Przemysław MAZUREK

West-Pomeranian University of Technology, Szczecin, Department of Signal Processing and Multimedia Engineering

Light estimation using light probe devices

Streszczenie. *W artykule przedstawiono metodę estymacji oświetlenia z wykorzystaniem próbnika oświetlenia, w szczególności z kołnierzem. Wykorzystując transformatę Hougha można wyznaczyć położenie i średnicę próbnika. W celu zmniejszenia kosztu obliczeniowego zaproponowano kilka algorytmów śledzenia w sekwencji klatek obrazu. (**Estymacja oświetlenia z wykorzystaniem próbników oświetlenia**).*

Abstract. *In the paper light estimation technique using the light probe and collar is presented. The Hough Transform is applied for the estimation of position and diameter of the light probe. Applications of the tracking algorithms for the video sequence allow reduction of the computation time significantly (about two orders).*

Słowa kluczowe: Estymacja oświetlenia, próbnik oświetlenia, śledzenie, cyfrowe przetwarzanie obrazów.
Keywords: Light estimation, light probe, tracking, Digital Image Processing.

Introduction

Light measurements are very important for the modeling of objects' illumination in computer graphics. There are different techniques of light modeling. The light sources modeling technique is usually used. This technique is not sufficient for realistic scenarios and complex configurations. Another technique is based on the measurement of incident light in real environment [1, 2]. Such approach allows lighting of objects using measurements only by the application of the light sphere. This sphere is a light filter used for modification of light rays emitted from the sphere to the centre of sphere (Fig.1). Light probe measurements are obtained using spherical or hemispherical panorama acquisition techniques. The multiple image stitching (panoramic technique) (Fig.2) and single image (light probe based) techniques are used typically.

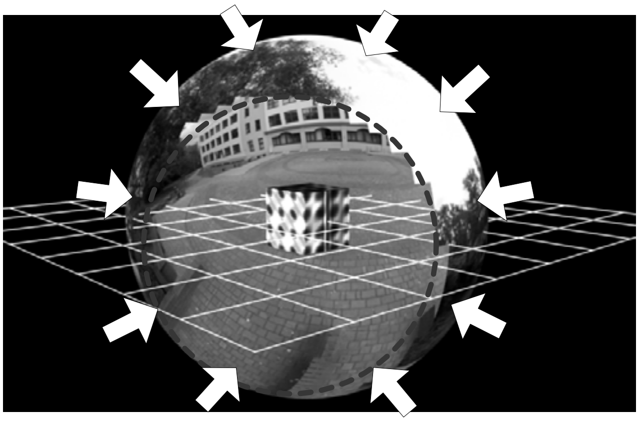

Fig.1. Idea of the light probe lighting

The light probe device (Fig.3) is spherical or hemispherical mirror placed in the measurement point. The camera is used for acquisition of the reflected hemispherical light from this mirror. Conversion of the circular area to the spherical image projection is necessary for application in computer graphic software [1].

Obtained measurements correspond to the vector light nature. The incident light meters acquire the scalar measurements of the light at some point only. The hemispherical matte lenses are used in such meters typically. Vector measurements are important for the realistic visualization of the 3D scene [1] and realistic lighting of the human or object [3,4]. The point measurements loose information about possible reflections and are accurate for the matte surfaces. The lighting simulations, where there are some realistic and virtual elements, need the vector-based lighting.

Fig.2. Panorama stitching technique (top: a set of images, middle: high resolution image light probe image, bottom: low resolution light probe image - used for non reflective surfaces)

Hemispherical mirrors as a light probe devices

Mirror balls (spherical) or hemispherical mirrors are useful light probes [1]. The image is recorded using the camera. Camera records static or moving mirror so measurements are dynamic. The reflected area may be variable (e.g. including people, vehicles). Camera movements are also possible. Such approaches are used in moviemaking nowadays, but exactly the same techniques would be used for other purposes, like architectonic space visualization, light design, etc.

The image obtained from the camera consists of reflected area and the background. The background is also important for the light measurements especially if the composite image should contain this background.

