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Research Article

An Iterative Approach to Reconstruct Depth Map for Image Relighting and Matching

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Abstract

Image matching is a fundamental aspect of many applications of computer vision, including object/ scene recognition, stereo correspondence, and motion tracking. The commonly used tool for Image matching is SIFT & SURF. While these features are robust to any geometrical deformations, they are usually less able to tackle dramatic illumination changes. In this paper we will propose an efficient iterative approach to relight the illumination condition of one of the two images in an image pair. After relighting process, the pixel-based key-point feature becomes more effective in the matching process. We will examine our method on a dataset containing image pairs which exhibits a range of dramatic variations in illumination and we will show that the proposed relighting algorithm is robust and can improve matching performance.

Keywords: *Intrinsic Image, Reflectance & Shading, Depth Map, key-point, SIFT, Jacobi iteration, Image matching*

1. Introduction

Image matching is homologous to feature detection & feature matching between image pair. Matching an image pair with different illumination condition is a challenging problem because the intensity of an image is not linearly dependent on its illumination. In this paper, we would cope with this challenging task, i.e. to match image pair with different illumination information conditions. Before getting into detail of relighting there is a need to discuss why relighting is necessary for image pair matching? Match between images pair is analogous to pixel based key-point matching more specifically SIFT (Scale Invariant Feature Transform) matching. It is basically advanced significant algorithms which detect and describes the local feature in an image (D.G.Lowe, 2004).These extracted distinct features are helpful in order to perform matching between image pair of same object or same scene. Although another robust and efficient technique to extract and describe local features SURF (Speeded Up Robust Feature Transform) has been developed (L. Van Gool, 2006) but it had few draw backs too i.e. they don't recognize object pretty well then SIFT and are unable to recognize object or scene if it is either rotated, scaled or any geometric transformation had been done. So we would be making use of SIFT matching in our particular algorithm because of its computational efficiency and effectiveness in object recognition. However it is noticed that SIFT can't handle large illumination changes too (L. J. Li and X. Long, 2010) i.e. they are invariant to illumination condition so different illumination conditions between two image of same scene would result in few matches between the two images.

We will propose a method to relit one of two images so that they have somehow equivalent illumination conditions. We will take help of prior illumination information i.e. modeling the lighting sources of known environmental conditions as discussed in (A.Blake, 1985). However the drawback of their method was it would be effective only if there is a single light source. In this research article we will propose a technique of using environmental map in which multiple, flexible light sources instead of single works well.

The remainder of this paper presents the proposed method in more detail. We first discuss related work in the next section. Then we give an overview of the proposed method and geometrical estimation by presenting a mathematical model in section 3. In section 4 we will present some experimental results. Finally, we conclude the paper with discussions in the last section.

2. Related Work

An important aspect is to first decompose the intrinsic image into two parts, reflectance and shading. The reflectance part of image describes the behavior of light reflecting from each point. It is practically complex to cope the light reflecting from each point so we would assume a lambertian model of image (Ronen Basri and David W. Jacobs, 2001). A lambertian model of image doesn't absorb or reflect light i.e. we assume that image appears equally bright from all viewing angles. If an attempt is made to extract reflectance part and match them it would be useless since the image would have a single

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smooth illumination i.e. it would appear equally bright from all angles. Hence this part is just extracted from image and is of no use in proposed algorithm. Moving towards the other part of image, the shading part, this part is composed of the interaction of surface in scene/object with the environmental lights. Shading part of image is helpful to obtain the geometry information i.e. Surface normal, gradients & depth map. So we can propose that a scene can be relit if we can compute the environmental lighting condition and surface normal. A number of algorithms have been proposed in past to estimate the geometry information using shading part.(P.N.Belhumeur and D.J.Kreigman, 1999) proposed that we can estimate the geometry information by assuming continuous family of surface equations. (JT. Barron and Jitendra Malik, 2012) proposed a computationally efficient and easy algorithm known as Shape from Shading which assumes a lambertian model and employs a discrete linear approximation of reflection functions.

In this research article, we will also assume the Lambertian model and would estimate the geometry information, light intensity and its direction using shading intrinsic part to relit the image. Afterwards environmental map is obtained using methods of (Paul E. Debevec and Jitendra Malik, 1997).

