A New View Planning Method for Automatic Modeling of Three Dimensional Objects

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Abstract. Sensor planning is a critical issue since a typical 3-D sensor can only sample a portion of an object at a single viewpoint. The primary focus of the research described in this paper is to propose a new method of creating a complete model of free-form surface object from multiple range images acquired by a scan sensor at different space poses. Candidates for the best-next-view position are determined by detecting and measuring occlusions to the camera's view in an image. Ultimately, the candidate which obtains maximum visible space volume is selected as the Next-best-view position. The experimental results show that the method is effective in practical implementation.

Keywords: View Planning; Sensor planning; Three-dimension (3-D) reconstruction; Next best view.

1 Introduction

Automatically constructing 3-D computer models of an unknown object or scene from range images has been an important role in the areas of machine navigation, object recognition, and automatic inspection and manipulation.

Recently, many methods on determining the location of the best next viewpoint have been proposed for different kinds of sensors [1-4],[16-18]. The next best view planning algorithm is an incremental model construction method composed of a number of observing-and-planning loops. It is convenient to classify existing view planning methods by the domain of reasoning about viewpoints- that is, volumetric, surface-based, or global. In there, volumetric methods select viewpoints by reasoning about the sate of knowledge of imaging work space [5]. Abidi [6] focuses on the use of a vision sensor to perform the volumetric modeling of an unknown object in an entirely autonomous fashion. An entropy-based objective functional is used to model the object or scene in areas of occluding contours. A local maximum of this function is found to determine the best next view position. Reed [7] determined the visibility volume, which is the volume of space within which a sensor has an unobstructed view of a particular target. Massions and Fisher [8] built on previous voxel occupancy

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methods by using the weighted sum of visibility and “quality” factors as an NBV objective function.

Surface-based algorithms reason about knowledge of object surface space S. for example, Maver and Bajcsy [9] describe an automated occlusion-guided view determining system for scene reconstruction. The system is given a priori knowledge of the environment and sensor geometry and returns the next view position from which a complete range image of the surface visible to the camera may be obtained. The system then computes new scanning planes for further 3-D data acquisition based on the discontinuities (occlusions) in the most recent range image. Maver et al. [10] propose a NBV system using the max-min principle as a heuristic. The system selects from all possible viewing orientates the one which maximizes the amount of new information. However this solution is limited to a particular sensor configuration. Another method is contour following [11], [12]. It works best with objects large size relative to sensor coverage and for relatively simple shapes with smoothly flowing lines.

A few methods derive a view planning cue from global rather local characteristics of the geometric data. Pito [13] present a system that automatically acquires a surface model of an arbitrary part. The concept of positional space is introduced as a basis for view representation. Two types of information are recovered from range data: the visible surface and the void surface. The criterion for determining the next view position is set by the void surface area visible from a point. Yuan [14] described the view planning based on Mass Vector Chain (MVC) mechanism. With MVC, only the view point orientate is obtained, but the position of view point is difficult to decide by this method.

It is important problem in view planning that how to automatically effective and efficiently acquire 3D model of object with minimal a priori object knowledge and sensor placement. To deal with this issue, we have to develop methods for determining the optimal next position of the viewpoint given the partial object description already acquired. The remainder of this paper is arranged as follows: Section 2 provides background information on constraints and view sphere on viewpoint. Section 3 describes the proposed viewpoint planning approach. Section 4, experimental results are given in implementing the proposed method. Finally, Section 5 summarizes the conclusions drawn.

2 Viewpoints and Visibility

2.1 Determination the Visual Region of the Laser-Vision System

In Fig.1, $P_{\min}$ 、 P_{arb} and $P_{\max}$ respectively denote three visual range surfaces which correspond to the nearest position, random position and farthest space position of the vision system, and $P_{\min}$ $P_{\max}$ denotes the largest range region of the Laser-vision system.

θ_i (θ_i') denotes the left-limit angle (the right-limit angle) formed by between the normal vector n_i ($n_i^{'}$) of the tangent plane at the point i and the laser plane. Namely, if the normal vector n_i and n_i' of the tangent plane at the point i belong to the area

θ_i θ_i', the surface is a visual surface. If θ_A、θ_A' and θ_B、θ_B' are known, θ_i、θ_i' at random position can be got. In this paper,suppose θ_i is linear with θ_i',the equation is obtained:

$$\theta_i = \theta_A + \frac{|O_L P - O_L A|}{|AB|}(\theta_B - \theta_A) \tag{1}$$

$$\theta_i' = \theta_A' + \frac{|O_L P - O_L A|}{|AB|}(\theta_B' - \theta_A') \tag{2}$$

