Rapid Prototyping Based on 2D Photographic Images

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Abstract

Generally it is difficult to get a 3D model from its 2D images. However, if the object is symmetric and its photograph is taken in appropriate perspective, then it is possible to extract pertinent 3D information from its 2D images. In this paper, a reverse engineering method to derive the 3D surface model from 2D photographs is introduced. Through a case study, the entire process from photo taking to 3D model making and subsequent rapid prototyping of a model car is introduced. The techniques and related problems of reverse engineering and rapid prototyping are discussed and the future research direction is proposed.

Introduction

By combining reverse engineering, CAD system and rapid prototyping technology together, a rapid product development system can be formed. This system can accelerate the iterative design process from initial conceptual and aesthetic design, product prototyping, and performance testing to model modification. Much work has been done in the area of reverse engineering, such as techniques using laser scanner, CMM, structured lighting, moiré interferometers, etc. A comprehensive summary on these approaches can be found in [1].

There are two ways to reconstruct a 3D model from its 2D images according to the types or different features of 2D images. One approach uses 2D images from medical CT, MRI or industrial CT systems. Each of these images presents one intersection layer of the 3D object. The 3D solid model of an object can be reconstructed from a large amount of this type of 2D images. The 3D model obtained possesses both exterior and interior features of the object. Extensive research has been done using this approach[2][3]. Another approach employs 2D photographic images or images of an object taken for different angles. The 3D model can be reconstructed based on one or more of this type of photographic or perspective images. In this case, only the surface or external features of the object can be captured.

Generally it is impossible to get a unique 3D model from the 2D images because of inadequate information. However, if the object is symmetric and its photographic image is taken from a perspective view, it is possible to extract necessary 3D information from its 2D image. In this paper, a 3D-model reconstruction process based on the 2D photographic images is introduced. The integration of the reverse engineering method and rapid prototyping technology is also discussed. Through a case study, the entire process from photo taking to 3D surface model reconstructing and rapid prototyping of a model car is presented.

The approach of creating 3D model out of one or more 2D photographic images has many applications. There are many situations where conventional reverse engineering methods cannot be used. One typical application is tourist souvenir product design and fabrication. This kind of design is often a miniature size of the original object based on existing buildings, statue, old car, etc. Normally this kind of applications does not require high accuracy and serves just as a basis for further modification.

3D reconstruction based on 2D photograph:

Perspective drawings are commonly used as a tool to express and record the objects in 3D space in architecture and mechanical engineering field. A photograph quite resembles perspective drawing if the photograph is taken in a perspective view. Theoretically it is possible to reconstruct 3D model of the object from the photographs of it from different angels or perspectives. The major difficulty is the determination of the corresponding coordinate systems and the unification of them into one coordinate system. If there is only one photograph, the reconstruction will be much more difficult. It requires additional information. The symmetry of the object can double the information obtainable from the photograph. In addition, manual input from an expert is also required to interpret vague information, rendering the reconstruction of the 3D surface model tedious and difficult.

There are numerous texts on methods to construct a perspective drawing to describe the 3D features of an object[4][5]. The process presented here is reversed. We already have the perspective photographs or images. The goal is to get the 3D features from these images. The reconstruction process is introduced as follows, assuming that the photograph is already scanned into the computer using a normal flat scanner.

- *Vanishing points and object coordinate system:*

Select two parallel lines on the object and extend them in the perspective view to meet in one point, called the vanishing point. For a two-point perspective there are two vanishing points, Vx and Vy, as shown in Fig.1

Select any point Q on the object as the origin of the object coordinate system. Through the origin, establish the two lines towards the two vanishing points. Then a right-hand object coordinate system can be established (Fig.1).

- *Station Point:*

If the station point is shifted, the vanishing points will also be shifted. The station point can be determined by the vanishing points.

In the Fig.1, PP is the picture plane. Vx and Vy are the left vanishing and right vanishing point respectively. Build a semi-circle based on the segment VxVy. Make a line that passes the middle point of the object in the image and is perpendicular to the VxVy. This line will intersect the semi-circle at point E, which is the station point.

