Segmentation Robust to the Vignette Effect for Machine Vision Systems

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Abstract

The vignette effect (radial fall-off) is commonly encountered in images obtained through certain image acquisition setups and can seriously hinder automatic analysis processes. In this paper we present a fast and efficient method for dealing with vignetting in the context of object segmentation in an existing industrial inspection setup. The vignette effect is modelled here as a circular, non-linear gradient. The method estimates the gradient parameters and employs them to perform segmentation. Segmentation results on a variety of images indicate that the presented method is able to successfully tackle the vignette effect.

1. Introduction

Machine Vision Systems (MVS) combine various hardware parts which introduce their own requirements to the overall design. Suitable illumination and proper image acquisition hardware are of prime importance [3], although in the real world tradeoffs are often made in order to keep the overall design cost low. In the system we examine here, used for quality control in an industrial environment, a 4.5 megapixel small factor digital camera and diffuse dome illumination is employed. The dome configuration is a standard illumination technique used to avoid shadows and reflections on surfaces with low-to-moderate specularity [1]. The experimental setup is illustrated in Figure 5a.
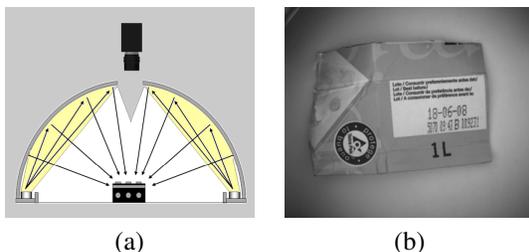

(a)   (b)

Figure 1. (a) Experimental configuration and (b) sample image.

Images acquired through this setup are indeed free of shadows and reflexions but generally exhibit a radial fall-off of intensity from the centre of the image; an effect known as vignetting (see Figure 1b).

The vignette effect is a common problem in photography. Vignetting presents problems to a wide variety of applications including image-based rendering, panoramic image mosaics, radiometric image estimation and vision-based industrial applications [6]. Various ad-hoc approaches have been introduced, where sequences of images are used to model the vignette effect, or a-priori knowledge is employed to calibrate the acquisition device. In [7] numerous images of a known illuminant at different location in the image field are acquired and a polynomial is fitted to the acquired irradiances. In [5] a simplified model of the vignetting model is used to calibrate the camera. In [2] a method for vignette correction in sequences of natural image is presented which does not require specific calibration objects or lighting.

In this paper we propose a method to perform segmentation in images which present vignette effect in the context of an industrial inspection setup. Segmentation in these images is not a trivial issue: some reasonable results can be obtained on solid objects using a Variable Threshold method as Niblack, but normally is it hard to get good results on objects which range of gray levels is similar to that of the background as is the case in the object of Figure 1b. Moreover, the parameters of the Variable Threshold algorithm have to be tuned to each specific object.The method presented here does not make use of any a-priori knowledge or calibration equipment; the single assumption is that the background is of constant colour, which is always the case for the apparatus used. The segmentation method is robust to the vignette effect and achieves good segmentation results under different degrees of vignetting. The vignette effect is modelled here as a circular, non-linear gradient. The method, through a series of steps, linearises the gradient and estimates its parameters using a Hough transform inspired technique. The gradient parameters

are subsequently used to perform segmentation.

The paper is organized as follows. In the next section we give the basic theory underlying the vignette effect. Section 3 details the method. In Section 4, the experimental evaluation of the method and the results are provided. Finally, in Section 5 we provide some conclusions about the work.

2. Background

Vignetting refers to the formation of a circular darkened border around an image, caused from a non-linear drop-off in image irradiance from the image centre toward the periphery. Optical vignetting is inherent to each lens design and is introduced by the camera. It is the effect of three distinct factors (inverse square fall-off, Lambert's law, and foreshortening of the exit pupil), which result in an image irradiance approximately proportional to the fourth power of the cosine of the angle φ that an imaged object point makes with the optical axis [1] (see Figure 2).
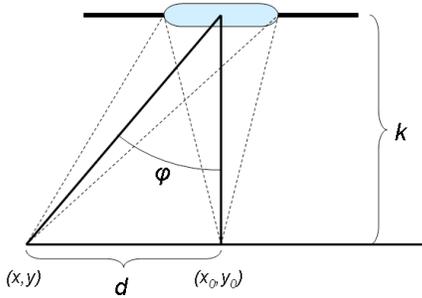
Figure 2. Illustration of the cos^4 law.

A common model for the vignetting is,

$$I(x,y) = I_i(x,y) \cdot cos^4(\varphi)$$
$$\varphi = arctan\left(\frac{d}{k}\right)$$

(1)

Where I is the pixel intensity, I_i the ideal pixel intensity, (x,y) the pixel coordinates, φ is the angle at which the light exits from the rear of the lens, d is the distance of a pixel to the gradient centre (x_0, y_0), and k the distance from the camera exit pupil to the image plane.

