Colors challenges in navigating autonomous vehicles

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Abstract

Will autonomous vehicles ever be able to drive around safely? In Germany lane markers on streets are white. In construction zones temporary markers are installed on top of the standard ones that are yellow and they direct the traffic e.g. into shifted lanes. So, the only differentiation is the color. But what about the white markers at times close to the sunset? Then we drive into Austria and the temporary markers are turning orange. Or driving in the US makes the whole country a construction zone because markers are always yellow. Automotive cameras are often times not RGB cameras. They have other color filters to maximize sensitivity, which often times does not help differentiating colors. So does the spectral reflectance matter? Which impact does the illumination have? And there are many different ones like daylight at different times of the day, different kinds of streetlights, different headlights of the cars etc. Traffic signs create another color problem. We drive from Switzerland to France. In Switzerland the freeway signs are green and the major road signs are blue. When you cross the French border, it is the other way around. How can these problems be solved?

Color differentiation of automotive cameras

Why do automotive cameras need to see colors? Are there any situations where color is the important differentiator for detecting objects? The simple answer to these questions is yes! Here are some examples:

1. To determine the status of traffic lights from a distance especially at night when the housing of lights may not be detectable
2. To detect other cars and the direction they are going (rear lights, head lights)
3. To help detecting traffic signs (color in addition to geometric information)
4. To detect the different kinds of lane markers that e.g. differentiate between regular and temporary construction zone markers.
5. To help detecting objects like animals, humans etc. e.g. a person in a red jacket in front of a green surrounding is more likely to be detected with color included that by simply using luminance information.

It is important to note that in automotive applications we typically do not define color as the perception of a specific spectral distribution of visible radiation by a human being. Color in this case it is the ability of a sensing system (camera) to differentiate different spectral radiations originating from objects the system is supposed to be able to detect.
The goal is that the system is able to detect objects reliably.
Only in a few cases like backup cameras or mirror replacements the human visual system with it specific color recognition comes into play.

Spectral sensitivity

Currently sensors in automotive cameras are not specifically designed for color. The design is focused around a high sensitivity and a high dynamic range in order to work under the various lighting conditions from high contrast backlit scenes to low light and night situations.
Many sensors used in automotive cameras do not have the typical R, G, B Bayer sensor pattern that is optimized for human vision. A lot of the sensors use different approaches like the spectral sensitivity of a cyan, magenta, yellow filtered sensor shown in figure 1 often times applied to the sensor as shown in the second example mentioned in figure 2 which has been copied from Wang et. al. paper [2].

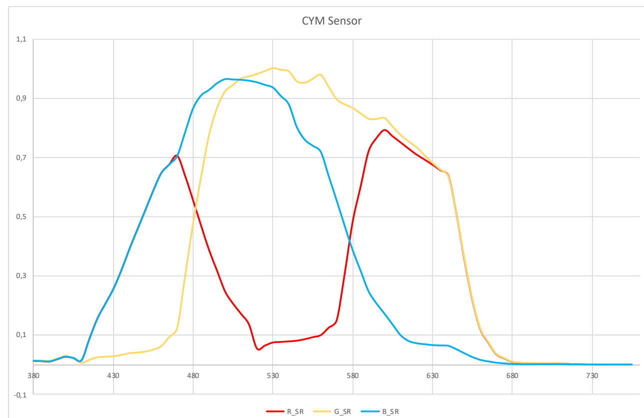

Figure 1: A cyan, magenta, yellow (CMY) filter design which can be found in some automotive cameras.

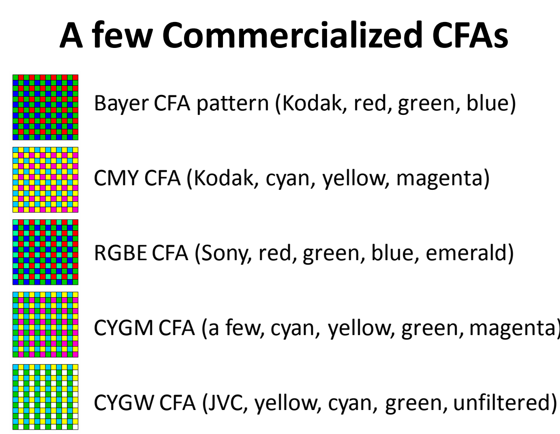

Figure 2: Different filter arrays used for sensors as described in [2].

Color Challenges

Weather and lighting conditions

The illumination and therefore also the radiation coming from the different objects changes drastically depending on the weather and lighting condition.

Figure 3: Street markers and traffic signs at night.

Figure 4: Street markers and traffic signs during the day with a cloudy sky.

Figure 5: Street markers and traffic signs during the day in the rain.

Figure 6: Street markers and traffic signs during the day with a sunny sky in a backlit situation.

Figure 7: Street markers and traffic signs during the day with a sunny sky in a frontlit situation.

Figures 3 to 7 show different lighting conditions that cameras in automobiles have to deal with. The blue traffic light at night looks black and the contrast changes significantly with the lighting condition.

Regional differences

Objects may not look the same depending on the location.