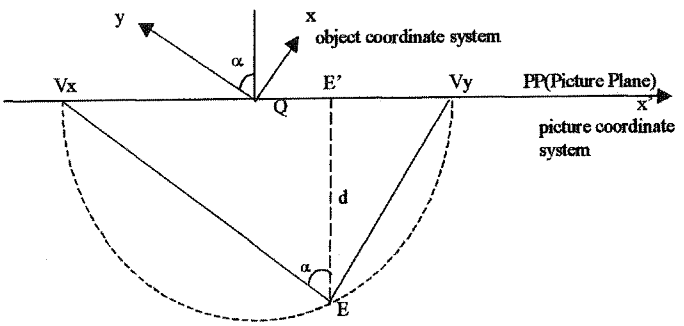


Fig.1 Building of Coordinate System and Station Point

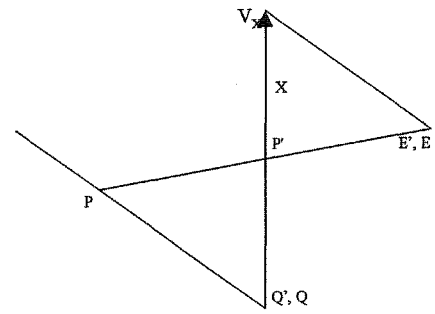


Fig.2. Calculation of symmetry plane

The distance d between the station point E and picture plane PP can be calculated by the following equations:

$$d = |EE'| = sqrt(VxE'*E'Vy) = sqrt\,(\,|x'_{Vx} - x'_{E'}| * |x'_{E'} - x'_{Vy}|\,) \qquad (1)$$
$$\sin\alpha = |x'_{E'} - x'_{Vy}| \,/\, sqrt\,(\,d^2 + |x'_{E'} - x'_{Vy}|\,) \qquad (2)$$
$$\cos\alpha = d \,/\, sqrt\,(\,d^2 + |x'_{E'} - x'_{Vy}|^2\,) \qquad (3)$$

Where the x'_{Vx}, x'_{Vy} and $x'_{E'}$ are the coordinates of points Vx, Vy and E' in the picture coordinate system.

Then the coordinate E (x_E, y_E, z_E) is:

$$\begin{bmatrix} x_E \\ y_E \\ z_E \end{bmatrix} = \begin{bmatrix} -d*\sin\alpha + x_{E'} \\ -d*\cos\alpha + y_{E'} \\ z_{E'} \end{bmatrix} \qquad (4)$$

- *Symmetry plane of the object:*

When the object to be reconstructed is symmetric, the symmetry plane can be calculated. The symmetry plane should be the plane where all the middle points of the two symmetry points of the object lie. The normal of the symmetry plane is assumed to be in the direction of the x axis. Using the coordinate origin Q and its symmetry point P, the equation of the symmetry plane can be calculated as $x = x_P/2$, where x_P is the coordinate of point P.

The determination of x_P is in Fig.2. V_x is the vanishing point in the x axis direction. E' is the orthographic projection of the station point E on the image. Q is the origin of the coordinate system. Notice that only the x axis is drawn. P' is the perspective projection of point P, which is the symmetry point of the origin Q.

$$| QP | = x_p = | Q'P' | / | P'V_X | * | EV_X | \quad (5)$$

Here $| EV_X | = sqrt\,(d^2 + | E'V_X |^2)$

Thus the equation of the symmetry plane is:

$$x = |Q'P'| / (2* |P' V_X |)* sqrt\,(d^2 + | E'V_X |^2) \quad (6)$$

- *Feature points retrieving from surface of object:*

Based on the above principles, the points on the surface of the object can be uniquely determined. According to the symmetry characteristics, two points can be obtained at the same time. These feature points are selected interactively. The coordinates of the feature points and their corresponding points can be calculated using equation (1)-(6). For straight lines, two points are enough to reconstruct them. For curves and free surfaces, more feature points are necessary.