3. Method

In order to match two images of same scene with different lighting condition we will assume a lambertian model of image. This model as stated before assumes that equivalent amount of energy is reflected from scene in all directions. The reflected energy obeys Lambert's cosine law i.e. it is dependent on the incident angle more specifically the cosine angles. The fundamental specifications of this model are shading and albedo. In the proposed algorithm the albedo is assumed to be constant and shading is used to estimate the surface normal (n_x, n_y, n_z), surface gradients (p,q) , depth map Z(x,y), tilt and slant. Normalization is done so that the shading image values depend only on surface normal and lighting directions, regardless of light source intensities. The proposed algorithm would then linearize the model by using discrete approximation (finite difference method). This is achieved by computing Taylor Series expansion about a single point and then using an iterative approach to construct the whole map. Two basic iterative algorithms are there in numerical analysis to solve the set of linear equation, Jacobi and Gauss-seidel, we would make use of Jacobi for depth map reconstruction since it is computationally efficient and accuracy rate is greater too. Usually 5 to 20 iterations are sufficient for the process to converge. After linearization and reconstruction of depth map we would compute tilt and slant at each pixel since light intensity is different at each pixel.

After relighting procedure we would compute pixel-based key-point matching use SIFT algorithm. Scale Invariant Feature Transform helps to transforms image data into scale-invariant coordinates relative to local features. The basic purpose of SIFT is to extract features, finding key-point, scale, and location orientation and then match features.

3. Mathematical Model of Proposed Algorithm

A work flow of proposed algorithm is shown in Fig.1

The input image, I(x, y), can be expressed as the product of the shading image, S(x, y), and the reflectance image, R(x, y).

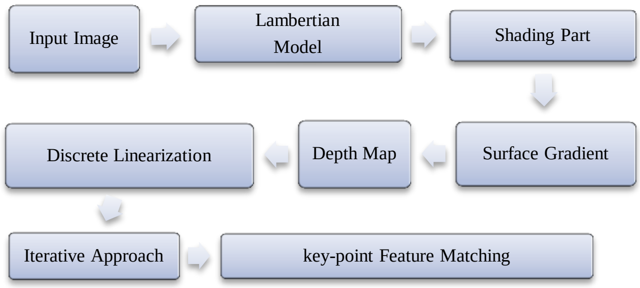

Fig.1 Flow Chart of Proposed Algorithm

The proposed algorithm will decompose the input image into two parts,

$$I(x,y) = R(x,y) + S(x,y)$$

The reflectance part is assumed to be of lambertian surface so the function of reflectance is modeled as:

$$S(x,y) = Ref(p,q)$$

$$Ref(p,q) = \frac{1+pp_s+qq_s}{\sqrt{1+p^2+q^2}+\sqrt{1+p_s{}^2+q_s{}^2}}$$

$$= \frac{cos\sigma + pcos\tau sin\sigma + qsin\tau sin\sigma}{\sqrt{1+p^2+q^2}}$$

Where p & q are surface gradients,

$$p = \frac{\partial Z}{\partial x} \quad , \quad q = \frac{\partial Z}{\partial y}$$

Tilt and slant of illuminant is denoted by τ and σ and Z(x, y) (reconstructed) is the depth map of image.

$$p_s = \frac{cos\tau sin\sigma}{cos\sigma} \quad , \quad q_s = \frac{sin\tau sin\sigma}{cos\sigma}$$

We would compute the discrete approximation for p and q in order to achieve linearization of reflectance.

$$p = \frac{\partial Z}{\partial x} = Z(x,y) - Z(x-1,y)$$

$$q = \frac{\partial Z}{\partial y} = Z(x,y) - Z(x,y-1)$$

Using this linearization the reflectance map equation would be written as

$$f(S(x,y), Z(x,y), Z(x-1,y), Z(x,y-1)) = 0$$

Hence

$$S(x,y) - Ref(p,q) = 0$$

We would use Jacobi iteration to compute the n^{th} iteration of depth map but before that Taylor series expansion is required for reconstruction of depth map.

$$f\left(I_{i,j}, Z_{i,j}, Z_{i-1,j}, Z_{i,j-1}\right) = 0$$

$$f\left(I_{i,j}, Z_{i,j^{n-1}}, Z_{i-1,j^{n-1}}, Z_{i,j-1^{n-1}}\right) + \left(Z_{i,j} - Z_{i,j^{n-1}}\right) = 0$$

Computing partial derivatives with respect to Z (i,j), Z(i-1,j) & Z(i,j-1) yields

$$f\left(Z_{i,j}\right) = f\left(Z_{i,j^{n-1}}\right) + \left(Z_{i,j} - Z_{i,j^{n-1}}\right)\frac{d}{dZ_{i,j}} f\left(Z_{i,j^{n-1}}\right)$$

Using Jacobi iteration the depth map would be:

$$Z_{i,j}^{n} = Z_{i,j}^{n-1} + \frac{-f(Z_{i,j}^{n-1})}{\frac{d}{dZ_{i,j}} f(Z_{i,j}^{n-1})}.$$

After reconstruction of depth map we would compute factors like lighting effect, surface normal (reference) on each pixel by using tilt and slant.

