

IRREGULAR SURFACE RECONSTRUCTION FOR 3D OBJECTS RECURSIVE CREATION

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Abstract. The 3D objects recursive creation basis steps are presented. The physical objects video digitizing method is considered for irregular CAD model construction. The irregular surface reconstruction from points cloud is described. The conversion of triangular surface into Rapid Prototyping format is shown.

Introduction

The modern industrial objects often are characterized by high complexity (irregularity) of their geometrical forms. It is caused by increase of the consumer requirements to production properties, such as functional, aesthetic and others. The increased resource consumption of traditionally used industrial systems does not allow to provide irregular products serial manufacturing effectiveness. Therefore the Compact Reverse Engineering System was developed to provide such objects manufacturing most effective [1]. Both the information input module realizing the Reverse Engineering technology and the industrial module which caring out the Rapid Prototyping technology are integrated in this compact system. The information processing module is included in it too. The compact reverse engineering system efficiency is achieved by the structural and functional redundancy minimum level.

The Compact Video Digitizing System is used as the information input subsystem of compact reverse engineering system. Such digitizing system allows to create 3D model of analogue objects quickly and effectively. These CAD models are exposed to selective transformations during design process. This process is carried out in the information processing and control module. Then received CAD model is compiled into Rapid Prototyping file format. It is used to make physical object by the Rapid Prototyping module [2]. Thus new Irregular Objects Computer Recursive Creating Technology is realized.

3D point cloud creation by irregular objects video digitizing

In order to carry out digitizing process the video system includes a video camera, a projector, a rotary table and a personal computer [3]. The projector is equipped with a slide with the image of a regular grid. The video camera is established on a certain angle to a horizontal plane and the projector is horizontal. Such system is inexpensive and is simple for use.

In order to describe irregular object geometrical shape the grid light strips are projected onto the surface object. Then the camera observes the deformed projections of these strips. The varying shape of the object is coded in surfaces fragments images with deformed light strips projections. In order to digitize a full surface the object turns in spatial frame. Then the received images are processed. The main procedures scheme for irregular object reconstruction by video digitizing is shown in Figure 1.