Figure 8: Lane markers in the US may be white or yellow depending what kind of markers we are looking at.

Figure 9: White lane markers are the standard ones in Germany. In construction zones yellow markers are added temporarily and overrule the white ones.

Figure 10: In Austria construction zone lane markers are orange.

Figure 11: Freeway traffic signs in France are blue and signs for highways are green.

Figure 12: In Switzerland Freeway traffic signs are green and signs for highways are blue.

A lot of regional differences have to be taken into account for the detection of traffic signs, lane markers and traffic lights especially when it comes to colors.

While a lot of lane markers in the US are white a lot of specific ones mostly in the center of the road are yellow (figure 8). In Germany all lane markers are white except for the ones in construction zone where they overrule the white ones (figure 9). In complicated setups in construction zones it is sometimes difficult to find the right path even for humans. For automatic detection systems it is even more difficult. The color of construction zone markers vary from country to country (figure 10).

Also, the color of traffic signs varies. In fact, the ones in Switzerland and France are exactly opposite (figure 11 and 12).

Solving the problem

In order to implement reliable detection of objects in automotive imaging the regional differences have to be recognized by the detection system and applied based on the location information derived from GPS data.

Sensors and camera systems have to be designed and manufactured to differentiate the important colors. To make that possible a spectral database of typical objects is needed together with spectral information on the illuminants that are likely to occur and are critical for differentiating colors.

Predicting the camera output

The good thing is, that with the spectral information of the objects and the spectral data of the illuminants we only need the spectral sensitivity of the camera system to be able to predict if the camera is able to differentiate two colors under a specific illumination.

$$R_{camera} = k \cdot \int_{380nm}^{780nm} s(\lambda) \cdot r(\lambda) \cdot c_R(\lambda) \cdot d\lambda$$

$$G_{camera} = k \cdot \int_{380nm}^{780nm} s(\lambda) \cdot r(\lambda) \cdot cG(\lambda) \cdot d\lambda$$

$$B_{camera} = k \cdot \int_{380nm}^{780nm} s(\lambda) \cdot r(\lambda) \cdot cB(\lambda) \cdot d\lambda$$

With: (1)

$s(\lambda)$ spectral distribution of the light source
$r(\lambda)$ spectral reflectance of the object
$c_X(\lambda)$ spectral sensitivity of the camera

In case of a RGB sensor the values would be RGB but the same applies for each individual channel of the images generated by the camera as long as we have access to the linear raw data generated by the sensor.

Knowing the spectral sensitivity

It is essential to know the spectral sensitivities of the camera in order to perform the prediction stated above for all colors in a database and all illuminants.
To measure the spectral sensitivities of a camera a monochromator or similar methods described in [3] can be used.

Color Database

There are no available test charts that can do the job in testing the capabilities of cameras to recognize all important colors because test charts use specific colorants with typically are not representative of real-world objects and they are limited in the amount of available colors.
Currently there is no publicly or commercially available database for objects in the automotive world. This database needs to be created in order to be able to solve the color related problems described in this paper. A database of in situ measured natural objects has been created and is commercially available [2]. However, this database needs to be extended to objects that are relevant to automotive applications and the spectral range needs to be extended beyond the visible spectrum because a lot of cameras in this field of application are infrared (IR) sensitive. The used spectral range should be between 380 nm and 1050 nm because this is the range of natural light that can be captured by silicon-based cameras. Figure 13 and 14 describe the principle of the measurement using a tele-spectroradiometer.

Figure 13: Capturing spectral data of natural objects. Here Skin tones and a white tile on the right to measure the characteristics of the illuminant.

Figure 14: Capturing spectral data of natural objects with a tele-spectroradiometer. Here Skin tones and a white tile on the left side of the person to measure the characteristics of the illuminant.

Figure 15: The representation of the object in a database.

Conclusion

- A database of relevant objects in the automotive world is essential to make sure that all significant colors can be distinguished by a given camera.
- The database is also needed to develop a camera spectral sensitivity optimized for these colors.
- The database needs to consist of colors from all over the world to ensure the performance in all countries
- It would be a huge help and simplification if all traffic objects (signs, lights, markers etc.) would be the same all over the world. But global jstandardization in this area seems difficult if not impossible.

References

[1] Jue Wang, et. Al., New Color Filter Arrays of High Light Sensitivity and High Demosaicking Performance, IEEE ICIP 2011

[2] D. Wueller, In Situ Measured Spectral Radiation of Natural Objects, 17th Color and Imaging Conference, pp. 159-163(5)

[3] E. Walowit, Best Practices for Production Line Camera Color Calibration, https://www.image-engineering.de/library/conference-papers/1031-best-practices-for-production-line-camera-color-calibration

Author Biography

Dietmar Wueller studied photographic technology at the Cologne University of applied sciences. He is the founder of Image Engineering, an independent test lab that tests cameras for several photographic and computer magazines as well as for manufacturers. Over the past 20 years the company has also become one of the world's leading suppliers of camera test equipment. Dietmar Wueller is the German chair of the DIN standardization committee for photographic equipment and also active in ISO, IEC, VCX, IEEE and other standardization activities.