

3D MODELING USING STRUCTURED LIGHT PATTERN AND PHOTOGRAMMETRIC EPIPOLAR GEOMETRY

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Abstract:

Three Dimensional (3D) Surface Modeling is one of the most important photogrammetric tasks due to its spread range of applications. It is performed toward image based ranging techniques. There are two main image ranging techniques. The first one, which is named active projector ranging technique, uses a single camera and high focusing projector. The second approach (which is called passive projector) is based on finding correspondence between stereo images taken from same object surface. Both the techniques use a light projector which projects a structured light pattern. In this study, a color slits pattern have been designed to uniquely labeling and precisely extracting the image points along slits edges. The label of any image point is assigned according to hue value of next and previous slits. Edge points of slits are extracted along the epipolar lines of stereo images and labeled simultaneously. The effects of surface color have been reduced by subtracting the background. The designed slit pattern has been applied using a flat wall, industrial part and human face. The color point clouds of the three different surfaces have been calculated. The calculated points on the flat wall have represented an acceptable accuracy of the designed pattern. The stability of the point extraction and labeling algorithm has been tested for industrial part. The point cloud of the human face shows the capability of the proposed algorithm to get and assign the true color of the scene to the point cloud. The proposed slit pattern has reduced the effects of imaging and point extraction noises.

1. INTRODUCTION

Three Dimensional (3D) Surface Modeling is one of the most important photogrammetric tasks due to its spread range of applications. The applications may be instanced as industrial inspection, reverse engineering of manufactured bodies and object recognition which are basically the advantages of 3D range measurement performed by image based ranging techniques (pages et al. 2005).

There are two approaches for surface modeling in the photogrammetry and computer vision. The first approach is active projector technique. The active projector technique uses a specified light pattern projected on the surface and a single camera. The projected light pattern must be sharply focused to obtain reliable measurement on the images took by camera (Salvi et al., 2004). It means that the light projection device must have high focusing performance. 3D coordinate of the surface points calculated using the image coordinate of the points and geometrical positioning of the projector and the camera. Therefore, geometrical angle of projection device axis and view axis of the camera must be known previously.

The second approach is passive projector technique which is based on finding correspondence between projected light patterns on stereo images. The projected light pattern should be focused to obtain reliable measurement accuracy on the image point. The pattern of light may be a random pattern or a coded structured pattern. The surface model is calculated using triangulation between the corresponded points based on geometrical configuration of the cameras and aerial intersection. Passive projector technique (Stereovision) is based on viewing the scene from at least two points of view and then finding correspondences between the different images in order to triangulate the 3D position.

Comparing the approaches, active projector technique must be done using high performance expensive projector. The most commonly used devices are LCD video projectors, although the slide projectors can be replaced. The active projector technique is forced to use a specified light pattern. However, the pre-specified pattern may lose some area of the 3D surface. The geometrical positioning of the projector and the camera must be known. However, the photogrammetric orientation algorithms (or camera calibration algorithms, as it called in the computer vision) need the known inner orientation of the light projector.

The passive projector technique does not use a high performance projector. The light pattern can be random or structured light pattern. There are different reliable orientation algorithms in Photogrammetry using stereo images. However, difficulties in finding the correspondences arise, even when taking into account geometrical constraints using the passive projector technique.

In this paper, we combined the significant advantages of the two techniques to implement a practical 3D modeling technique.

2. THE ALGORITHM

Two cameras view toward the surface and take images. At first, the cameras take image of the surface with a white color light. The light does not contain any pattern. Some pasted paper targets are used for relative orientation of the cameras. Therefore the geometric configuration of the cameras is solved using a standard relative orientation method. Although, the relative orientation of the cameras can be solved previously using a bar to fix the cameras on it and a photogrammetric test field.

Then a colored slit pattern of light is projected on the surface by a simple video projector and the cameras take another image. The pattern shift and more images are taken to make a denser model.

As a contribution, we have applied two simultaneous strategies to enhance the unique and precise occurrences of the slits. The first strategy was background elimination. The white color image has been subtracted from the second image (which contains projected slit pattern) and the background was simply excluded. So process of images become quicker and effect of object color on pattern reduce. The second strategy was a color ordering for light slits which is explained in the following section (2.1. Design of color slits).

As it is mentioned before, difference of the two images of each camera was an image which includes the slit pattern and excludes the background. Now, there is a pair of subtracted images contain only the slit pattern. The edge points of the slits have been extracted on the left image and uniquely labeled using hue value of previous and next slits. The unique marking of the points is the advantage of the specialized color ordering of slits which is explained in 2.1.

Using epipolar geometry which is derived by the relative orientation, the corresponding epipolar points on right image is found. The edge coding based on the specialized color ordering simplified the matching of correct point among corresponding epipolar points on the right image (Sun et al, 2006). 3D object coordinate of the corresponding points is then calculated using a simple space intersection.

2.1. Design of color slits

In this study, we have designed and applied a specified pattern based on color (hue value) order of the slits. The pattern results some specifications according to unique occurrences and precise extraction of the slits edges.