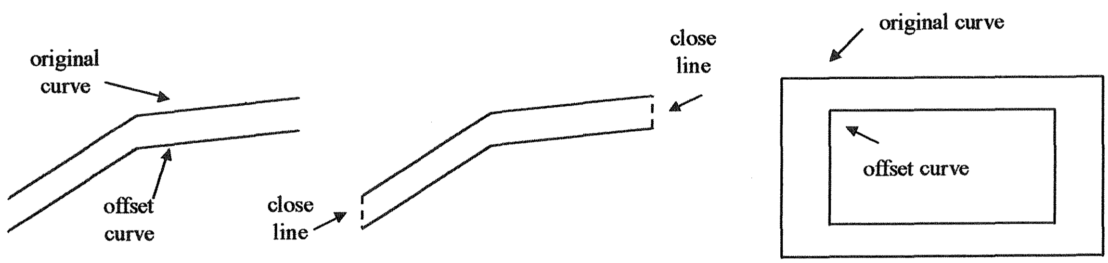
- *Reconstruction of surface model*

After extracting the feature points, different kinds of curves can be chosen to interpolate the feature points and form the boundary lines of the surface patch. Four boundary lines that form a closed loop can be used to interpolate the freeform surface. The surface model can then be derived from these free surface patches[6].

The TDS (Three Dimensional Surface) modelling system is developed based on above principles.

Integration with RP system

The surface model derived from the TDS modeling system consists of a set of surface patches. There exist two major problems in its application in RP technology. Firstly, the surface model often has zero-thickness and open surfaces. This is not suitable for rapid prototyping, which requires the model to be solid or closed surface model. There are three ways to generate a solid or closed model from an open surface model.



(a). Open section curve (b). Close section curve

Fig.3. Get a shell by offsetting the 2D sliced section of STL model.

- To close the surface manually by including additional surface patches to close the open surfaces.
- To offset the open surface model so as to create a shell model with a certain thickness.
- Using the layer manufacturing features of the rapid prototyping technology, instead of generating a 3D offset to create the shell model, it is possible to first determine the 2D sliced section of the model, offset the curve and then close the open ends of the curve and its offset to form a 2D closed path, as shown in Fig.3. This will be much simpler than 3D offset.

STL file generation is another problem. By meshing the surface model the STL file can be generated. The problem is that in many cases the boundary curves of the two neighbouring surface patches do not match exactly. There exist some cracks and holes on the surface model. These small cracks cause no problems for rendering and display, but become critical if the models are used for rapid prototyping. The STL files generated from this kind of surface model will also have cracks and holes. Thus sliced layer curves maybe not be closed or continuous and this results in cross-section raster filling errors and ruins the fabricated parts. It is necessary to inspect and modify the STL model. This involves using flat plane to fill the gaps and holes in the STL model. Hence the missing freeform surface patches are replaced by flat planes, rendering the model less accurate.

Above method can not generate an error-free STL model because of the lack of topological information of the surface model. Once its topological information is reconstructed, the surface model can be transferred into a solid model. Then the error-free STL file can be generated. At present only few articles discuss this approach[7].

Besides STL file, another way to bridge the surface model and rapid prototyping is to slice surface model directly. Direct slicing is more accurate and also easier to be converted into an RP slicing file format, such as the CLI or SLC file format[8].

In our case study, two transfer methods are considered. One is to generate, check and repair the STL output. Another is direct slicing of the surface model and then converts it into CLI or SLC format.

The above processes can be summarized in the Fig.4.

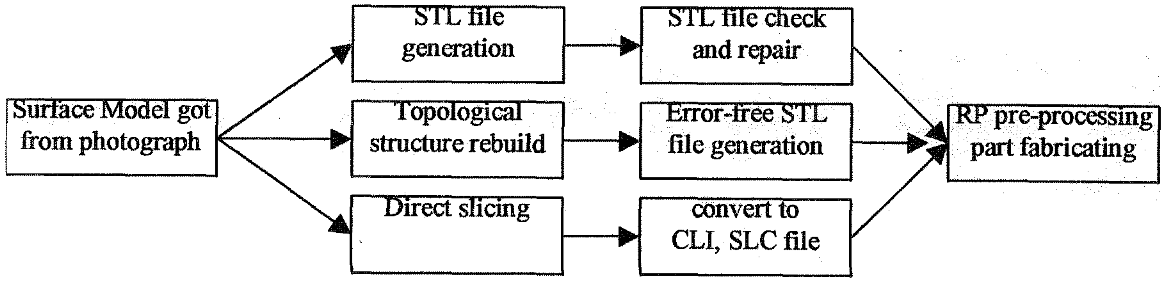


Fig.4. Process from surface modeling to part fabricating

Case study:

In this case study the integration of the TDS modeling system and MRPMS (Multi-functional Rapid Prototyping Manufacturing System) machine of Tsinghua University is investigated. The entire process is introduced from photo taking and scanning, feature point selection, curve reconstruction, surface reconstruction, STL file generation, inspection, modification and final rapid prototyping fabrication.

