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A HIERARCHICAL DETERMINATION OF OPTIMAL CAMERA AND LIGHT-SOURCE POSITIONS FOR MODEL-BASED RECOGNITION

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Abstract

This paper propose a hierarchical design method of camera and light-source positioning for model based vision. In this method, first, the geodesic dome is constructed for given objects to place their initial candidate positions of camera and light-source. Then, they are selected out step by step using criterions of viewing angle, specular reflection, and edge contrast, and the final optimal positioning is obtained. We show that our hierarchical and step by step strategy achieves great reduction of computational time over the conventional direct configuration method to obtain good contrasts of object edges.

1 Introduction

In Computer Vision, it is very important to determine the camera and light-source positions to get good images for processing and recognition.

This paper proposes a hierarchical design method for model based vision systems. Here, we mainly focus on how to determine optimal camera and light-source positions to detect edges of objects whose shapes are given in advance as model data. The camera and the light- source are placed on the surface of a geodesic dome which is obtained first through constraints of other vision tasks such as field of view or depth of focus etc.

We determine next the camera positions by considering the viewing, and then the occlusion for the object edges is judged. This is because, generally, to obtain the *occlusion free* needs a large amount of computations when the object has a complex form or many occluding objects exist in environment. This approach decreases its total amount.

In the previous works, the camera and light-source positions have been determined independently, and to obtain good contrasts of edges only the diffuse component of the reflection has been considered [2, 3, 4]. In this paper, we consider the camera and light-source position as a pair and arrange it to get the best contrasts of the target edges.

The criterion is defined as to provide sufficient contrast to detect the edge, which is evaluated by the difference between the image intensities of two facets on both sides of the edge.

In calculating the edge contrasts, we use the specular and diffuse component of reflection because the observed objects in the industry consist of metal materials.

We show that our hierarchical and step by step strategy achieves great reduction of computational time over the conventional direct method to obtain good edge contrasts. The efficiency of this method of the positioning the camera and the light-source is demonstrated by experiments.

2 Hierarchical Positioning of Camera and Light-source

This section describes the steps of hierarchical positioning of camera and light-source. First, the candidates of the camera and light-source positions are selected on a geodesic dome by evaluating a rather simple criterion. We assume that the dome is already obtained through constraints of other vision tasks such as field of view or depth of focus etc. [1]. Then, the part of the candidate points which belongs in the occlusion region is cut off, and finally the optimal position pair is determined in consideration of the target edge contrasts on the image.

Generally, the occlusion avoidance and the edge contrasts need much calculation. So selecting the candidates in advance by using the easy criterions is efficient in reducing the total amount of computations.

The final criterion to determine the optimal position are based on that,

- the viewing angle of camera and the incident angle of the light to the object edge are not large, and,
- the specular component of the reflection does not incident directly into camera.

Now, the details of these criterions are described in the followings.

2.1 Criterion of the Viewing Angle

We introduce a criterion for the viewing angle to the target edge and evaluate it at all the selected points on the dome. Let $\mathbf{n}_1$ and $\mathbf{n}_2$ be the unit normal vectors of the two side plane segments of the target edge, respectively, and $\mathbf{h} = (\mathbf{n}_1 + \mathbf{n}_2)/|\mathbf{n}_1 + \mathbf{n}_2|$. And $\mathbf{v}$ denotes the unit vector from the middle point of the edge to the camera view point(**Figure 1**). Then this criterion is defined as $\mathbf{h} \cdot \mathbf{v}$. When a set of edges must be observed simultaneously, the product of these criterions is evaluated. By this criterion, the view points from where two side surface of the edge can be observed with nearly orthogonal angle to the edge itself are selected.

Next, we apply the criterion of the occlusion avoidance to the points of the candidates which are good for the criterion of the viewing angle. In this paper, the criteion of the occlusion avoidance is defined as; The part of the target edge which can be observed from the camera position is greater than a threshold. This threshold is set to 80 % in the experiments described later.

2.2 Criterion of the Specular reflection

The directly specular reflections of the light into the images are not desirable. The condition to have such a incidence is,

$$\mathbf{n} \cdot (\mathbf{v} \times \mathbf{l}) = 0, \text{ and} \tag{1}$$

$$\mathbf{n} \cdot \mathbf{l} \cong \mathbf{n} \cdot \mathbf{v} \ \ (\mathbf{l} \neq \mathbf{v}), \tag{2}$$

where $\mathbf{n}$ is the unit normal vector of a infinitesimal facet of the object surface, $\mathbf{v}$ is the unit vector in the direction to the view point, and $\mathbf{l}$ is that to the light-source.