There are two main color systems in the computer graphic applications (Gonzalez). One of them is Red-Green-Blue (RGB) system which uses the principle of combined main color to derive a sample color. In the digital or mechanical cameras, the RGB system is affected by workspace light, surface reflectance, f-stop and shutter speed. Another color system is Hue-Saturation-Brightness (HSB) system which uses a color index accompanied by color saturation and intensity of the light. In the HSB system, the hue value (*i.e.* color index assigned to each pixel) is free from the above environmental effects and camera settings. The hue color index is a single value which simplifies the color interpretation. The hue value also gives the advantage of more color labels without confusion. Furthermore the effect of object and background color reduced by subtracting white light image from patterned one. Therefore, the hue value helps us to recognize the color index of image pixel better than RGB system.

The image points have been labeled using hue value of previous and next slit. The conditions of color slits order have been considered as the following:

- 1) Two consecutive slit with same color are not allowed.
- 2) The sequence of colors must give maximum hue value differences on adjacent slit.
- 3) Optimum color slit patterns with *n* colors satisfy the following relations:

$$P = \frac{1}{n-1} \sum_{i=1}^{n-1} |h(i+1) - h(i)| \rightarrow Max$$

$$Q = \frac{1}{(n-1)(n-2)} \sum_{i=1}^{n-1} \sum_{j=2}^{n-1} |h(i+1) - h(i+2)| \rightarrow h(i) - h(i+1) \rightarrow Max$$

Where *n* is the number of colors, *h(i)* is the hue value of the *i_{th}* slit and *i, j* are the slit number in the pattern order. It can be simply seen that if hue space is divided to *n* color and each color is used only once, the sequence with maximum *p, q* values will be:

$$h_1, h_2, h_3, h_4, \dots, h_n \quad k = \frac{n+2}{2} \text{ or } k = \frac{n+3}{2} \quad h_{i+1} - h_i = \frac{360}{n}$$

Where 360 is the hue maximum value. If hue space is divided to *n* color and each color is used *n-1* times, the sequence with maximum *p, q* values will be:

$$h_1, h_2, h_2, h_2, h_2, \dots, h_1, h_2, h_2, h_2, \dots, h_{n-1}, h_n$$

It can be seen that the above color order match exactly with the order which is empirically proposed by Hugli (Hugli, 1989). The *n-1* times occurrence of each color results the minimum difference of adjacent slits color and introduce confusions.

2.2. Edge detection along color slits with epipolar lines

After projecting pattern and taking images of surface, the stereo images are scanned along epipolar lines. The points extracted on intersection of epipolar line and slits edges. Each point on any of the image pair is extracted and labeled.

3. IMPLEMENTATION AND RESULTS

The proposed color sequence has been calculated based on 10 hue values. Each color comes twice in slit pattern. The maximum *p* and *q* obtained by testing a large number of proposed sequences. Fig 1 represents the color sequence.



Figure1: a color sequences which satisfy the proposed condition.

The camera resolution has been 3.2 megapixels. The slits edge pixels have had a blurring effect mainly due to camera resolution. Edge detection has been performed using the maximum of first derivation method. As it can be seen in the Fig 2, an average of the peaks must be used as the exact edge pixel. The averaging approach has lead to accurate edge detection both in noisy and sharp boundaries.

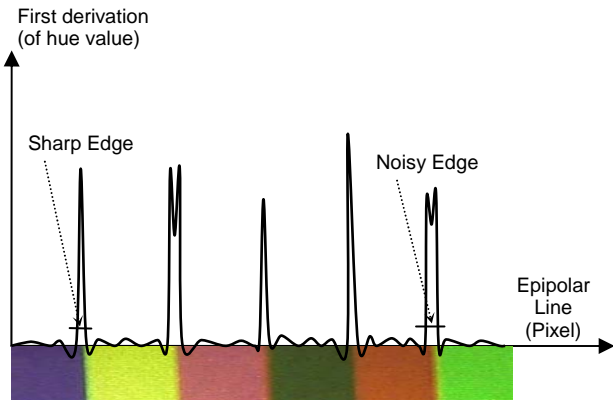


Figure2: First derivation along epipolar line and the types of edges

Sharpness of the edges depends on the focusing of the LCD video projector and stability of the camera. As mentioned before, each edge point has taken the label according to previous and next hue value. Two corresponded points on stereo images have had similar label.