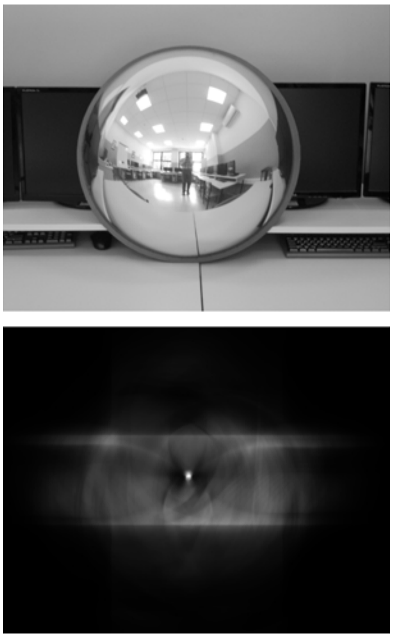

Fig.3. Hemispherical mirror with the collar as a light probe device and maximal value for the position after Hough Transform (white area corresponds to the maximal fitness)

Separation of the reflected area is rather simple for the human, but it is very exhausting if there are movements of the camera or light probe. The automatic techniques for the extraction of the light probe from the background are necessary. In [5] is proposed collar based hemisphere. The collar has blue color and chromakeying techniques for estimation of position are applied. Additional techniques for improving separation are also used [5]. The estimation of the position is not possible using chromakeying only. The chromakeying may fail if the there are similar colors in image. Additional edge detection of the inner and outer edge of the collar and data fusion is used [5].

Estimation of the light probe position using Hough Transform

The Hough Transform (HT) [6] is used, for the detection of lines in images usually. The generalization of the HT allows detection of any shape, which is located at any position. Detection of the circular shape related to the collar is quite simple from theoretical point of view. The output of the HT is 3D space (two dimensions are related to the position of the light probe centre; third dimension is related to the radius). Subpixel estimation of the position is possible if the input image is upsampled (interpolated) to higher resolution. Following formula allows computation of HT for the input image:

$$H(x,y,r)=\sum_i I\left(x+r\cdot\sin(\alpha_i),\, y+r\cdot\cos(\alpha_i)\right) \quad (1)$$

where: I – image, x,y – circle centre, r – radius, i – particular angle, α – angle.

Such formulation of the HT (1) uses accumulation by sampling selected points located on the circle. Image pixels values are accumulated and the constant number of points is used [5]. Such technique allows comparison of different circles. The estimated position $(x,y,r)_{est}$ is obtained by the maximum value search.

$$(x,y,r)_{est}=\arg\max_{x,y,r} H(x,y,r) \quad (2)$$

The main limitation of HT is the scale of the computations. This algorithm is very slow even if the sine and cosine functions are stored in a table. Matlab computations are very slow even for algorithm tests. The GPGPU (General Purpose Graphics Processing Units), that support parallel processing of optimized code, is the best available processing device [7,8]. Processing 32 radiuses for 512x512 image size takes about 0.9 seconds using Nvidia CUDA [5,6] processing platform and G80 processor (GeForce 8800GTS card) [9]. Larger image sizes and amount of radiuses increase computation time linearly [8,9].

The advantage of the HT is the optimality of results, what is necessary for automatic and precise estimation of the position and radius of the light probe. Gradient and non-gradient techniques for estimation (search best fitting over image) are not suitable and the computation time depends on the image content. Another promising technique for the reduction of the computation time is the application of the tracking algorithms for selection of the most probable position of the light sphere with a collar.

Performance of the Hough Transform

In this test is used a set of synthetically generated images consisting the light probe (100 samples) from the database of exterior images [5,10] from different countries and under different light conditions. Estimated distribution of position error is shown in Fig 4.

