Edge-driven color constancy
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Chapter 1

Introduction

Imagine trying on that new sweater in a store. You like the color, so decide to buy it. But when taking a second look at your purchase outside, you notice that the color is not quite the same. This is an example where the human visual system falls short. Fortunately, most of the time, the colors of a particular surface appears to be the same, inside or outside, in the morning or late afternoon. However, the example of the sweater reminds us that the wavelengths reflected off an object reaching the eye may be quite different, when it is observed under different light sources (e.g. in different locations or on different times of day). The ability to correct for different illumination colors is called color constancy.

An example is given in figure 1.1, where the same cube is rendered under two different light sources. When seen in reality, the two patches indicated by the green circle are generally termed red patches by human observers, while the reflected colors in fact are very different. Similarly, the patches indicated by the red circle are generally termed yellow and blue patches, respectively, while in fact the color is exactly the same.

The ability of color constancy allows for the interpretation of colors within the context of their

![Figure 1.1](image-url)

Figure 1.1: Image adapted from [79], showing the same colored cube rendered under two different light sources. The color of the patches indicated with the green circle is usually termed red, while the actual color of the two patches differs greatly. On the other hand, the colors of the patches indicated with the red circle are generally termed yellow and blue, while the color of these two patches is exactly the same.
surroundings. The human visual system is equipped with this ability, to some extent, but computer vision systems often perform quite poor. On digital cameras, this ability is usually implemented as white balancing in such a simplistic way that results often are not satisfactory. This can cause images to appear very different from the actual scenes, e.g. an unnatural yellowish/orange or blue cast to all colors in the scene. Consequently, extensive calibration of the camera or manual post-processing is necessary to make the output realistic and appealing. Other computer vision applications, like object and scene recognition, image and video retrieval and object tracking, could also benefit from accurate color constancy, to increase the robustness of color features.

Typically, computational color constancy methods consider pixel values only, completely ignoring spatial relations between pixels. This severely constrains the algorithm’s potential, since not all information is be used. Furthermore, it has been suggested that the human visual system is specifically sensitive to local contrast [97]. This indicates that the response of the human visual system depends on local variations to the surrounding background luminance values, rather than on the absolute luminance values. Therefore, the possibilities are to be explored to improve existing computational color constancy algorithms by incorporating spatial relations in the form of edge information and higher-order statistics.

Another aspect worthy of further studying is selecting the most appropriate type of information to achieve accurate color constancy. Considering the redundancy of natural images [78], it is unlikely that the same type of visual processing in the brain is performed for the same task on different kinds of input. The focus of the human visual system will be on the most important information first. When, however, this information is missing, the task will still be performed based on other information, albeit with lower performance. Hence, multiple types of information can be used for the same task, resulting in different levels of performance.

Finally, performance evaluation of color constancy algorithms is important. Computational color constancy algorithms are often compared among one another using a distance measure that is based on mathematical principles. However, the extent to which the mathematical distance between algorithms correlates with the perceptual difference has not yet been established. Therefore, this correlation is studied in this thesis as well.

1.1 Color Constancy

From a computational point of view, color constancy is defined as the transformation of an input image, taken under an unknown light source, so that it appears to be taken under a known canonical, often white, light source. The process that is used throughout this thesis is shown in figure 1.2. First, images are gathered that are taken under an unknown light source. Then, the color of the light source is estimated for each input image. These estimates are used to transform the input image, resulting in an output image. These output images depict the same scene as the input image, but now appear to be taken under a known (white) light source.

1.1.1 Illuminant Estimation

Images are composed of a combination of object reflectance and light source properties. This causes the problem of illuminant estimation to be ill-posed, i.e. the color of the light source can not be retrieved unambiguously given only the colors in images, and consequently all algorithms make use of simplifying assumptions. One of the most well-known and often used assumptions is the Grey-World assumption [16]: the assumption that the average reflectance in a scene, under a white light source, is achromatic. Another well-known algorithm is based on the White-Patch assumption, i.e. the assumption that the maximum response in the RGB-channels is caused by a perfect reflectance [73]. Other methods that are based on simple statistics of images include the Shades-of-Grey algorithm [42] and Local Space Averaging algorithm [31].

Rather than only using statistics of pixel values for estimating the illuminant, more complex methods are developed that use information acquired in a learning phase. Possible light sources, distributions of possible reflectance colors and prior probabilities on the combination of colors are
In this thesis, three main objectives are addressed. The first objective is to use local contrast rather than absolute pixel values in the estimation of the color of the light source. The second objective is analyzing existing color constancy algorithms with the aim of combining them dynamically and steered by image content. Finally, the third objective is to find an appropriate evaluation measure to compare different color constancy algorithms.

First, the question is addressed whether spatial relations between pixel values, possibly in addition to pixel values alone, can be used for the purpose of color constancy. Hence, we arrive at the first objective:

1. **Incorporate spatial information**: Extend color constancy algorithms by using spatial relations between pixels rather than absolute pixel values.

This objective is addressed in chapter 2 by extending the Grey-World assumption to incorporate edge information. We analyze whether the Grey-World assumption is also valid for edges and...
higher-order statistics. In chapter 3, the gamut mapping algorithm is extended to incorporate
the statistical nature of images. It is analyzed whether the gamut mapping framework is able to
improve performance when linear filter output is added. The main focus in this chapter is on the
local N-jet, describing the derivative structure of an image. Finally, in chapter 4, different types of
edges are analyzed for their influence on the performance of illuminant estimation, by classifying
edges based on their photometric properties. We will extend edge-based color constancy methods
to emphasize and exploit certain types of edges more than others.

Starting from the framework proposed in chapter 2, several types of information can be used
to estimate the illuminant of a single image. Consequently, the same task can be performed using
different algorithms, all with their own advantages and disadvantages. From this, we can formulate
the second objective:

2. **Combine**: Use image statistics to select and combine color constancy methods.

Existing color constancy methods are all based on specific assumptions such as the spatial and
spectral characteristics of images. As a consequence, no algorithm can be considered to be uni-
versally applicable. However, with the large variety of available methods, the question is how to
select the method that performs best for a specific image. Furthermore, the next question is how
to combine the algorithms in a proper way. These issues are addressed in chapter 5.

Finally, the third objective is regarding the performance evaluation of color constancy algo-
rithms:

3. **Evaluate**: Analyze performance measures that can be used to evaluate color constancy
algorithms on a perceptual level.

The performance of color constancy algorithms is often evaluated using a distance measure that
is based on mathematical principles, like the angular error or the Euclidean distance. However,
it is unknown to what extent these distance measures correlate to human vision. In chapter 6, a
taxonomy of different distance measures for color constancy algorithms is presented. The main
goal is to analyze the correlation between these performance measures and the quality of the
output images. The output images are the result of color corrections based on the illuminant
estimates of the color constancy algorithms. The quality of these images is determined by human
observers. Another issue is the distribution of performance measures, suggesting additional and
alternative information to summarize the performance over a large set of images. Finally, the
perceptual significance of these improvements is evaluated to see whether the improvement is just
noticeable to a human observer.