SURFACE BASED OBJECT RECOGNITION AND INSPECTION BY PHOTOMETRICALLY EXTENDED BUNDLE ADJUSTMENT TECHNIQUE

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ABSTRACT :

Object or product recognition and inspection has been an active and popular area of various industrial applications in last two decades. The demands on more effective algorithms are increasing by the needs for recognition and inspection of more complicated industrial products. The Extended Bundle Adjustment technique presented in this paper is aiming to integrate geometrical object surface data (which are determined using photogrammetrical bundle adjustment technique) with the surface reflectance properties (measured by a remote CCD camera) to yield more efficient object recognition results. This combined technique is assumed to be more practical for the industrial environment and may give better result than Photometric Stereo technique, which was first formulated by Woodham and required almost perfect laboratory conditions. Since the Extended Bundle Adjustment technique based on perspective geometry of the stereo image pairs is already able to yield both the orientation properties of the object surface and the surface reflectance data separately , it may be the more convenient method to extract object surface information, unlikely to Photometric Stereo whose surface geometry and reflectance data are highly correlated to each other.

1. INTRODUCTION

The most common techniques of object surface determination are basically guided by shape-from-shading tasks which are principally referred to the object surface reflectance properties. In these techniques, the patch of object surface can be analysed with the contribution of light reflectance from the surface. Within this technique, scene radiance information plays an important role to extract surface slant and tilt values (surface orientation parameters) which already means 3-D surface information itself. An example of shape-from-shading technique can be given as Photometric Stereo, which was first formulated by Woodham (1980). Since the other similar shape-from-shading techniques (Harrt and Carlotto, 1989 ; Ikeuchi, 1980) depend on almost same principles , here as an example, only Photometric Stereo technique has been compared to Photometrically Extended Bundle Adjustment method. The idea of Photometric Stereo, basically refers to the determination of relationships between the object local surface (patch) orientation and its reflectance by varying the direction of incident illumination between the successive images. In Photometric Stereo, the reflectance characteristics of an object surface must be known. An ideal surface is to be used such as Lambertian with the perfectly controlled illumination condition to gain surface parameters. Each image is taken from the different directions while the viewing direction is constant. The object surface intensity value at any surface point for three different views may be described as :

$$\begin{aligned} I_1\ (x,y) &= R_1\ (p_1,q_1)\ ; \\ I_2\ (x,y) &= R_2\ (p_2,q_2)\ ; \\ I_3\ (x,y) &= R_3\ (p_3,q_3)\ ; \end{aligned} \tag{1}$$

Here at least three images are required to solve p_i and q_i of the same surface. The function R_i (p_i , q_i) characterises the reflectance map and p,q are surface gradients along x,y directions. In Photometric Stereo technique, so many unknown parameters should accurately be measured in the laboratory environment, such as ; surface reflectance pixel values, incident angles (between the light source and surface normal), etc. Briefly, Photometric Stereo technique needs the following features ;

1-Image projection used is assumed to be orthographic.
2-Light source should be a single distant point source.
3-Light source displacement to provide different incident angles should be very accurate in degree or if differently located sources are used, they should have exactly equal illumination.
4-The object surface should be perfectly diffuse (Lambertian, etc.) surface.

(Woodham, 1979). In addition to the above limitations, Photometric Stereo technique can not operate in real-time since the light source has to be rotated around the camera axis to change the direction of incident illumination meanwhile multi images have to be acquired as the object remains constant. Using Photometrically Extended Bundle Adjustment technique, most inconveniences above are solved. The tests at the laboratory environment have been done on some objects types such as ; metal,plastic, wood, etc.

2. THE SYSTEM SPECIFICATIONS

The system which utilizes Photometrically Extended Bundle Adjustment technique, consists of CCD camera pairs for stereoscopic view, frame grabber in a PC, laser six-point pattern generator (as it is shown in Figure 1), rotating platform (to manipulate the object for inspection from different views) and the light source (filament lamp). Before recognition tasks, the CCD cameras have to be equally calibrated. This should contain ; principal distance determination, perspective and lens distortion corrections and camera grey-scale calibration. Some other minor corrections to frame grabber jitter effects, CCD detectors location errors, etc. may be neglected. During the recognition task, each camera acquires the images in real-time simultaneously even if the object is in motion.

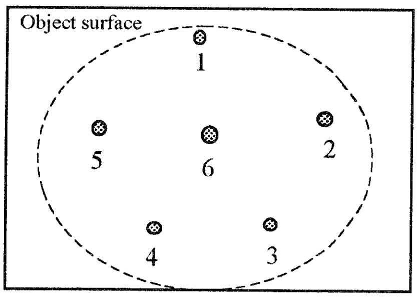

Figure 1. Six-dots laser pattern

The stereoscopic data acquired by photogrammetric system, unlikely to photometric stereo, contains only the image coordinates of six-dot laser pattern (Figure 1). Matching of the corresponding points of pattern in stereo images is very easy and suitable to real-time applications due to shorter time requirement than full-frame image processing. In next step, the image data set contributes to Bundle Adjustment solution (simply the solution of collinearity equations by iterations) and the real X,Y Z cartesian coordinates of six-dots are found with the camera orientation parameters. The formulation of the link between image coordinates and real cartesian coordinates is as below ;

$$x_i = -f \; \frac{r_{11}(X_i - X_s) + r_{21}(Y_i - Y_s) + r_{31}(Z_i - Z_s)}{r_{13}(X_i - X_s) + r_{23}(Y_i - Y_s) + r_{33}(Z_i - Z_s)} \qquad (2)$$

$$y_i = -f \; \frac{r_{12}(X_i - X_s) + r_{22}(Y_i - Y_s) + r_{32}(Z_i - Z_s)}{r_{13}(X_i - X_s) + r_{23}(Y_i - Y_s) + r_{33}(Z_i - Z_s)}$$