4. Experimental Result

In this section we will evaluate the quantitative performance of the proposed algorithm through simulation experiments on large number of image pairs. The Experiments was implemented in Matlab R2012a on a machine with an Intel Core i5, 2.4 GHz processor with 4GB memory. The experimental dataset consist of random image pairs from internet .The images in the data set are in one of three formats: JPEG, BMP, and TIFF. The image resolution varies from 722 × 480 to 800 × 600 pixels.

The input image pairs is shown in Fig.2.Follwing the mathematical procedure as discussed in previous section matlab implementation of algorithm is shown in Fig3, 4,5,6.

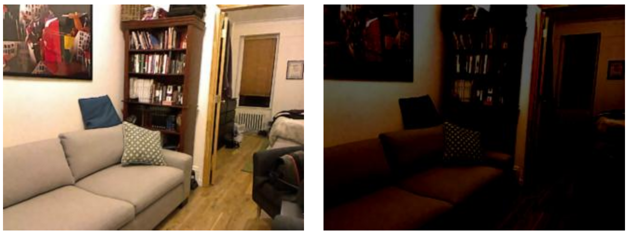

Fig. 2 Input image pair

Fig.3 Decomposing image into shading part

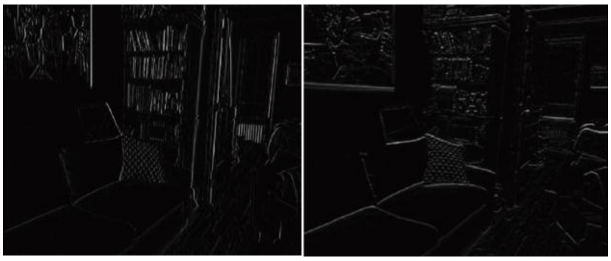

Fig.4 Computing x-y gradient of image

Fig.5 Depth map reconstruction

Fig.6 Relit image

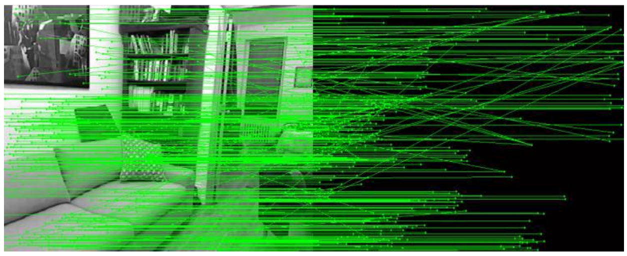

Fig.7 SIFT matching between uneven illuminated images (282 features matched)

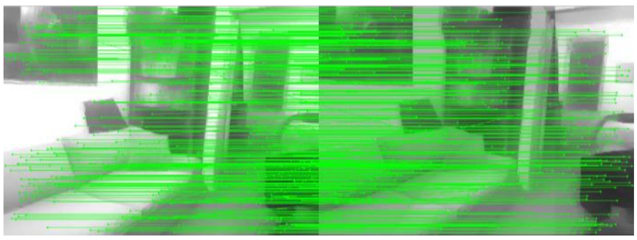

Fig.8 SIFT matching after relighting algorithm (444 features matched)

With the above assumptions satisfied, the proposed relighting method is promising in matching these challenging images. SIFT based feature matching is then used to compute match between two images. It is evident from Fig.7, 8 that after relighting point based feature matching will produce good results. While there are very few matching points on the original test image with different illumination conditions, the number of matches is largely increased on the relit image.

Conclusions

An iterative novel method to match image pair under different illumination environment is developed. The designed algorithm estimates the surface normal for each pixel in the image from the shading component and prior illumination information. The image is then relit using estimated depth map. This algorithm work effectively on the basis of two assumptions i.e. the lighting sources should be distant from the object in the image so the light directions can be considered uniform on the object & the exhibition of object surfaces is supposed to be Lambertian. A key-point based technique-SIFT feature matching is then used to compute match between two images. With the above assumptions satisfied, the proposed relighting method is promising in matching image pairs with different illumination conditions.

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