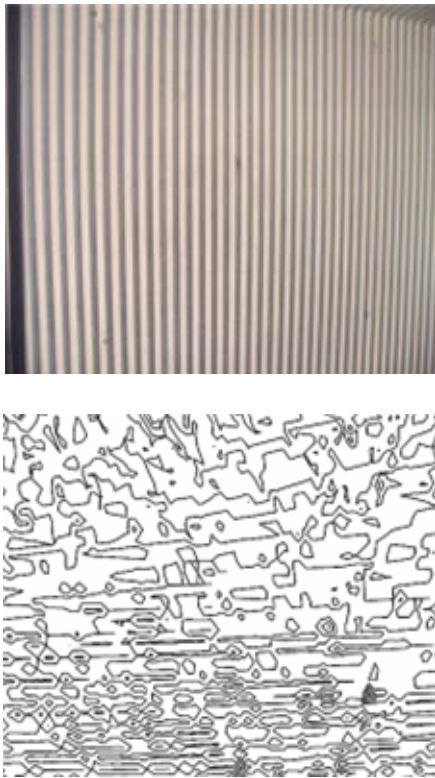


Figure3. The modeled wall and its counter plot

The proposed method is performed using three different objects (A flat wall, human face and an industrial part). A flat wall is modeled using the proposed method to know the accuracy of the method. In this case we used a simple slide projector. The cameras captured whole projected area so the label of edges was the number of slit from left to right. Contour plot of the wall represents the accuracy less than 3 mm (Fig 3).

Then, an industrial part is used. About 30000 points is extracted in about 0.35*0.35 square meters area. The 3D points are structured in one direction (parallel to slit light pattern) and 3D

model can be constructed simply. The part has a lot of surface discontinuities which the proposed technique shows reliable treatment against them (Fig 4).

Then, a human face is used as surface model. The natural color of each surface point is get from white light images. The color is used for the final 3D model to demonstrate a natural 3D model of the human face (Fig 5).

Furthermore, the stability of the point extraction and labeling algorithm has been tested for industrial part. The method does



Figure4a: Industrial part left images. From top left: Slit pattern projected image. White light image and subtracted



Figure4b: Industrial part right images. Same as Fig 4a, from top left: Slit pattern projected image. White light image and subtracted image.

4. CONCLUSION

The point clouds of the three different surfaces have been calculated. The calculated points on the flat wall have represented an acceptable accuracy of the designed pattern. The point cloud of the human face shows the capability of the proposed algorithm to get and assign the true color of the scene to the point cloud. The proposed slit pattern has reduced the effects of imaging and point extraction noises. not require

rectification of images based on photogrammetric principles of epipolar line.



Figure4c: The point cloud model of industrial part.

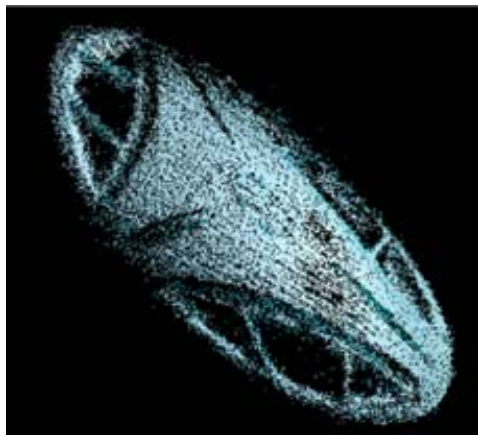


Figure4d: The point cloud model of industrial part from a different angle.

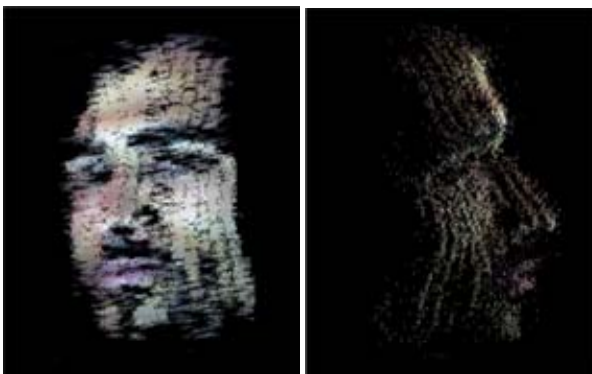


Figure5: the modeled human face.

REFERENCES

- Fusiello, A., Trucco, E., Verri, A., 2000. A compact algorithm for rectification of stereo pairs. *Machine Vision and Applications*, 12(1), 16-22.
- Gonzalez, Woods, *Digital image processing*. Hugli, H., Maitre, G., 1989. Generation and use of color pseudo random sequences for coding structured light in active ranging. *Proceedings of Industrial Inspection*, 1010(1989), 75-82.
- Pages, J., Salvi, J., Collewet, Forest, J., 2005. Optimised De Bruijn patterns for one-shot shape acquisition. *Image and Vision Computing*, 23(2005), 707-720
- Salvi, J., Pag'es, J., Battle, J., 2004. Pattern codification strategies in structured light systems. *Pattern Recognition*, 37 (2004), 827 - 849
- Stefanoa, L., Marchionnai, M., Mattoccia, S., 2004. A fast area-based stereo matching algorithm. *Image and Vision Computing*, 22 (2004), 983-1005
- Sun, J., Zhang, G., Wei, Z., Zhou, F., 2006. Large 3D free surface measurement using a mobile coded light-based stereo vision system. *Sensors and Actuators*, 132 (2006), 460-471
- Zhang, W., Gao, X., Sung, E., Satter, F., Venkateswarlu, R., 2006. A feature-based matching scheme: MPCD and robust matching strategy, *Pattern Recognition Letters*, 28(2007), 1222-1231