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Automatic selection of color constancy algorithms for dark image enhancement by fuzzy rule-based reasoning

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A B S T R A C T

This work introduces a fuzzy rule-based system operating as a selector of color constancy algorithms for the enhancement of dark images. In accordance with the actual content of an image, the system selects among three color constancy algorithms, the White-Patch, the Gray-World and the Gray-Edge. These algorithms have been considered because of their accurate remotion of the illuminant, besides showing an outstanding color enhancement on images. The design of the rule-based system is not a trivial task because several features are involved in the selection. Our proposal consists in a fuzzy system, modeling the decision process through simple rules. This approach can handle large amounts of information and is tolerant to ambiguity, while addressing the problem of dark image enhancement. The methodology consists in two main stages. Firstly, a training protocol determines the fuzzy rules, according to features computed from a subset of training images taken from the SFU Laboratory dataset. We choose carefully twelve image features for the formulation of the rules: seven color features, three texture descriptors, and two lighting-content descriptors. In the rules, the fuzzy sets are modeled using Gaussian membership functions. Secondly, experiments are carried out using Mamdani and Larsen fuzzy inferences. For a test image, a color constancy algorithm is selected according to the inference process and the rules previously defined. The results show that our method attains a high rate of correct selection of the most well-suited algorithm for the particular scene.

1. Introduction

Rule-based systems allow representing knowledge, and capturing the personal expertise in a set of IF-THEN rules. In the rules, a set of premises is evaluated for concluding a result. Rule-based systems have shown to be useful in a number of applications [1–3]. Moreover, such systems increase their flexibility, robustness and interpretability, when fused with soft computing techniques [4] like fuzzy logic, which was introduced as an extension of the classical theory of sets [5,6]. Nowadays, fuzzy logic has been recognized as an effective tool for managing information in rule-based systems [7,8] because of its tolerance to imprecision, to ambiguity and to the lack of information, as occurs in tasks such as the extraction of high-level visual information. In our particular case, we determine the algorithm most well-suited to be applied on an image, according to the color content of the scene under evaluation.

Color is an important feature for pattern recognition and computer vision fields. Typical computer vision applications related to this study include feature extraction [9], image classification [10], object recognition [11,12], scene categorization [13,14], human–computer interaction [15] and color appearance models [16]. Color also represents an attribute of visual sensation and appearance of objects. It depends on three components: the reflectance of an object, the sensitivity of the cones in the eyes, and the illuminant. For a robust color-based system, the effects generated by the illumination should be removed.

The ability of a system to recognize the true colors in objects, independently of the illuminant present in a scene, is known as Color Constancy [17]. The human visual system has this innate capability to correct the color effects of the light source. However, the emulation of the same process is not trivial for machine vision systems in an unknown scene [18]. From the computational point of view, color constancy is defined as the transformation of an input image captured under an unknown lighting, to another picture apparently obtained under a known lighting, normally daylight [14]. For this reason, it is required to estimate the color of the light source in the image. The color values, corresponding to the illuminant, are used to transform the input image.

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In past decades, researchers have tried to solve the color constancy problem using several methods. Nonetheless, and in spite of the wide range of computer vision applications that require color constancy, a general solution to this problem has not been found. A number of algorithms using simple image statistics have been proposed, like the White-Patch [19,20], the Gray-World assumption [21], Shades-of-Gray [22], Gray-Edge [23], Spatio-Spectral [24] and Category by Correlation [25].

The color image enhancement is a very challenging research field, in comparison to the image enhancing in gray scale. A detailed and clear overview about image enhancement issues is the one by Lucchese and Mitra [26]. It is important to mention that color constancy algorithms enhance the chromatic content of images, although they have been originally developed just for the color estimation of a light source. Provenzi et al. [27] already explored the use of two color constancy algorithms for color image enhancement purposes. In particular, their work was oriented to local contrast enhancement using the White-Patch and the Gray-World algorithms in combination with an automatic color equalization technique. Image enhancement using color constancy algorithms seems to be more significant when these algorithms are applied on dark images, a premise taken into consideration in this study.

Some research works have been oriented to the selection of color constancy algorithms according to several features. The use of content-based image analysis for automatic color correction was originally proposed by Schroder and Moser [10]. This study classified the images into a number of classes (e.g. indoor, outdoor, vegetation, mountains), associated to a particular algorithm (White-Patch and Gray-World). Gasparini and Schettini [11] proposed a method for the analysis of a cast index in the images and their classification. This classification (e.g. skin, sky, sea, vegetation) also allows to detect the presence of a possible predominant color. The work by van de Weijer et al. [12] uses high-level visual information in order to model images as a mixture of semantic classes (e.g. skin, road, buildings, grass). This latter study, utilizes the visual information for selecting the best-suited color constancy algorithm. Bianco et al. [13] proposed classifying images into outdoor and indoor categories in order to select the best color constancy algorithm for each scenery. Later, they implemented an automatic selector for color constancy algorithms taking into account low-level properties of the images [28]. Most recently, Faghih and Moghaddam [29] used a classifier in order to determine the best group of color constancy algorithms for an input image and then, some of the algorithms in this group are combined using multi-objective Particle Swarm Optimization (PSO). It is important to note that these research works have been mainly addressed to the estimation of the illuminant. However, to our knowledge, there are no selection systems of color constancy algorithms focused on image enhancement purposes.