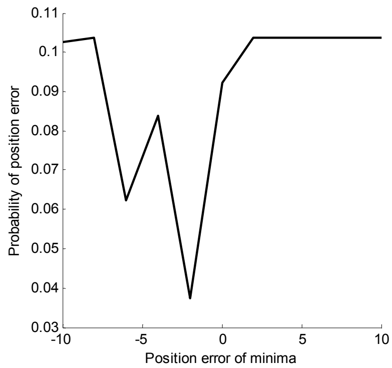

Fig.4. Probability of the position error in pixels of minima

Position error is not equal to the zero, because the collar has own width. In this example radius, equal to the 100 pixels is assumed. The much more precise position and radius should be obtained using gradient search algorithm.

Tracking algorithms for the light probe

The Hough Transform processing range (positions and radiuses) should be selected using knowledge based techniques. The position and the radius are similar for the following images. Processing of all combinations by HT is not necessary. Two first frames should be processed using full scan, because it allows estimation of the motion vector for the position and radius. Next image frames are processed using obtained knowledge (initialization) and the motion model by the tracking algorithm. The common part of the two following images is the collar, in the best case. The collar is spatially dispersed and conventional correlation techniques between frames are not feasible. The tracking algorithm predicts the position and radius of the collar and some errors may occur due to non-ideal motion model and movements noises.

Motion patterns during the light probe use

There are a lot of possible movements during the measurements. Four cases are typical: the smooth movement when operator is not moving (SS), the smooth movement during the operator walk (SW), the rapid movement when operator is not moving (RS), and the rapid movement during the operator walk (RW). The motion model supported by the tracking algorithm depends on the selected movement technique. Selected movements cases for both orthogonal directions are shown in Fig.5. The height of the light probe, placement relatively to floor or ground is almost constant. The camera used in the motion test has very low resolution 160x120.

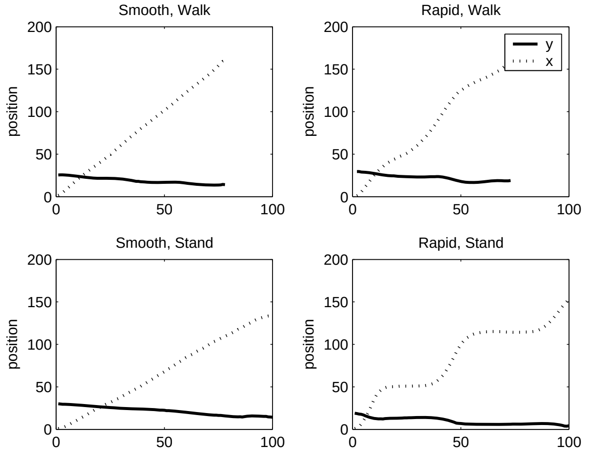

Fig.5. Example movements of the light probe for 30 fps camera

Most movements are linear or similar to linear. The Kalman filter [11] and the Benedict-Bordner [12] (simplified Kalman) filter (3) are sufficient for tracking:

$$\dot{x}^*_{n+1,n} = \dot{x}^*_{n,n-1} + \frac{h_n}{T}\left(y_n - x^*_{n,n-1}\right)$$
$$x^*_{n+1,n} = x^*_{n,n-1} + T\dot{x}^*_{n+1,n} + g_n\left(y_n - x^*_{n,n-1}\right) \tag{3}$$

where: $\dot{x}^*_{n+1,n}$ – predicted velocity, $x^*_{n+1,n}$ – predicted position, $\dot{x}^*_{n,n-1}$ – previously predicted velocity, $x^*_{n,n-1}$ – previously predicted position, y_n – currently observed position, g, h – filtering (smoothing) constants [12].

Even very simple local area tracker, based on the search in range of the maximal movement is sufficient. The RS case has movement up to 8 pixels between two following frames in horizontal direction. Such assumption reduces the HT search range 20 times (160 pix / 8 pix = 20) in horizontal direction. Similar assumption for the vertical direction, combined together with previous assumption, allows reduction of the computation by factor 400.