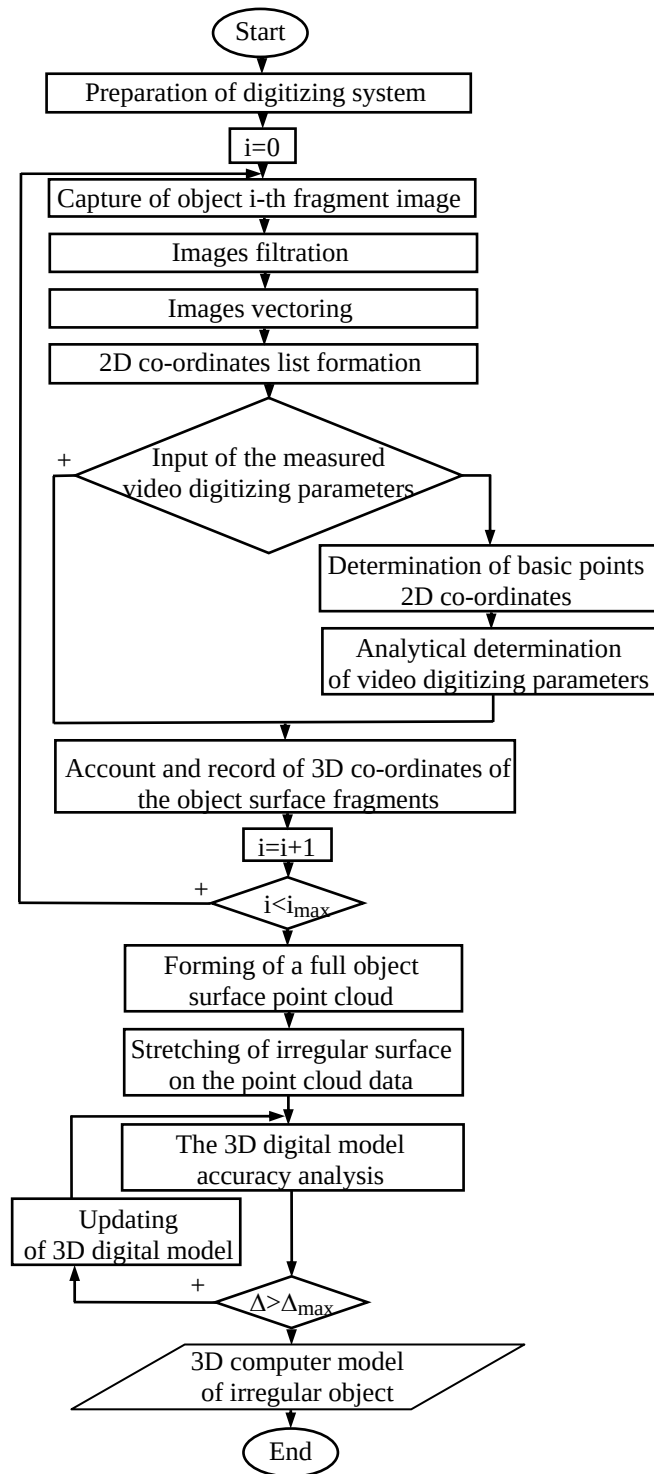


Fig. 1. Scheme of 3D digital model reconstruction by video digitizing

The video images processing is carried out by software with picture recognition functions. At first these raster images are filtered. Then cleaned video images are vectored by special software. The 2D co-ordinates list is formed in the file after images vectoring ending. The 2D co-ordinates are basic data for object 3D co-ordinates account. It is developed by specially developed video process mathematical model [3]. The algorithm of nu-

merical parameters recalculation includes the operations on formation of the video images orientation parameters data list, numerical parameters elements input from the received file and direct recording of mathematical calculations teams. The received results are organized in the files, which describe the points spatial positions for the object separate parts. Thus irregular object digital 3D model contains the 3D co-ordinates of the object surface captured points in the chosen spatial frame. In graphic software the irregular object fragments are presented as clouds of points (Fig. 2).



Fig. 2. The digital 3D model as points cloud

The irregular surface reconstruction from points cloud

The points cloud is composed by several sets T_j of points. These sets are intersected in frontier areas. Initially the boundary box is calculated for the each area:

$$[T_j] = \{ \inf (T_j), \sup (T_j) \}.$$

The area set is represented by the equation:

$$T_j = T_1^{n_1} \cup T_2^{n_2} \cup \dots \cup T_k^{n_k} \cup \dots \cup T_m^{n_m},$$

where subsets are represented as separated points line-up.

Then the subsets $T_k^{n_k}$ are interpolated by B-spline curves. The B-spline curve is defined by the following equation ($n_k = n$):

$$C(t) = N_{1 \times n} \cdot P_{n \times 3} = \begin{pmatrix} N_{0,p}(t) & N_{1,p}(t) & \dots & N_{n-1,p}(t) \end{pmatrix} \begin{pmatrix} P_{0,x} & P_{0,y} & P_{0,z} \\ P_{1,x} & P_{1,y} & P_{1,z} \\ \dots & \dots & \dots \\ P_{n-1,x} & P_{n-1,y} & P_{n-1,z} \end{pmatrix}, \quad (1)$$

where $N_{i,p}(t)$ – the B-spline basis functions [4].

In order to find this curve a control point matrix $P_{n \times 3}$ and the knot vector are determined. Knot vector equation is derived:

$$k = (t_0, t_1, \dots, t_{fl}, t_{fl+1}, \dots, t_j, \dots, t_{fr}, t_{fr+1}, \dots, t_m),$$

where $fl = p - 1$, $fr = n$, $m = n + p - 1$;

$$t_j = t_{j-1} + \Delta t, \text{ if } fl < j < fr, \text{ where } \Delta t = (t_{fr} - t_{fl}) / (fl - fr) = 1 / (fl - fr);$$

$$t_j = 0, \text{ if } j \leq fl; t_j = 1, \text{ if } j \geq fr.$$

On account of interpolation condition and Eq. (1):

$$N_{n \times n} \cdot P_{n \times 3} = T_{n \times 3}, \quad (2)$$

where $T_{n \times 3}$ – matrix of points from subset $T_k^{n_k}$.

The control point set is defined by Eq. (2).

$$\mathbf{P}_{n \times 3} = \mathbf{N}_{n \times n}^{-1} \cdot \mathbf{T}_{n \times 3}.$$

When all subsets $\mathbf{T}_k^{n_k}$ were interpolated the B-spline surface for area is created. The B-spline surface object has two knot vectors ($\mathbf{ku}$ for u parameter, $\mathbf{kv}$ for v parameter) and large enough control point matrix $\mathbf{P}_{N \times 3}$. The B-spline surface is defined by equation:

$$\mathbf{C}(u, v) = \mathbf{U}_{1 \times N} \cdot \mathbf{E}^T \cdot \mathbf{E} \cdot \mathbf{V}_{1 \times N}^T \cdot \mathbf{P}_{N \times 3}, \quad (3)$$

where $\mathbf{U}_{1 \times N}$, $\mathbf{V}_{1 \times N}$ – matrixes are built by basis functions $N_{i,p}(u)$, $N_{i,p}(v)$ accordingly. $\mathbf{E}$ – the unit matrix $\mathbf{E} \equiv \mathbf{E}_{1 \times N} = (1 \ 1 \dots 1)$.