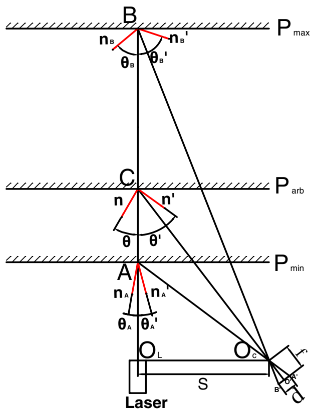


Fig. 1. The diagram of the visual region of the Laser-CCD camera

In our Laser-vision system, $O_L A$ =65 mm , $O_L B$ = 185 mm , $AB = O_L A - O_L B$ = 120 mm , $\theta_A = 20°$, $\theta_A' = 15°$, $\theta_B = 55°$, $\theta_B' = 72°$. Therefore, according to Eq.（1）、（2）:

$$\theta_i = 20 + \frac{|O_L P| - 65}{120}(55\text{-}20) = \frac{7}{24}|O_L P| + \frac{25}{24} \tag{3}$$

$$\theta_i' = 15 + \frac{|O_L P| - 65}{120}(72\text{-}15) = \frac{57}{120}|O_L P| - \frac{127}{8} \tag{4}$$

2.2 The View Planning Strategy

Suppose the Visual Space Volume(VSV) at the viewing point 1 is denoted as P , and when vision system rotates θ to the viewing point 2, VSV Q is got. Viewing point 2 should satisfy the condition that not only the boundary of P should be seen, but also should the invisible volume elimilated is largest.

In Fig.2, at the original position of the object, the largest VSV at the viewing point 1 is denoted as P. Although the surface information of the object at the invisible region is unknown, it is known that the object should be in the region $ABCDEFG$, shown as the shadow in the fig.2, where the surface FG is the farthest space surface of the Laser-vision system, denoted as $P_{\max}$. The normal vector of the tangent plane at any point in the surfaces EF and AG satisfies the Eq.（3）and（4）.

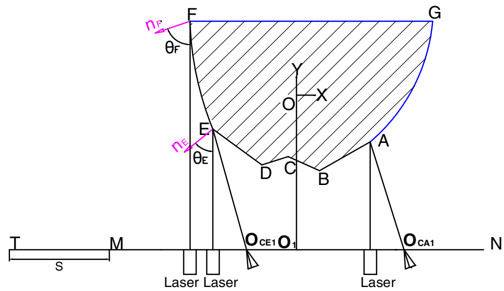
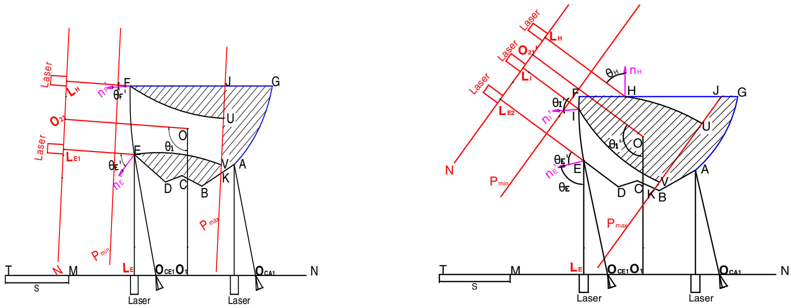


Fig. 2. The viewing point 1 and its visual region

2.3 Selecting the Potential Positions of View Point

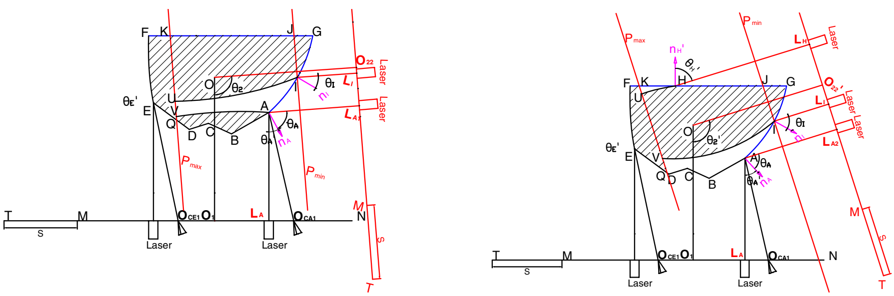
Firstly, let the object be static and the Laser-vision system,whose space position is denoted as TN ,could rotate around the center O of the turntable. After TN is clockwise rotated θ_1, the right-limit angle θ_E' is formed by between the laser plane and the normal vector n_E' of the tangent plane of the viewing point 1 at the point E. That is, the limit position where the tangent plane of the viewing point 1 at the point E can be seen, if TN is kept on clockwise rotating any angle, the point E is or not. So, the viewing point 2 can be got (shown in the Fig.3(a)), and the region $UVEF$ is a visible space region at the viewing point 2, which volume is denoted as Q_{21}. The normal vector of the tangent plane of the surfaces EV and FU at any point satisfies the Eq.（4）.

