Illumination and its effect on CMUcam

1 Intro

As you use CMUcam it will become quickly apparent to you that lighting matters very much! The summary is as follows: the best possible lighting environment is a well-lit fluorescent indoor space or an indoor space that is indirectly illuminated by a cloudy day. For anything involving incandescent lighting or direct sunlight, it is critical that you block out the infrared end of the spectrum because it saturates the CMOS camera, blinding it to the visible wavelength light that you care about.

The problem really originates in the fact that the light-sensitive pixels in the CMOS camera are actually more sensitive to infrared than visible light- especially the red-detecting pixels. So, in environments that have a great deal of infrared- such as a room lit by a light bulb, the world looks very, very red. So red that there is no room left to successfully measure the visible red light. So the picture begins to look like a bad black and white picture.

The key step you can take to protect the camera is to place a filter that blocks IR in front of the lens. We are also working on identifying a good lens that has an IR filter coating so that the lens does this for you. But, regardless, this is a good educational opportunity.

So, below, we have collected some images to show you just how damaging infrared light can be. There is one variable that we manipulate that is very important. You probably know what AutoGain is. AutoGain enables the camera to adjust up and down the gain on the R, G and B channels equally so that dark images are artificially brightened and bright images are artificially darkened. This is useful in order to make the spectrum of brightnesses in a picture more visually appealing. We tend to use CMUcam with AutoGain on if we feel the robot will be moving through different lighting conditions. On the other hand, if the robot is in a particular room, you could let autogain adjust for a while, then turn it off, making it fixed. This is useful if you are tracking objects and do not want their brightness to change much.

The variable we manipulate below is not AutoGain but Auto White Balance. When Auto White Balance is enabled, it will take the entire image and try and adjust the relative gains of R, G and B so that, overall, the picture's total R, G and B brightnesses are equal. So, if Auto White Balance is on and you put a large green sheet of paper in front of the camera and start dumping frames, at first the image will look green but, after 5-10 seconds, it will have become grey!

Auto White Balance can be useful when you have incandescent or outdoor light sources, as we show below. It is not necessary at all for indoor areas illuminated by fluorescent lights, such as a workplace.

On to the experiments!

2 The Setup

Figure 1 shows the still-life we use in these experiments. We will dump CMUcam frames in a variety of illumination conditions, with Auto White Balance on and off, and see how well and how poorly CMUcam can discriminate these colors.

Fig. 1: The actual setup: a green coat, a lime, a bright green piece of paper, a red coat and a blue tupperware lid.

The picture in Figure 1 is taken with a high-quality CCD digital camera. Of course, this Sony Mavica has an IR filter coating, and the CMUcam in its current incarnation does not come with one (although we are working to identify the right new lens).

3 The Best of Worlds

Figure 2 shows our still life under fluorescent labs at the laboratory at Carnegie Mellon University.

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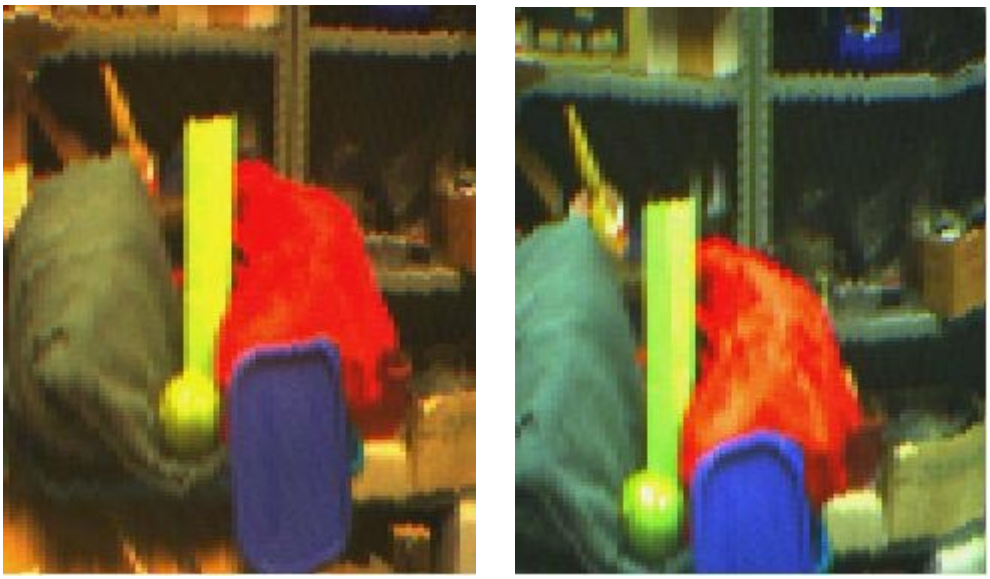

Fig. 2: Indoor, bright fluorescent lighting at the Lab with auto white balance off (left) and on (right).

Whether or not Auto White Balance is used, the colors are strong and so CMUcam could easily track a green, red or blue object. Note that when Auto White Balance is enabled it does turn up the relative gain on the Blue channel, and so the blue lid becomes somewhat brighter. The green coat also becomes somewhat brighter. In these and all following pictures AutoGain Control is enabled

4 Outside

During cloudy weather, outdoor lighting has a great deal of infrared, but not quite enough to completely saturate CMUcam. The images below were taken under a cloudy sky, and you can see the effect of infrared radiation on the image at left in Figure 3.

Fig. 3: Outdoor, in bright cloudy weather. The objects are on top of concrete. With whit balance off (left) and on (right).

Note that Auto White Balance (Figure 3, right) does a good job of removing the red "bias," but not without a penalty. Since this was accomplished by turning down the red, we almost completely lost the color of the red coat. Of course, the green paper and the blue lid do not suffer from this saturation problem.

5 Incandescent Lighting

Think of incandescent light bulbs as evil casters of infrared light. They have far more infrared than a cloudy day, and so on a nice day you will find that CMUcam works perfectly well as-is in your home with ambient light from the windows; but that in the evening the image quality degrades significantly without some IR filtering.

Figure 4 shows our still-life in an environment completely lit by incandescent bulbs (4 60-watt bulbs).

Fig. 4: Bright indoor incandescent lighting, white balance off (left) and on (right).

The saturation of the infrared is very high, and white balancing of the image completely removes not only red color from the scene but also virtually all other colors. The image is almost greyscale, although a hint of pink can be seen in the red coat at the right.

Fig. 5: My kitchen, fluorescent + incandescent lighting.

Finally, Figure 5 shows the still-life in my kitchen, where the lighting includes both a fluorescent bulb that fits in a standard light bulb housing and an incandescent bulb. Again, color information is almost completely lost, although the green tiles in the background are picked up nicely, probably because of the partially fluorescent illumination.