- Photographic image capture

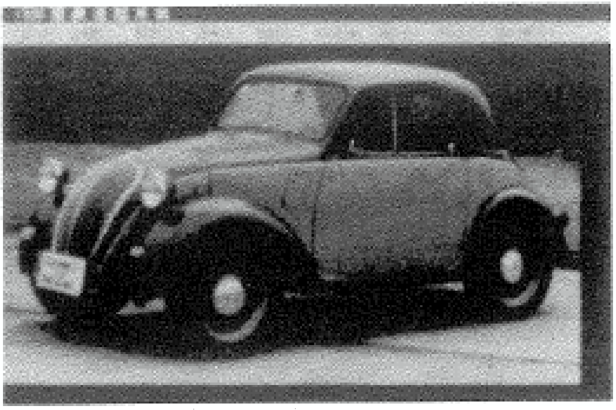
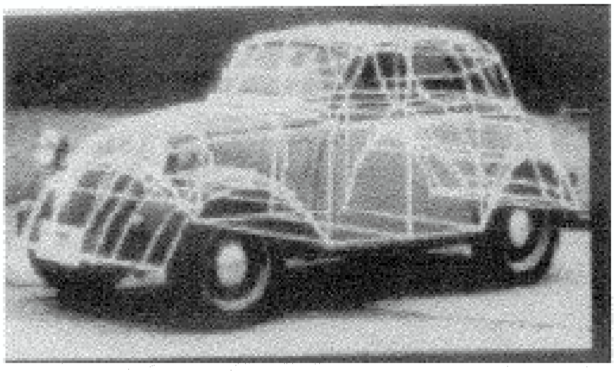


Fig.5. Photograph of the car

Take photo of the object according to different perspective requirements. For a symmetric object, generally only one photograph is needed. Use a normal flat scanner to scan the photo into the computer.

- Feature points selection and the construction of the surfaces.



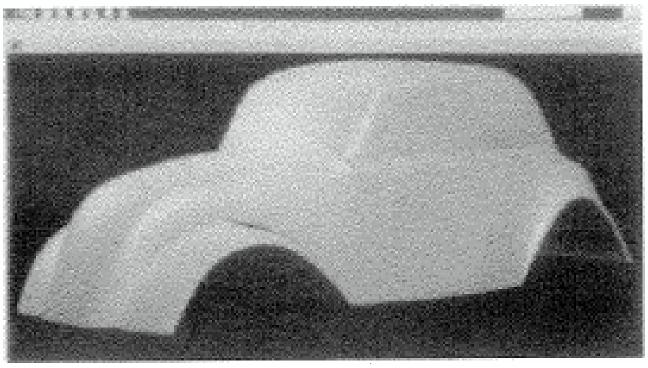


Fig.6. Feature point selection

Fig.7. Rendering of surface model

The feature points are selected interactively. According to symmetry, two points can be obtained at one time. Appropriate curves can be determined based on the selected feature points and the corresponding surface can then be computed. Good knowledge and understanding of perspective are required in the selection of the feature points.

- STL file generation:

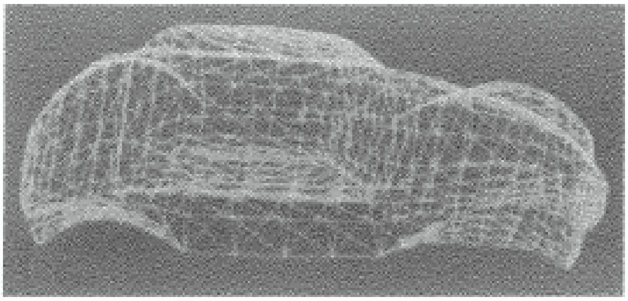


Fig.8. Generated STL model

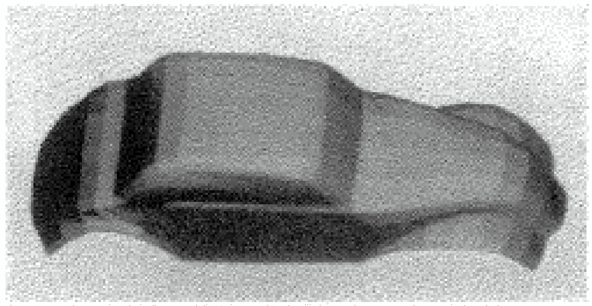


Fig.9. Rendering of the STL model

The STL model can be generated based on the surface model. Fig. 9 is the shaded display of the STL model.

