel part of their functions. At first, the MATLAB *.m files were converted into *.h and *.cpp files of C++. Then, it was to extract the kernel part of the function, and to add them into the 23D system. It was necessary to implement all the related functions. Therefore, no *.dll or *.lib files of MATLAB were used. This method is quite simple and easy to change or enhance the implemented functions.

7. Conclusion

The approach here has been to reduce the problem of pre-processing of the sketch into a number of separate stages, each of which refines or extracts a particular piece of information embodied in the sketch. Some conclusions are summarized below:

- The pre-processing of sketches plays an important role for the input sketches. The more precise the sketches are, the easier the sketch processing is. Pre-processing can be used to translate 'imprecise' sketches to more 'precise' ones, providing a better starting point for the transformation process. This approach allows the system to deal with sketches that have roughly closed boundaries, in turn allowing easier separation into patches.
- For the pre-processed sketches, the related processing algorithms have been investigated in order to obtain the separated patches with single-pixel and closed boundary, which are ready for the 2D to 3D transformation. Facing the specific sketches, some existing or new algorithms and new hybrid algorithms have been proposed.
- Some basic features are extracted from the patches to present points, curves and patches. They are listed below.
 - The boundary points
 - The relationships of the patches
 - The minimum rectangle containing the patches
 - The start and end points for each boundary
 - The areas and geometric centres of the patches
 - The attributes of the points whether they are the selected, break or crossing points

Related searching and calculating algorithms have been also developed. Some features are discussed and may be applied in further research.

- The sketch processing and feature extraction depend on the raster data. Therefore, the method is device dependent. The inherent error is one pixel. Increasing the sketch size can reduce error. But the important issue is the quality of the input sketch. A good sketch will produce significantly better results.
- Curve fitting supplies an additional way to improve the patches. Through the selection and modification of the edge points, the shapes of the patches can be smoothed or even

be changed in some places. This process allows resolution of a further set of imperfections in the original sketch.

- Direct implementation of MATLAB functions is a feasible way to enhance 23D system functions.

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