(Moffit and Mikhail, 1980). The r_i elements belong to the Rotation matrix and contribute to the ω, φ, κ tilts of each image plane. Each element may be written as follows :

$$\begin{aligned}
r_{11} &= \cos\varphi \; \cos\kappa \\
r_{12} &= -\cos\varphi \; \sin\kappa \\
r_{13} &= \sin\varphi \\
r_{21} &= \sin w \; \sin\varphi \; \cos\kappa + \cos w \sin\kappa \\
r_{22} &= -\sin w + \sin\varphi \sin\kappa + \cos w \cos\kappa \\
r_{23} &= -\sin w \cos\varphi \\
r_{31} &= -\cos w \sin\varphi \cos\kappa + \sin w \sin\kappa \\
r_{32} &= \cos w \sin\varphi \sin\kappa + \sin w \cos\kappa \\
r_{33} &= \cos w \cos\varphi
\end{aligned} \qquad (3)$$

In Equation 2, f : camera lens principal distance (same for both cameras), X_s, Y_s, Z_s : perspective center coordinates (camera locations), r_i : the elements of image rotation matrix, X,Y,Z : cartesian coordinates of a single point on the object surface. For both cameras, the collinearity equations are solved in Bundle Adjustment algorithm. With the solution, the local surface orientation parameters can be easily and accurately determined since at least X,Y,Z coordinates of three surface points are already known. In this case the average slopes of X and Y directions of this local surface patch surrounded by the three perpendicularly distributed points (such as points 5-4-2) may be found as; p = dz / dx (along X direction) ; q = dz / dy (along Y direction). This surface patch later will be illuminated by a circular pattern (with about 10 mm diameter) for surface quality inspection, which is totally based on the analysis of surface reflectance characteristics related to randomly selected pixels on the corresponding image segment. The formulation of reflectance map which corresponds to surface intensity values for the ideal surface is as below ;

$$I = \frac{g(1 + p_i p_s + q_i q_s)}{\sqrt{1 + p_{s_i}^{\,2} + q_{s_i}^{\,2}}} \qquad (4)$$

here, "g" is the surface reflectance factor, the vector $[p_s, q_s, -1]$ points the direction of the light source. The surface characteristics formulated above does not suit to the practical applications nor does not give the correct results at non-ideal conditions. To overcome this, a data set acquired by the Photometrically Extended Bundle Adjustment technique which contains the surface patch orientation parameters (p_i , q_i) and the randomly selected pixel values of the surface reflectance within the patch (I_i), gives us the planar curves shown in Figure 2.

In the figure, each curve belongs to different type of object surface. At the beginning of recognition task, each object surface must be introduced once to the system for object model curve achievement. To realize this procedure, the object takes place on the rotating plate and surface reflectance values are then remotely acquired by a CCD camera (from 1-2 meter distance) and recorded, with the corresponding angles of the surface rotation. The data of graph, likely to Figure 2, is to be stored in the data base.

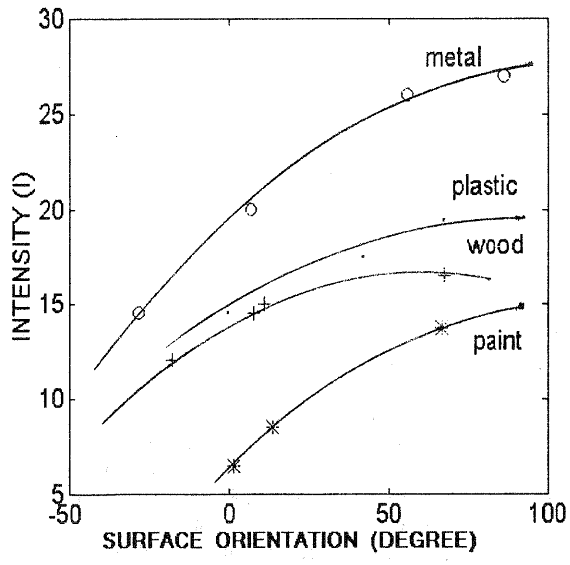

Figure 2. The reflectance values of different surfaces

Later, all acquired data during the questioning of unknown object will be matched with these graphs. The closest graph will assumed to belong to the examined object. As shown in Figure 2, each curve has been determined by the polynomial curve fitting for the corresponding object, which may be formulated as :

$$I_I = a_0 + a_1 x_i + a_2 x_i^2 + a_3 x_i^3 \qquad (5)$$

for each node. here a_i are the coefficients of the polynomial curves belong to each characteristic surface. I_I and x_i are the intensity and surface orientation values. For four nodes of curve, as it is in Figure 2, four equations (5) are needed.

3. OPERATION OF THE SYSTEM

The system software operational steps are as follows ; The stereo images of the object is taken as it is actively illuminated by six-point laser source. By the properly selected threshold value, only six points image coordinates are extracted and stereoscopically matched. Then the Bundle Adjustment technique with the additional parameters is used to determine X,Y,Z coordinates of six points. Later, the six-point pattern on the surface is replaced by circular light (e.g. filament lamp) dot. Then randomly selected pixel intensity values of the local surface patch (illuminated by the dot), are collected and analysed. The set of composite data (both geometric and photometric) yields sufficient information of the examined object surface type.

Finally, object surface classification subprogram utilizes the model surface parameters and attributes them to the certain object type registered in database for the ultimate recognition.

4. REFERENCES

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