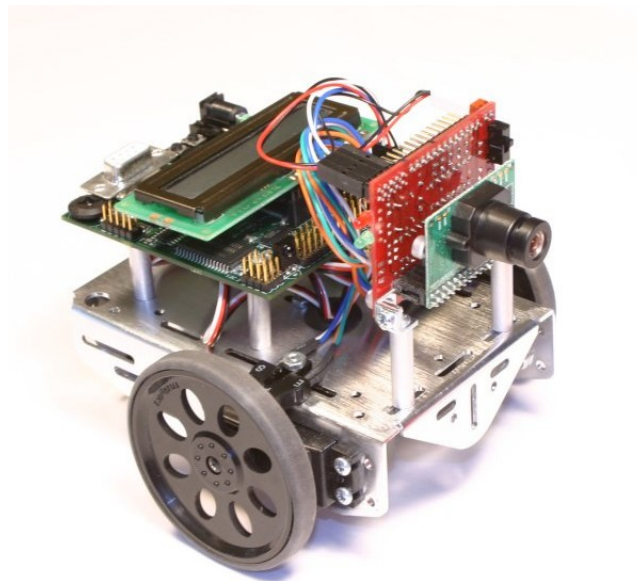




# Vision Sensing with the CMUcam



[www.ridgesoft.com](http://www.ridgesoft.com)

## Introduction

This document provides information on using the CMUcam and CMUcam2 vision sensors with the IntelliBrain™ robotics controller and the IntelliBrain-Bot educational robot.

The CMUcam vision sensor is a sophisticated sensor incorporating a camera and a microcontroller. The sensor is capable of identifying and tracking an object that has a color that can be distinguished from other objects in the camera's field of view. The CMUcam2 is a second generation sensor that has enhanced capabilities and is somewhat larger and more costly than the original CMUcam.

The CMUcam and CMUcam2 communicate color tracking data to a robotics controller via an RS232 serial port. The IntelliBrain robotics controller includes an RS232 serial port, COM2, which may be used to interface to either the CMUcam or CMUcam2. This port provides a 6 volt power source to power the camera.

Either CMUcam sensor mounts easily on the front of the IntelliBrain-Bot chassis, as shown in Figure 1 and Figure 2.

## Obtaining a CMUcam Sensor

The CMUcam and CMUcam2 sensors are available from several sources, including Seattle Robotics ([www.seattlerobotics.com](http://www.seattlerobotics.com)). When purchasing the CMUcam be sure to order the standard camera kit.

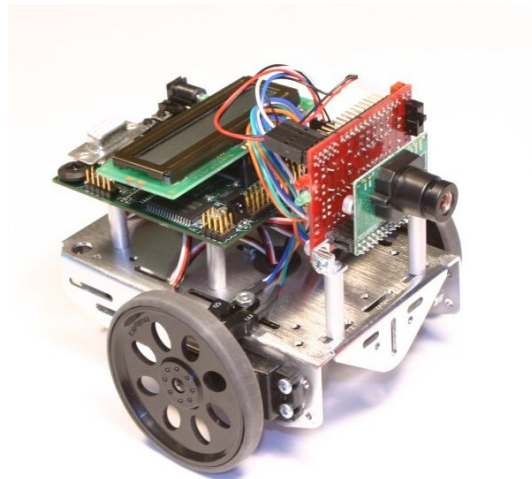


Figure 1 - IntelliBrain-Bot with CMUcam Sensor

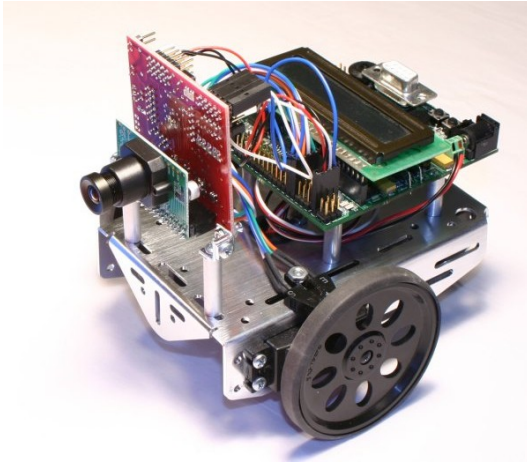


Figure 2 – IntelliBrain-Bot with CMUcam2 Sensor

### Mounting a CMUcam or CMUcam2 on an IntelliBrain-Bot

You can easily mount the CMUcam or CMUcam2 on the IntelliBrain-Bot chassis, as shown in Figure 1 and Figure 2. A cable and the mounting hardware for the CMUcam are shown in Figure 3. The CMUcam2 uses the same cable, but the mounting hardware is slightly different. The hardware for mounting the CMUcam is listed in Table 1. The hardware for mounting the CMUcam2 is listed in Table 2.

The only tool you will need to mount the camera on the IntelliBrain-Bot educational robot is a #1 tip Phillips head screw driver.