After TN is clockwise rotated θ_1' , the right-limit angle θ_E' is formed bybetween the laser plane and the normal vector n_E' of the tangent plane of the surface EF at the point E. This is the limit position where the tangent plane of the surface EF at the point E can be seen (if TN rotates an angle clockwise again, the tangent plane of the surface EF at the point E cannot be seen), then the viewing point 3 can be got (shown in the Fig.3(b)). The regions *VKCDEI* and *HUJ* are a visible space region at the viewing point 3.Its volume is denoted as Q_{21}'. The normal vector of the tangent plane of the surfaces HU and VI at any point satisfies the Eqs. (3)and(4).



(a) (b)

Fig. 3. (a) The viewing point 2 and its visual region, (b)the viewing point 3 and its visual region



(a) (b)

Fig. 4. (a) The viewing point 4 and its visual region, (b)the viewing point 5 and its visual region

Secondly, when TN is counterclockwise rotated θ_2, accoring to the above principle, the regoin $AIUV$ a visible space region at the viewing point 4(shown in the Fig.4(a)).Its volume is denoted as Q_{22}. The normal vector of the tangent plane at any point in the surfaces VA and UI satisfies the Eq. (3).

And then,the regions $VQDCBAI$ and HKU are visible space region at the viewing point 5(shown in the Fig.4(b)).Its volume is denoted as $Q_{22}{}'$. The normal vector of the tangent plane at any point in the surfaces VI and HU satisfies the Eq. (3) and (4).

3 The Algorithms of View Planning

As shown in fig.2, the coordinates (x_E , y_E) of the point E and the normal vector $n_E{}'$ of the tangent plane at the point E can be got. Then the angle θ_E formed by the normal vector and the minus direction of y axis can be got. According to the Fig.2:

$$\theta_1 = \theta_E + \theta_E{}' \tag{5}$$

Clockwise rotating θ_1 from the viewing point 1 to 2, the rotating-transform of the coordinate is:

$$\begin{pmatrix} x_{O21} \\ y_{O21} \end{pmatrix} = \begin{pmatrix} \cos\theta_1 & \sin\theta_1 \\ -\sin\theta_1 & \cos\theta_1 \end{pmatrix} \begin{pmatrix} x_{O1} \\ y_{O1} \end{pmatrix} \tag{6}$$

The equation of line $0_{21}L_{E1}$ is:

$$\frac{y - y_{O21}}{x - x_{O21}} = tg(\pi - \theta_1) = -tg\theta_1 \tag{7}$$

$$|L_{E1}E| = \frac{|x_E tg\theta_1 + y_E - y_{O21} - x_{O21} tg\theta_1|}{\sqrt{1 + tg^2\theta_1}}$$

$$= |x_E \sin\theta_1 + y_E \cos\theta_1 - y_{O21}\cos\theta_1 - x_{O21}\sin\theta_1| \tag{8}$$

According to the Eq. (4):

$$\theta_E{}' = \frac{57}{120}|L_{E1}E| - \frac{127}{8} \tag{9}$$

So, according to the Eq.(5)-(9), θ_1 can be got.

At the viewing point 3, according to the above principle

$$\theta_1{}' = \theta_E + \theta_E{}' \tag{10}$$

and:

$$|L_E E| = y_E - y_{L_E} = y_E - y_{O_1} \tag{11}$$

According to the Eq. (3):

$$\theta_E = \frac{7}{24}|L_E E| + \frac{25}{24} \tag{12}$$

According to the principle above, then the equation of line $0_{21}{}'L_{E2}$ is :

$$\frac{y - y_{O21}{}'}{x - x_{O21}{}'} = tg(\pi - \theta_1{}') = -tg\theta_1{}' \tag{13}$$

$$|L_{E2}E| = \frac{|x_E tg\theta_1{}' + y_E - y_{O21}{}' - x_{O21}{}' tg\theta_1{}'|}{\sqrt{1 + tg^2\theta_1{}'}}$$

$$= |x_E \sin\theta_1{}' + y_E \cos\theta_1{}' - y_{O21}{}'\cos\theta_1{}' - x_{O21}{}'\sin\theta_1{}'| \tag{14}$$

According to the Eq. (4):

$$\theta_E{}' = \frac{57}{120}|L_{E2}E| - \frac{127}{8} \tag{15}$$

So, according to the Eq.(10)-(15), $\theta_1{}'$ can be got.