Equations (1) means that $\mathbf{n}, \mathbf{l}$ and $\mathbf{v}$ are on the same plane, and (2) means that the incident angle of the light equals to the reflection angle at the point on the edge. We denote this position as $\mathbf{r} = \mathbf{a} + s(\mathbf{b} - \mathbf{a})$,

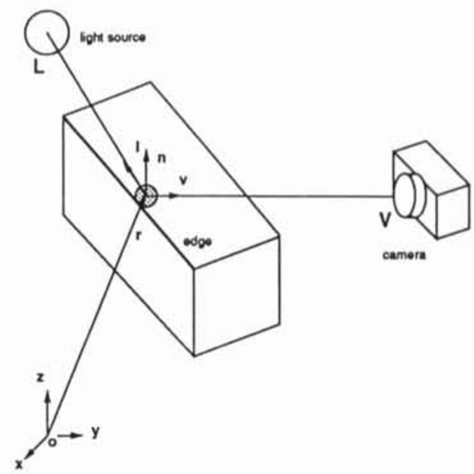

Figure 1: The geometric relation of camera, edge and light.

where $\mathbf{a}$ and $\mathbf{b}$ are the respective end points of the edge and $0 \leq s \leq 1$. Using this form, equation (1) is rewritten as,

$$s = \frac{\mathbf{n} \cdot (\mathbf{V} \times \mathbf{L}) - \mathbf{a} \cdot \mathbf{n} \times (\mathbf{V} - \mathbf{L})}{(\mathbf{b} - \mathbf{a}) \cdot \mathbf{n} \times (\mathbf{V} - \mathbf{L})}. \tag{3}$$

If $0 \leq s \leq 1$, we must examine the condition (2) at $\mathbf{r}$ corresponding to this s. To avoid the direct incidence of the light, all the point pairs of camera and light-source are evaluated by the above criterions.

2.3 Camera and Light-source positioning with respect to the Edge Contrasts

Next, the target edge contrasts are evaluated for the camera and light-source pairs. This test will be carried out for all remaining positioning pair which satisfy two previous criterions. Here, the contrast is defined as the intensity difference between two side facets of the edge(**Figure 2**). The reflection intensities from these facets are estimated by the next Blinn's reflection model,

$$I_{ref} = \left(kR_s \frac{FDG}{\pi(\mathbf{n} \cdot \mathbf{l})(\mathbf{n} \cdot \mathbf{v})} + (1-k)R_d \cos\theta_i \right) I_{in}, \tag{4}$$

where

k	:	ratio of the specular reflection,
R_s	:	specular coefficient,
R_d	:	diffuse coefficient,
F	:	Fresnel term,
D	:	roughness of the surface, and
G	:	geometric attenuation.

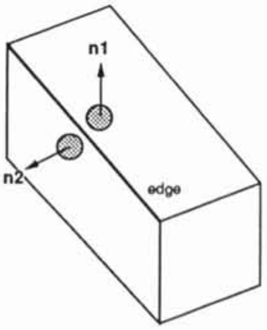

Figure 2: A pair of two side facets of an edge and vectors to evaluate edge contrast.

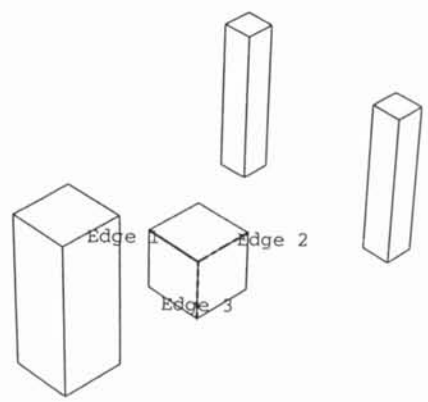

Figure 3: Test objects and target edges.

The number of facet pairs whose contrast w.r.t. a pair of camera and light-source are greater than a threshold are counted along the edge. This pair is selected if the ratio of these facets to the whole length of the edge is greater than a value required. When a set of edges should be evaluated for an positioning of camera and light-source, the pairs which satisfy above conditions for all the edges are selected.

3 Experimental Results

In this section, we show the efficiency of our approach by experimental simulations. A placement of the objects is shown in **Figure 3**. The target edges are shown as three thick edges of the object at the center. Edge 1 is the thick continuous edge, edge 2 is the thick chain edge, and edge 3 is the thick dotted edge. The geodesic dome for these target objects were obtained as shown in **Figure4** based on other vision tasks of field of view. Camera and light-source are placed on the lattice point of the dome.

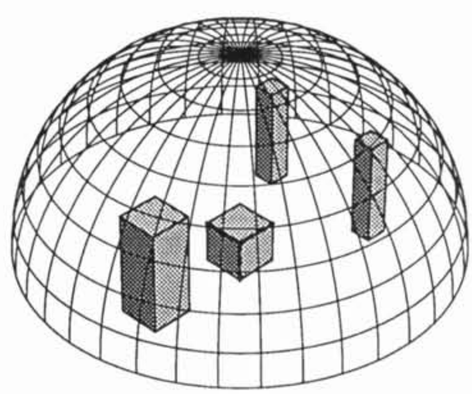

Figure 4: The geodesic dome for test objects.