3 Method Description

In order to segment the foreground objects, we make use of the fact that the background is of constant colour; thus, it is possible to model the vignette effect based on the lightness distribution among the pixels of the background. In order to achieve this, the vignette effect on the background is modelled as a radial gradient in the

image. The method employed here follows 4 steps. Initially, the Hough transform is used to obtain the centre of the radial gradient of the background. Then, using the mathematical model underlying the vignetting phenomenon, we provide a process to linearise the lightness values of the image pixels in respect to their distance from the gradient centre. The gradient parameters are subsequently calculated and used to segment the background area. We also show how the gradient parameters can be used to compensate the background area for the vignette effect. These steps are described in detail next.

3.1 Detection of the Gradient Centre

The gradient centre location is performed in two steps. First we binarize the image according to the following expression:

$$I_p(x,y) = \left\{ \begin{array}{ll} 1 & \text{if } I(x,y) = p * max(I) \\ 0 & \text{otherwise} \end{array} \right.$$

(2)

That is, pixels having intensity equal to p times the maximum intensity in the image are set to one. Ideally, pixels of the background having a given intensity will form a perfect circle and the gradient centre would correspond to the centre. The second step applies the Hough transform [4] to detect circles in this binary image to obtain the gradient centre. However, some object pixels can have the same intensity as background pixels, introducing noise in the binary image. Therefore, more than one potential centre are typically found for a given image. To overcome this problem, these steps are repeated for several values of p. The gradient centre is decided in a voting fashion as the location supported by more hypothetic centres among the centre extracted for different values of p. In Figure 3, the superimposition of several binarized images for different values of p ranging from 0.85 to 0.6 (a) and the identified circles and centres (b), for the coins image of Figure 6.

(a)   (b)
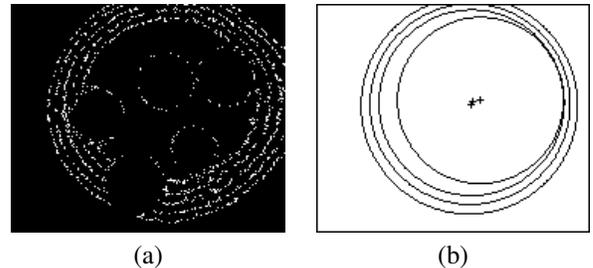
Figure 3. (a) Binary image. (b) Detected gradient centre.

3.2 Linearization Process

Given the centre of the vignette radial gradient, the intensity of each pixel versus its distance from the iden-

tified gradient centre approximately follows Eq. 3

$$I(d) = I_i(d) \cdot cos^4\left(arctan\left(\frac{d}{k}\right)\right) \qquad (3)$$

For $d < k$, (or else φ values smaller than $45°$), the quantity I' defined by Eq. 4 below, is approximately linearly related to the distance d.

$$I'(d) = \sqrt{1 - I(d)} \qquad (4)$$

We can use therefore Eq. 4 to linearise the intensity values of all image pixels in respect to their distance from the gradient centre. The I' distribution versus d for two images (one showing only the background and the example image of Figure 1) is shown in Figure 4.

(a)

(b)
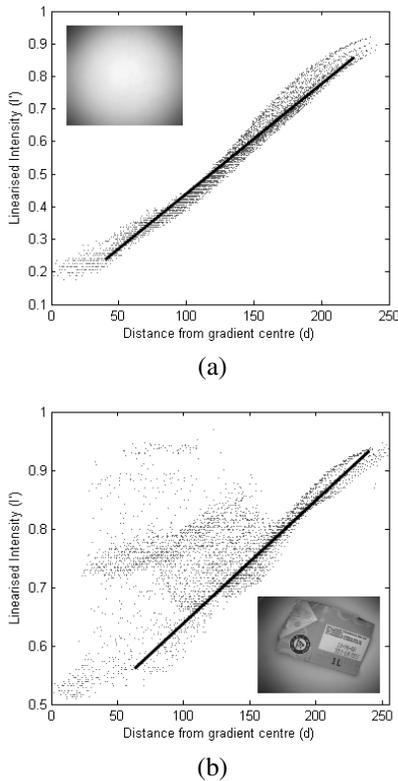
Figure 4. Linearised intensity distribution.

3.3   Computation of Gradient Parameters

Having linearised the intensity values and expressed them as a function of the distance from the gradient centre, the difficult problem of detecting the background gradient is now reduced to the equivalent problem of identifying a line in the (I', d) 2D space of Figure 4.