The knot vectors are made as described above. The control point matrix $\mathbf{P}_{N \times 3}$ is derived from Eq. (3) having replaced $\mathbf{C}(u, v)$ on $\mathbf{T}_{N \times 3}$.

The knot vectors $\mathbf{ku}$, $\mathbf{kv}$ have identical dimension. Therefore the points identical account is taken from each obtained B-spline curve in order to create matrix $\mathbf{T}_{N \times 3}$.

After conversion of all areas from point set to the surfaces the next stage consists in conversion the obtained surfaces to the uniform triangles set.

In order to create the triangular mesh the identical cubic elements (voxels) are build. It is based on special partition of bordering space surface. The voxel is intended for the guaranteed arrangement of a triangle (unit of regular structure). Therefore the greatest length of triangle leg:

$$l_{\max} < \sqrt{3}B,$$

where B - the voxel leg.

The voxel is disjointed by 27 bins in order to orient the triangle inside of it (Fig. 4).

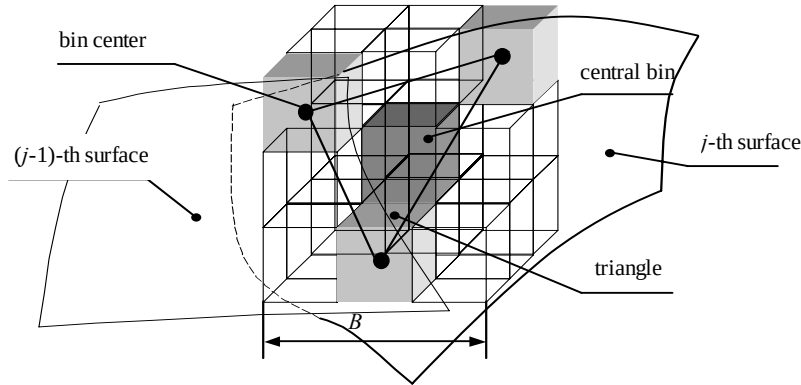


Fig. 3. The voxel triangle orientation scheme

In triangulation process the current voxel bins are checked on intersection with surface (one or more). This surface should contain flowing voxel in surface boundary box. It means that some surfaces are formed into such bin. Three bins are selected among all bins which have at least one hit. The hits amount and realization of the special conditions [5] for a triangle constructed on these bins are taken into account.

The mesh object is created from triangles vertexes. This vertexes represent full object surface. The mesh is saved in DirectX output binary file (*.x - file). This file can be visualized and transformed by any 3D editor (for example 3D-Studio Max).

The Rapid Prototyping format creating

In order to automatically make irregular object the Rapid Prototyping files formats are developed. It is .SLI, .SLC, .STL files and other. The STL format is the graphic stan-

dard of data representation about model for all Rapid Prototyping systems. The method 3D triangulation of a model surface is fixed in basis STL file creation. The information about object includes the triangular legs list. These legs describe a surface of its solid model with the given accuracy. It allows to submit such surface as ASCII or binary file. The ASCII .stl file should begin by a key word “solid” and to terminate “endsolid”. The triangles description is resulted inside these key words.

The description of each triangle includes ordered set triangle vertexes and normal vector description (Fig. 4). All co-ordinates are submitted in Cartesian frame. They are written as numbers from a floating point too.

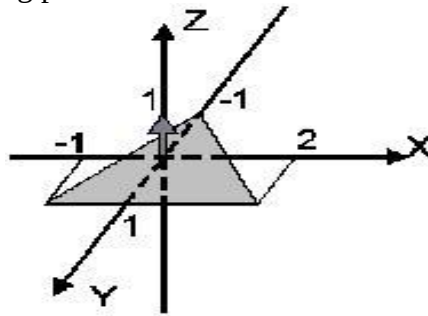


Fig. 4. The single triangle for STL file creation

Conclusion

The considered video digitizing method allows easily and effectively to create digital 3D models by the non-contact measurement of analogue irregular objects. The offered compact video digitizing system is inexpensive and easy-to-use. The presented method of B-spline curve interpolation and consequent triangulation provides qualitatively to reconstruct model irregular surface from digital points cloud. Such reconstructed solid models are successfully used in CAD process for manufacture preparation of new industrial products with complex form. The virtual models have good presentation in the decision of different design tasks too. The 3D digitizing results allow to create Rapid Prototyping file format for automated manufacture of the irregular objects. It allows to realise Irregular Objects Recursive Creation Computer Technology. This technology will stridently shorten the time of many industrial designs. Also it will raise irregular objects manufacture efficiency.

References

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