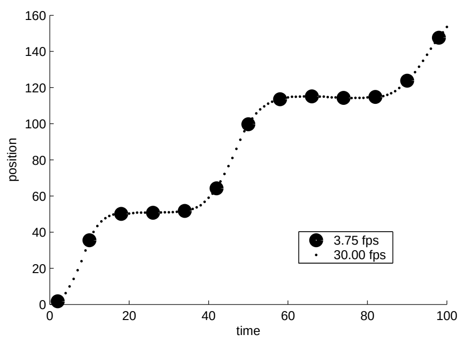

Fig.6. Example influence of fps on linearity of trajectory in horizontal direction

The linear motion model is assumed in the Kalman or Benedict-Bordner for the standard speed camera (25 or 30 fps). Such cameras has low resolution typically, the digital still camera is the best cost effective solution, but the number of fps in the serial photo modes are reduced to a few fps typically. High resolution images are important especially for the estimation of the light near to the collar of the light probe. The reduced number of fps degrades linearity of the motion, especially for the rapid movements (RW, RS), what is shown in Fig.6. The reduction of fps to the 3.75 fps influents on rapid changes of the trajectory that is non-linear. The search area should be extended for such case to the 20 pixels (Fig.6).

Extended search area reduces benefits of the tracking for horizontal direction (160 pix / 20 pix = 8). Assuming similar reduction factor for vertical direction the total reduction is about 64 times.

Conclusions

The Hough Transform is well suited for the collar tracking of the light probe. Reduction of the computation cost proposed in this paper is possible by the application of the tracking filters or simpler local area search algorithm. Reduction of computation up to two orders for low fps and prediction of position is possible. Video camera rates (25 or 30 fps) are preferred if the high resolution light measurements are necessary. There are possible optimizations of the radius search and vertical movements due to linearity of movement, but the correct acquisition is required. Estimated reduction of the HT requirements depends on the distance and the camera focal length. Presented results are related to the medium focal length and typical a few meters of distance between the light probe and the camera.

This work is supported by the UE EFRR ZPORR project Z/2.32/I/1.3.1/267/05 "Szczecin University of Technology -- Research and Education Center of Modern Multimedia Technologies" (Poland)

REFERENCES

[1] Debevec P., Rendering Synthetic Objects into Real Scenes: Bridging Traditional and Image-based Graphics with Global Illumination and High Dynamic Range Photography, SIGGRAPH 98, 1998, 189-198
[2] Debevec P., Image-Based Lighting, IEEE Computer Graphics and Applications, March/April, 26-34, 2002
[3] Plch J., Mohelnikova J., Influence of colour shading obstacles on indoor daylighting, *Przeglad Elektrotechniczny (Electrical Review)*, 86 (2010), n.4, 36-27
[4] Darula S., Kittler R., Oberman P., Luminance Distribution in an office during daytime, *Przeglad Elektrotechniczny (Electrical Review)*, 86 (2010), n.10, 173-176
[5] Mazurek P., Estimation of position of the light probe device for photorealistic computer animation purposes, *Elektronika – konstrukcje, technologie, zastosowania*, 52 (2011), n.1, 42-44
[6] Hough P.V.C., Arbor A., Method and Means for Recognizing Complex Patterns, US Patent no. 3,069,654, 1962
[7] NVIDIA CUDA C Programming Guide v.3.2, NVidia, 2010
[8] NVIDIA CUDA, CUDA C Best Practices Guide v.3.2, NVidia, 2010
[9] Mazurek P., Circle parameters estimation using Hough transform implemented on GPGPU, *Pomiary Automatyka Kontrola*, 57 (2011), n.8, 896-698
[10] Groundtruth Image Database, www.cs.washington.edu /research/imagedatabase/groundtruth
[11] Kalman R.E., A New Approach to Linear Filtering and Prediction Problems, *Journal of Basic Engineering, Trans. of ASME, Ser.D*, 82, (1960), n.1, 35-45
[12] Brookner E., Tracking and Kalman Filtering Made Easy, Wiley Interscience, 1998

***Author:** Przemysław Mazurek PhD Eng., West-Pomeranian University of Technology, Szczecin, Department of Signal Processing and Multimedia Engineering, 26. Kwietnia 10 Str., 71-126 Szczecin, Poland, E-mail: przemyslaw.mazurek@zut.edu.pl*