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ORIGINAL ARTICLE

Fuzzy split and merge for shadow detection

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Abstract Presence of shadow in an image often causes problems in computer vision applications such as object recognition and image segmentation. This paper proposes a method to detect the shadow from a single image using fuzzy split and merge approach. Split and merge is a classical algorithm used in image segmentation. Predicate function in the classical approach is replaced by a Fuzzy predicate in the proposed approach. The method follows a top down approach of recursively splitting an image into homogeneous quadtree blocks, followed by a bottom up approach by merging adjacent unique regions. The method has been compared with previous approaches and found to be better in performance in terms of accuracy.

1. Introduction

Shadows are formed when light from a source is partially or totally blocked. It is difficult to catch images and videos free from shadows. Hence, the only possibility is to remove once it is caught. If we ignore the existence of shadows in images it may introduce serious issues such as alternation of object shape, object merging and object lose in various visual processing applications such as image segmentation, scene interpretation, classification, and object tracking. Hence, Shadow detection and removal is considered as a preprocessing step in various image processing applications such as automated driving [1], surveillance system [2], satellite imaging [3] and medical imaging modalities [4].

2. Background

An image $I(x,y)$ is composed of reflectance component $R(x,y)$ and the illumination component $L(x,y)$ as follows [5]:

$$I_k(x,y) = R_k(x,y) \cdot L_k(x,y) \tag{1}$$

where $k \in \{\mathrm{R,G,B}\}$ and "·" denotes pixel-wise multiplication. Shadow regions are formed by reduction in the illumination component, resulting in changes of image intensities by multiplicative scalars $C_k(x,y)$. Thus, (1) can be rewritten as

$$I_k(x,y) = R_k(x,y) \cdot L_k(x,y) \cdot C_k(x,y) \tag{2}$$

Taking the logarithm on both sides of Eq. (2) we obtain

$$\mathrm{I}_k(x,y) = \mathrm{R}_k(x,y) + \mathrm{L}_k(x,y) + \mathrm{C}_k(x,y) \tag{3}$$

where I, R, L and C are the logarithms of I, R, L and C, respectively. Thus, in the log domain, a shadow implies an

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additive change in intensities. Many works have been reported in the literature by trying to reduce the additive shadow component. However, finding the regions affected by shadow needs intelligent shadow segmentation methods, and hence, it is not an easy task. Self-shading, inter-reflection, non-uniform shadow, geometry of the object casting shadow, and the artifacts involved in image capturing make the process of shadow detection more complicated.

The rest of the paper is organized as follows: A brief review of some of the important work in shadow detection and removal is carried out in Section 3. The proposed fuzzy split and merge approach and ANFIS architecture are presented in Sections 4 and 5 respectively. Implementation details and experimental results are given in Sections 6 and 7. Finally the paper is concluded in Section 7.

3. Related works

A number of shadow detection algorithms have been proposed in the literature for still images, satellite images and videos. Most of the works reported in the area of moving shadow detection are specific to a particular domain such as traffic monitoring [1] and video surveillance systems [2]. Hence, they are not suitable for general application. Shadow detection from still images involves methodologies to detect shadows generated by nonpoint light sources called soft shadow [6] and point light sources called hard shadow [1]. A general method that can be commonly applied to all categories has not been devised till now. State of the art methods that use multiple images [7], video frames [2,8] or methods that allow user intervention [9,10] have given impressive results, but detecting shadows accurately from a single indoor or outdoor image having various geometrical features and illumination constraints remains an open problem. This is because the appearances and shapes of indoor and outdoor shadows depend on several factors such as the color, direction, size of the illuminants (sun, sky, clouds), geometry of the objects that are casting the shadows and the shape and material properties of objects onto which the shadows are cast. This section gives a brief overview of various shadow detection approaches reported in still images.

Zhu et al. [9] proposed a learning based method to detect the shadows in single monochromatic image using a shadow invariant, shadow variant and near-black features. This method is based on boosted decision tree classifier which is integrated into a Conditional Random Field (CRF). To make it possible to learn the CRF parameters, they use a Markov Random Field (MRF) model for labeling.

An approach to extract shadows from an image using the information supplied by the user is proposed in [10]. This method requires user help as the shadow, non-shadow and background regions are interactively specified by the user.

Ruiqi et al. [11] proposed a method for detecting shadows using a relational graph of paired regions. But, this method cannot differentiate between shading differences due to surface orientation changes and due to cast shadows. Also, shadow detection fails in case of multiple light sources.

Fuzzy based approach of shadow detection is proposed by Muthukumar et al. in [12]. This method is based on tricolor attenuation model (TAM), and considers shadow regions as special kind of image degradation. Shadow edge detection is conducted based on the color constancy. A fuzzy c-means algorithm is adopted for segmentation.

In [13], trained decision tree classifier is used to detect ground shadow edges in outdoor images. The shadow edges are then grouped by a Conditional Random Field (CRF) based optimization. This method focuses on shadows cast by objects onto the ground plane.

Shadow detection method that works on the basis of the mean value of A and B planes of an LAB image is proposed by Murali and Govindan in [14]. Combining the values from L and B channels, the pixels with values less than a threshold are identified as shadow pixels, and others as non-shadow pixels. The method works well only for images whose yellow to blue ratio is maintained within a range.

Finlayson et al. [15] proposed a method to locate the shadows by generating an illumination-invariant image, in which the shadows do not appear. The illumination-invariant image is used with the original color image to locate the shadow edges. This method requires images acquired using a calibrated camera to get better result.

A physical model of shadow based on the properties of shadow under the sun and sky is proposed in [16]. This method cannot characterize the indoor shadows.

Most of the works reported on shadow detection need multiple images, user interaction/inputs and calibrated camera. Shadow detection and removal from a single image, having various geometrical features and textures exhibiting different reflection parameters remains an extremely challenging problem.

4. Proposed approach

This paper proposes a split and merge approach that uses a fuzzy predicate for shadow detection from a single image. As a first step we perform a top down approach of splitting an image into four quadtree blocks and produce a sparse representation of the image in tree form. Then a Fuzzy predicate is used to check for any adjacent homogeneous region that can be merged among the quadtree blocks. Adjacent homogeneous regions are merged and the splitting merging process is repeated recursively. Fuzzy predicate is trained using ANFIS.

4.1. Fuzzy split and merge

Classical split and merge is a famous algorithm developed by Horowitz and Pavlidis [17,18] during mid-1970s, and it has found application in image segmentation, data mining, etc.

Split and Merge technique has a convenient representation in the form of quad-tree. The root of the tree corresponds to the entire image, each node corresponds to a subdivision and leaves of the final tree define the set of regions contained in the image.

Let R represents a $2^n \times 2^n$ image composed of shadow and nonshadow subregion R_S and R_N respectively. Fuzzy split and merge for shadow detection uses a fuzzy predicate P_F which takes as input entropy, edge response, standard deviation and mean of a quadtree block for splitting merging decision. Split and merge process works by successively dividing image into smaller and smaller quadtree regions so that, for any quad region $R_i \in R$, $P_F(R_i)$ = TRUE. That is, if $P_F(R_i)$ = FALSE then R_i has to be newly subdivided. If only splitting was used the final partition would be likely to contain adjacent