This can be easily achieved by applying a line Hough transform to the points in the (I', d) space. The background pixels will form the most prominent line in this

space (i.e. Figure 4b). This is invariably true, since in the particular experimental setup used the background (1) occupies most of the space in the image and (2) has constant colour (therefore all its pixels fall to the same line in the (I', d) space). The parameters identifying of the background gradient will therefore correspond to the accumulator cell with the highest count in the Hough parameter space.
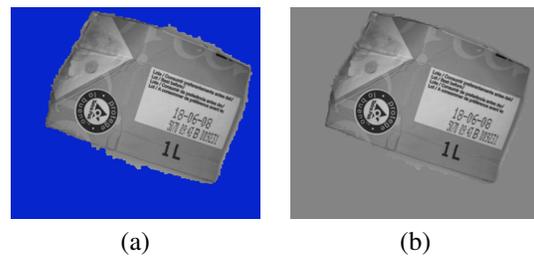
3.4   Segmentation

Having identified the parameters of the background vignette gradient in the (I', d) space, segmenting the background area can be easily achieved.

First, a simple 4-way flood-fill algorithm is used to label all the background pixels. As a seed pixel we choose the first pixel that satisfies the gradient parameters found (falls in the identified accumulator cell). This will invariably lie close to the edge of the image. A tolerance equal to 1.5 times the bin size of the Hough parameter space used before is used to assess whether a pixel belongs to the gradient or not. Employing a flood-fill algorithm, instead of simply labelling the pixels that contribute to the highest count bin ensures spatial continuity.

From the initial labelling, a closing operation is performed in order to include any missed pixels. Foreground objects and foreground connected components are extracted. Finally, foreground components of a size less than 1/250 of the image size (corresponding to a circular object with diameter $\sim$3.73mm in our particular experimental setup) are filtered out as noise since they are deemed too small to represent foreground objects.

The result of the above process for the image of Figure 1 can be seen in Figure 5(a).

(a)

(b)

Figure 5. Segmentation results and (b) compensated for the vignette effect.

3.5   Compensation for Background Vignette

The slope of the line (corresponding to the background gradient) identified before denotes the "rate of change" of the linearised intensity I' over distance.

Making use of this fact, we can compensate the background area for the vignette effect (see Figure 5(b)). Denoting ψ the slope of the background gradient, identified through the Hough transform of section 3.3, an easy way to obtain a corrected intensity value for the background pixels is through Eq. 5 . The corrected intensity I'_C can subsequently de-linearised using Eq. 4 above.

$$I'_C(d) = I'(d) - d \cdot tan(\psi) \qquad (5)$$

4. Evaluation

In order to evaluate the proposed method, we used a dataset of 20 images of six different objects photographed with the apparatus described. Each image has been manually segmented to provide the ground-truth information. The segmentation performance is assessed in terms of three metrics: the percentage of correctly segmented pixels (object pixels labelled as such), the percentage of missed pixels (object pixels classified as background) and false positives (background pixels classified as object). The above metrics are normalised based on the size of the objects. The method correctly segmented 94.8% of the object pixels in the dataset, while it missed 5.18% and produced 8.51% false positives. Some examples of the segmentation results are shown in Figure 6.

A typical segmentation problem is the presence of object shadows. This should have been compensated by the use of diffused dome illumination; nevertheless, in some cases shadows are still visible. In such situations the assumption of constant background is not valid.

5. Conclusions

In this paper we presented a method for object segmentation in images affected by a vignette effect in the context of an industrial inspection system. In addition, a simple compensation for the vignette effect is suggested to restore the image background. Assuming the background is of constant color, the vignette effect is modelled by a radial gradient which is linearised in terms of its intensity change over distance. A Hough transform based technique is used to identify the gradient parameters in order to segment objects from the background and to compensate the vignette effect. Evaluation over a number of images show that the presented method achieve good segmentation results. Difficult cases such as segmenting small objects with shadows or objects having a similar colour with the background are possible to tackle, but necessitate ad-hoc tuning of the methods parameters.
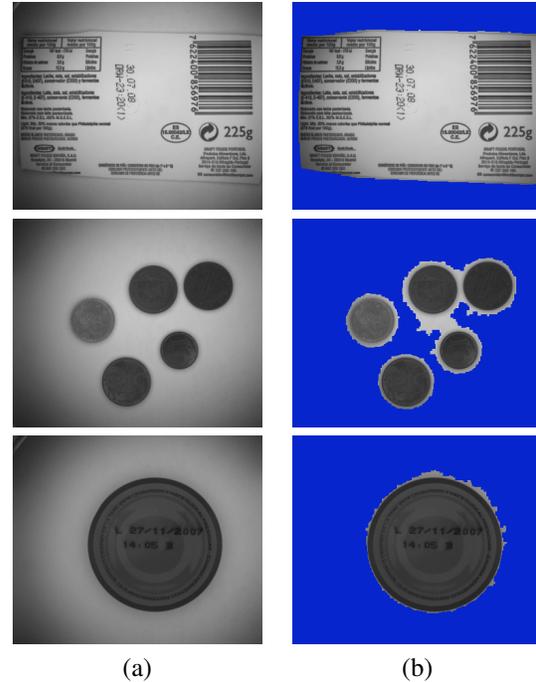
Figure 6. Original images and (b) Segmentation results.

Acknowledgments

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