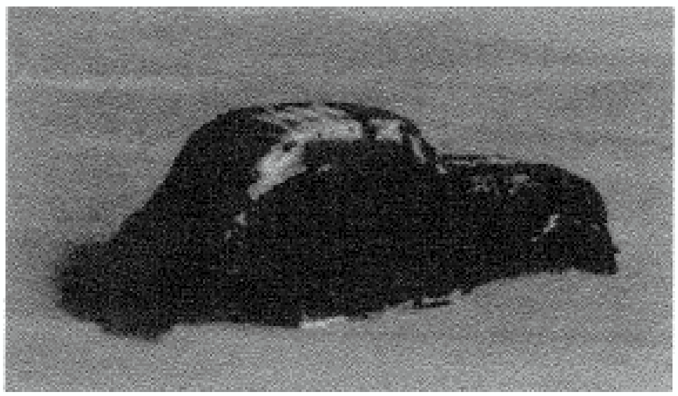


Fig.10. Model of the car fabricated by MRPMS machine

- STL file inspection, repair and slicing

The STL file generated directly from surface model is not error-free. Before slicing, the topological structure must be reconstructed to record the topological relations of vertices, edges and facets in the STL file. Then the errors of STL file can be checked according to the topological structure and be repaired.

- RP fabrication of the model.

Once the error-free solid STL model is obtained, the STL file can be used for various kinds of rapid prototyping fabricating. In this case study, the MRPMS machine developed in Tsinghua University is used. See Fig.10.

Direct slicing is also tested. The sliced data are converted into CLI or SLC file format for rapid prototyping fabrication. Fig.11 shows the directly sliced contour in the TDS modeling system.

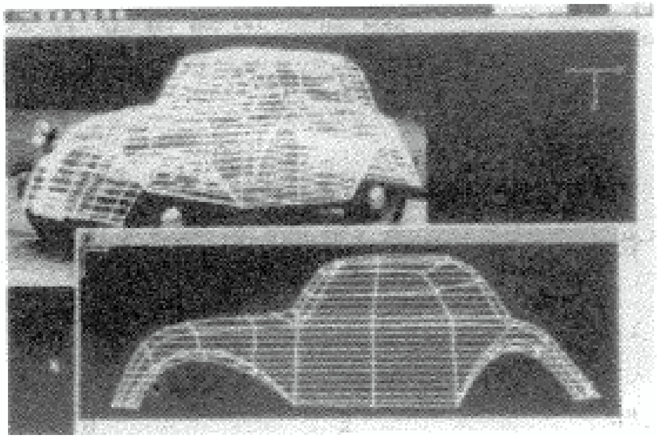


Fig.11. Direct slicing of the surface model in TDS modeling system

Conclusion and Future Research

This paper presents a reverse engineering method to reconstruct a 3D surface model based on the 2D perspective photographic images. The case study illustrates the feasibility of getting the approximate RP model of a car from its photographic image. It can be applied to tourist souvenir product design or similar application when other reverse engineering methods are difficult to use.

This work is still in a primary stage. The feature points are selected manually. For the complex object, the process is troublesome and tedious. The details are difficult to capture using a point. This will cause the inaccuracy of the model.

To improve the process, advanced image processing and pattern recognition techniques can be used to detect the feature points automatically. Besides the perspective and symmetry information, other parameters such as colour, shade, materials appearance, etc can also be included to improve the accuracy of the feature point selection.