3.1 The Result for Criterions of Viewing Angle and Specular Reflection

We examined two cases where the maximum limits of viewing angle are set to (1)60(deg) and (2)90(deg). In case of (1), the total of 289 lattice points on the dome were reduced to 36 points through the criterion of viewing angle. Two further points were cut off by the criterion of the occlusion avoidance. In this case, the criterion of the specular reflection did not work. In case of (2), 66 points were remained through the criterion of viewing angle and two further points were cut off by the occlusion avoidance. For three target edges, 12 pairs of camera and light-source were excluded by the the specular reflection criterion.

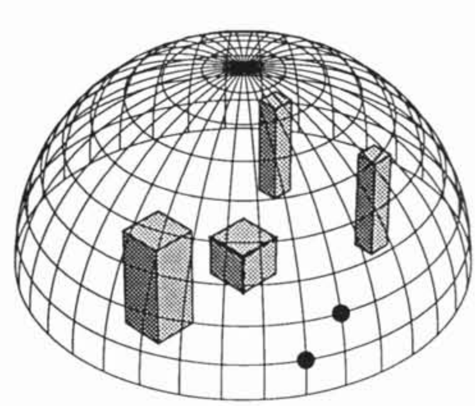

Figure 5: Optimal position of camera and light-source for the case (1).

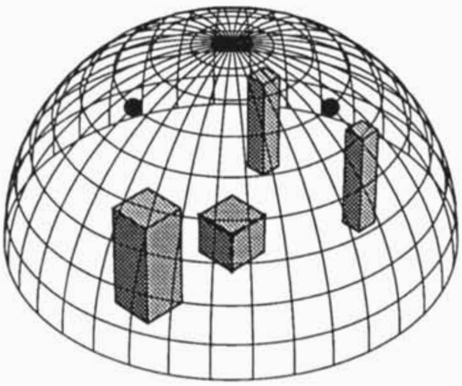

Figure 6: Optimal position of camera and light-source for the case (2).

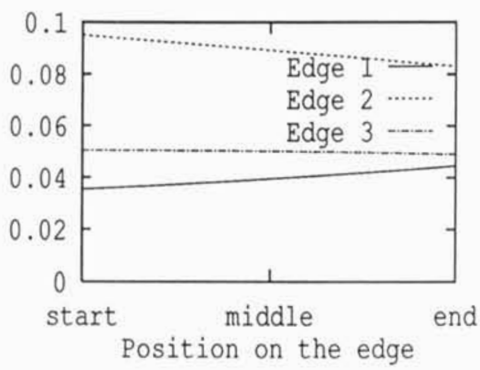

Figure 7: Contrast of three edges for the optimal camera and light-source position in the case (1).

3.2 Optimal Positioning for Camera and Light-source

Cameras were placed on the remaining points in 3.1. For each camera position, desirable positions of the light-source were determined. In this simulation, some number of pairs remained through the final contrast criterion. We define the optimal pair as one generating the largest average contrast of the three target edges.

The optimal positionings obtained were shown in **Figures 5** and **6** for the case of (1) and (2), respectively. **Figures 7** and **8** show the contrasts of three target edges obtained by the final optimal positioning, respectively. Their contrast values are plotted with respect to the position along the edge.

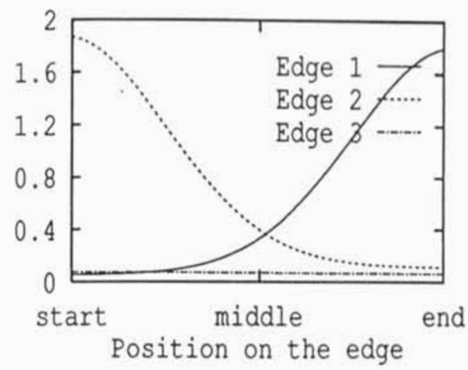

Figure 8: Contrast of three edges for the optimal camera and light-source position in the case (2).

4 Conclusion

In this paper, we introduced the method of determination of the optimal camera and light-source positions to observe given model objects. We selected out the candidates from the points on the dome by the criterions of the viewing angle, the specular reflection,and the contrasts of target edges, and optimal position of camera and light-source was determined. We showed that our hierarchical and step by step strategy achieved great reduction of computational time over the conventional direct configuration method to obtain good contrasts of the object edge.

References

[1] C. K. Cowan and P. D. Kovesi, "Automatic Sensor Placement from Vision Task Requirements," *IEEE Trans. on PAMI*, vol. 10, no. 3, pp. 407-416, May 1988.

[2] C. K. Cowan, "Automatic Camera and Light-Source Placement Using CAD Models," *Proc. IEEE Workshop on CAD-Based Computer Vision*, pp. 22-31, June 1991.

[3] K. Tarabanis, R. Y. Tsai, and P. K. Allen, "Automated Sensor Planning for Robotic Vision Tasks," *Proc. 1991 IEEE Int. Conf. on Robotics and Automation*, Sacramento, pp. 76-82, April 1991

[4] S. Sakane, "A Study on Setup Planning of Active Vision Sensing Systems for Robot," *Researches of the Electrotechnical Laboratory*, No. 903, Nov. 1989