At the viewing point 1， the coordinates（x_A， y_A）of the point A and the normal vector n_A' of the tangent plane at the point A can be got. According to the Fig.4:

$$\theta_2 = \theta_A + \theta_A' \tag{16}$$

Rotating the angle θ_2 from the viewing point 1 to 4, the rotating-transform of the coordinate is:

$$\begin{pmatrix} x_{O22} \\ y_{O22} \end{pmatrix} = \begin{pmatrix} \cos\theta_2 & -\sin\theta_2 \\ \sin\theta_2 & \cos\theta_2 \end{pmatrix} \begin{pmatrix} x_{O1} \\ y_{O1} \end{pmatrix} \tag{17}$$

Then the equation of line $0_{22}L_{A1}$ is:

$$\frac{y - y_{O22}}{x - x_{O22}} = tg\theta_2 \tag{18}$$

$$|L_{A1}A| = \frac{|x_A tg\theta_2 - y_A + y_{O22} - x_{O22} tg\theta_2|}{\sqrt{1 + tg^2\theta_2}}$$

$$= |x_A \sin\theta_2 - y_A \cos\theta_2 + y_{O22}\cos\theta_2 - x_{O22}\sin\theta_2| \tag{19}$$

According to the Eq.(3):

$$\theta_A = \frac{7}{24}|L_{A1}A| + \frac{25}{24} \tag{20}$$

So, according to the Eq.(16)-(20) $\theta_2$can be got.

At the viewing point 5， according to the principle above:

$$\theta_2' = \theta_A + \theta_A' \tag{21}$$

and:

$$|L_A A| = y_A - y_{L_A} = y_A - y_{O_1} \tag{22}$$

According to the Eq. (4):

$$\theta_A' = \frac{57}{120}|L_A A| - \frac{127}{8} \tag{23}$$

Then the equation of line $0_{22}'L_{A2}$ is:

$$\frac{y - y_{O22}'}{x - x_{O22}'} = tg\theta_2' \tag{24}$$

$$\left|L_{A2}A\right| = \frac{\left|x_A tg\theta_2' - y_A + y_{O22}' - x_{O22}' tg\theta_2'\right|}{\sqrt{1+tg^2\theta_2'}}$$

$$= \left|x_A \sin\theta_2' - y_A \cos\theta_2' + y_{O22}' \cos\theta_2' - x_{O22}' \sin\theta_2'\right| \tag{25}$$

According to the Eq. (3):

$$\theta_A = \frac{7}{24}\left|L_{A2}A\right| + \frac{25}{24} \tag{26}$$

So, according to the Eq.(21)-(26), θ_2' can be got.
The VSV can be calculated by the following method:

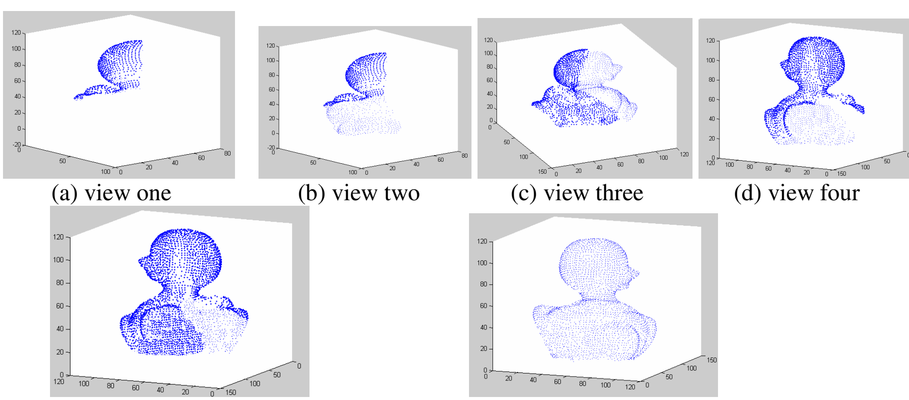
(1) Calculate the area of the visible region(denoted as S) by section-by-section integration method;

(2) If the height (denoted as h) of the object is known, then the VSV can be calculated approximately : $\mathrm{VSV} = \frac{1}{3} S \cdot h$

According to the requirement, the next best viewing point should make the visible volume be largest. Therefore, the strategy is proposed. The next best view is position which obtaining the largest visible space region by compare the volumes of the visible space region at four viewing points.

4 Experiment

The experiment was carried in our laboratory for construction of the object models. The range data are obtained by the VLS-200+ Laser-vision system. The process of the reconstruction object is shown Fig.5(a-e). The final model is shown Fig.5(f).



(a) view one (b) view two (c) view three (d) view four

(e) view five (f) the final constructed model by our view planning

Fig. 5. The process of the reconstruction model:duck

5 Conclusions

In this paper, we presented a new approach of generating 3-D models automatically, putting emphasis on planning of NBV. The proposed algorithm is based on analysis and evaluation of the suitability of viewpoints as the NBV on scanning coverage. The final NBV position which obtains the largest visible space region by compare the volumes of the visible space region among viewing points.

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