In this work, a fuzzy rule-based system is proposed for the selection of one out of the three basic color constancy algorithms aforementioned: the Gray-World, the White-Patch and the Gray-Edge. This framework is a threefold approach to solving the problem. (1) Our study is focused on the color enhancement using color constancy algorithms, at the same time that the remotion of the influence of the illuminant is solved. Besides, it is particularly focused on processing dark images. (2) An important problem for developing the rule-based system is the correct choice of the image features. Twelve low-level features are chosen carefully: seven color features, three texture descriptors, and two lighting-content features. (3) We use a set of fuzzy rules, encoding the knowledge necessary to take a decision about the most well-suited algorithm to be applied to an image under consideration. In order to perform the selection, a test image is submitted to an inference process, where the best algorithm is chosen if one of its corresponding rules gets the highest firing strength.

The rest of this paper is organized as follows. Section 2 presents the proposed framework and introduces the image dataset used and the color constancy algorithms. Section 3 details the image features used and, in Section 4 the design of the fuzzy rule-based system is explained. Section 5 shows the results obtained by experimental tests. Finally, the conclusions are presented in Section 6.

2. Selection of a color constancy algorithm

We introduce a rule-based system for the selection of a color constancy algorithm, in order to attain chromatic improvement in a given scene, particularly a dark one. Our approach consists in a MISO (Multiple Input, Single Output) system, including twelve inputs computed from the scene under analysis and a single output, the label of the corresponding algorithm. Inputs and outputs are linguistic terms, linked through a set of *IF-THEN* rules.

Basically, our framework has been divided into two main stages. On one hand, a training protocol determines the fuzzy rules, according to features computed from a set of training images. As said before, we use twelve low-level image features for the selection process: seven color features, three texture descriptors, and two lighting-content descriptors. On the other hand, in a testing mode, given a test image, the best algorithm is chosen according to the rule evaluation in two inference models, Mamdani [30] and Larsen [31]. Fig. 1 shows a flowchart of the methodology in our study.

In order to develop the rule-based system, we use images from the SFU Laboratory dataset [32]. This dataset is conformed by 529 dark images under controlled illuminant. The complete database contains 22 scenes with minimal specularities, 9 scenes with dielectric specularities, 14 scenes with metallic specularities and 6 scenes with at least one fluorescent surface. It is important to note that this

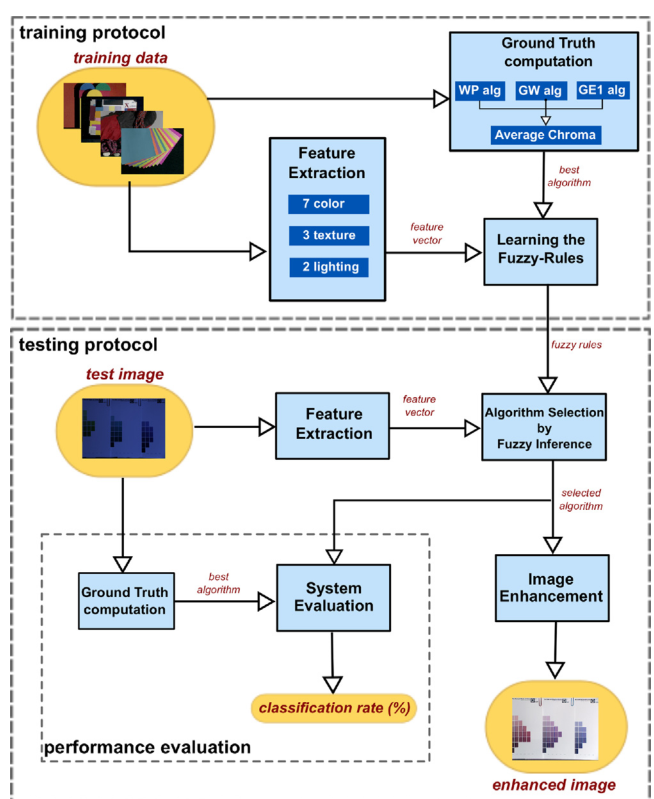

Fig. 1. Flowchart of the methodology carried out in this study.