Illumination and its effect on CMOS cameras

1 Intro

As you use CMUcam it will become quickly apparent to you that lighting matters very much! The summary is as follows: if you plan on using CMUcam in outdoor environments or under incandescent lighting, you need to ensure that the lens on CMUcam filters out IR (infrared) and only lets through visible light. If you have an untreated lens, the best possible lighting environment is a well-lit fluorescent indoor space or an indoor space that is indirectly illuminated by a cloudy day.

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. It will look so red, in fact, that there is no room left to successfully measure the visible, color light. So the picture begins to look like a bad black and white picture.

Below we have collected some images to show you just how damaging infrared light can be, and how effective an IR-blocking lens is. Several camera parameters are important to understand. *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 dramatically.

The effect of Auto White Balance is more subtle. When Auto White Balance is enabled, it will 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 10-15 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 normally not necessary for indoor areas illuminated by fluorescent lights, such as a workplace. One useful approach we use is to reset the camera with Auto White Balance enabled, wait five to ten seconds, then freeze the white balance. This way, the robot adapts to its current environment, then stops adjusting this camera parameter so that a looming, colorful object can stay colorful indefinitely.

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 used below did not come with one – but look at the final figure in this article to see a snapshot using CMUcam with an IR-blocking 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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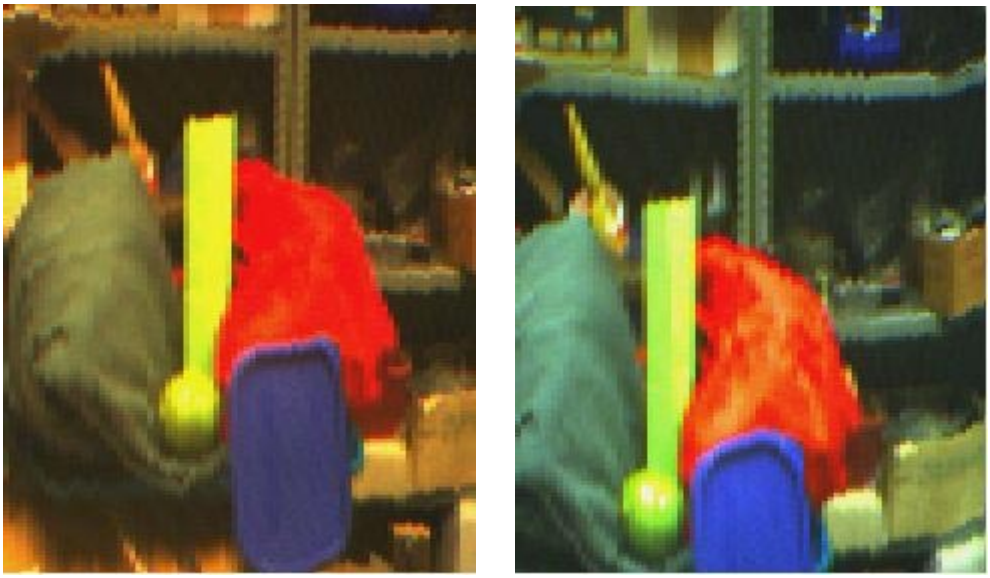

Fig. 2: Indoor, bright fluorescent lighting at the Lab with auto white balance off (left) and on (right).

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.

4 Outside

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

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 infrared sources. 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 an IR filtering lens.

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: Relief: CMUcam with an IR-blocking lens.

Finally, Figure 5 shows a sunny outdoor scene snapped by CMUcam with an IR-blocking lens. Without the right lens, this sunny day would show up as nothing but a bright red image; but with the IR-blocking lens the image is ideal. You can detect the green of the grass, the blue of the sky and even the red of the bricks and sign posts behind the trees.