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Fig.5

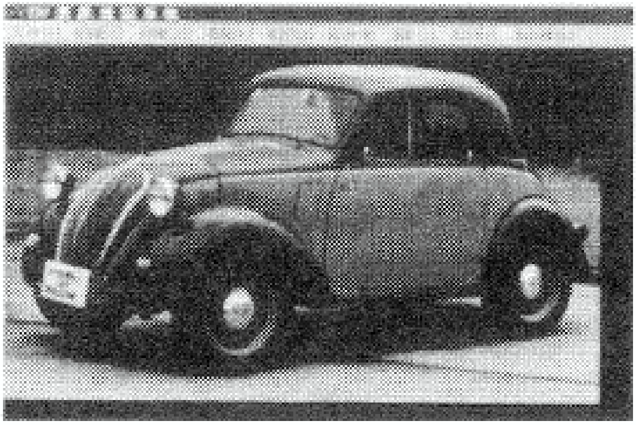

Fig.6

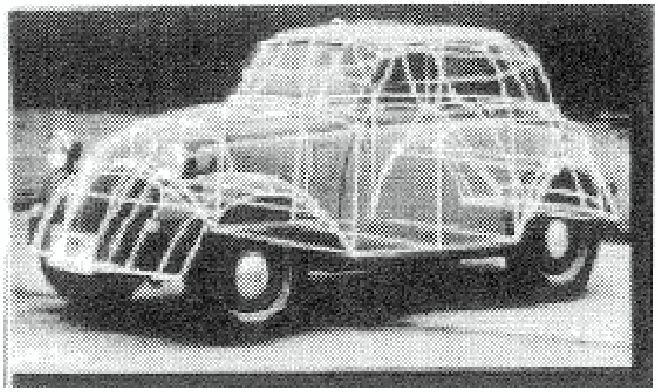

Fig.7

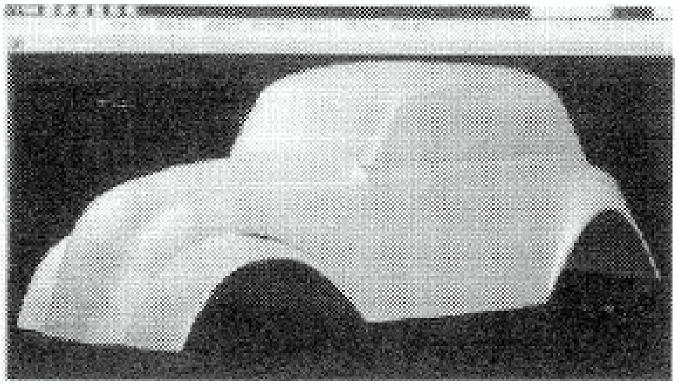

Fig.8

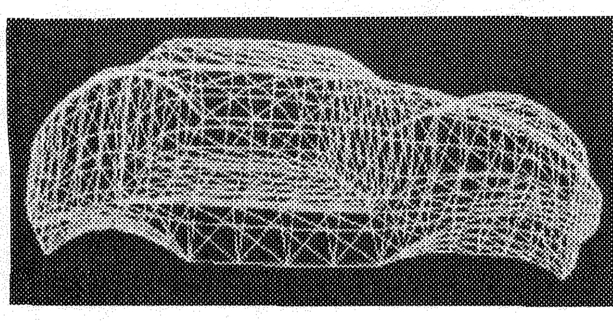

Fig.9

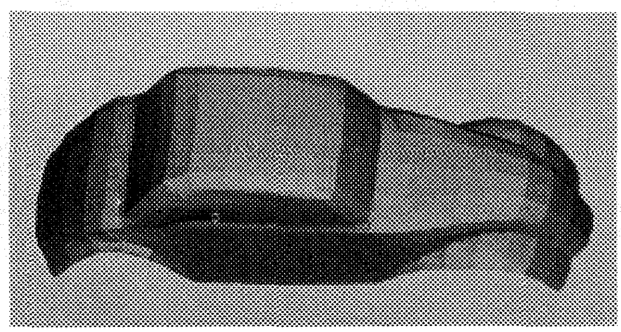

Fig.10

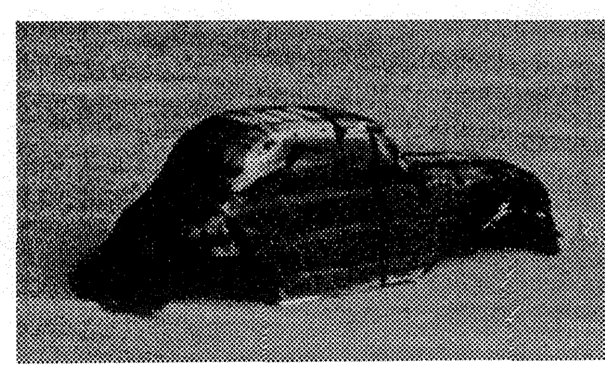

Fig.11