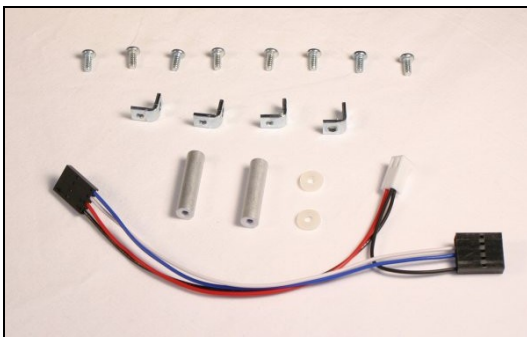


Figure 3 - CMUcam Cable and Mounting Parts

Table 1 – CMUcam Mounting Hardware

Qty	Description	Part Number	Source
2	1" standoff, 4-40 thread	3482K-ND	<a href="http://www.digikey.com">www.digikey.com</a>
4	Bracket w/4-40 threaded hole	612K-ND	<a href="http://www.digikey.com">www.digikey.com</a>
2	#4 nylon washer	3358K-ND	<a href="http://www.digikey.com">www.digikey.com</a>
8	1/4", 4-40, pan head screw	H342-ND	<a href="http://www.digikey.com">www.digikey.com</a>

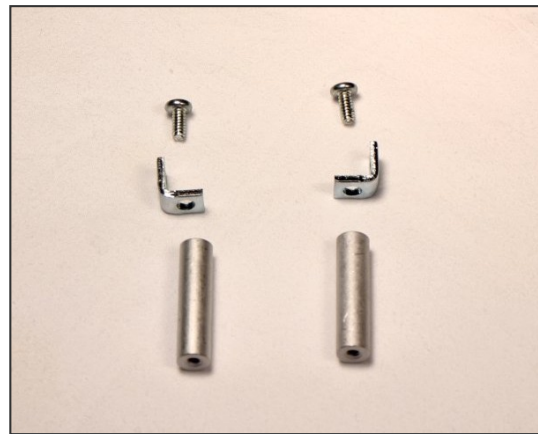
**Table 2 – CMUcam2 Mounting Hardware**

Qty	Description	Part Number	Source
2	1" standoff, 4-40 thread	3482K-ND	<a href="http://www.digikey.com">www.digikey.com</a>
4	Bracket w/4-40 threaded hole	612K-ND	<a href="http://www.digikey.com">www.digikey.com</a>
6	1/4", 4-40, pan head screw	H342-ND	<a href="http://www.digikey.com">www.digikey.com</a>
2	1/4", 2-56, pan head screw	H330-ND	<a href="http://www.digikey.com">www.digikey.com</a>
2	2-56 nut	H212-ND	<a href="http://www.digikey.com">www.digikey.com</a>

### Attaching Brackets to the Standoffs

#### Parts:

- 2 4-40 screws
- 2 brackets
- 2 standoffs



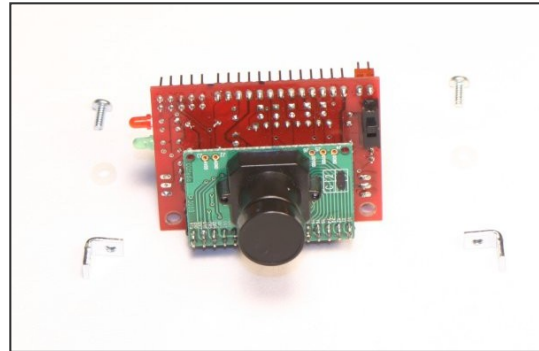
#### Instructions:

1. Insert a screw through the non-thread hole in a bracket.
2. Thread the screw into a standoff and tighten.
3. Repeat step 1 and 2 for the second standoff.

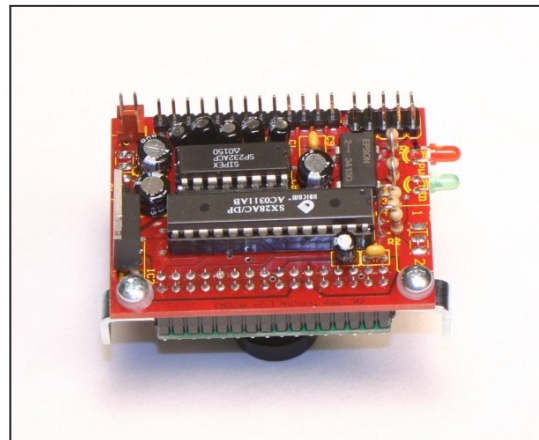


**Attaching Brackets to the CMUcam (CMUcam only)****Parts:**

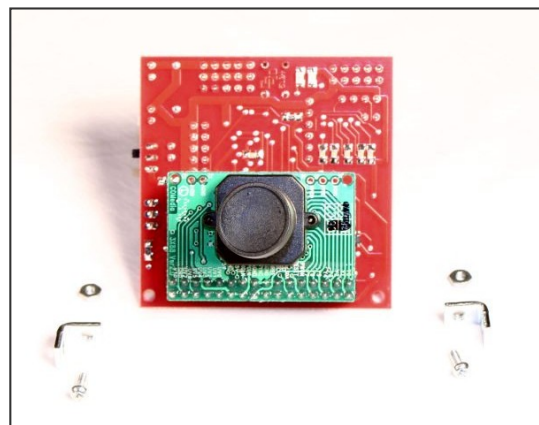
- 1 CMUcam module
- 2 4-40 screws
- 2 brackets
- 2 nylon washers

**Instructions:**

1. Insert a screw through a washer and a mounting hole from the rear of the camera module.
2. Thread the screw into the threaded hole in a bracket, orienting the bracket as shown, and tighten.
3. Repeat step 1 and 2 for the second bracket.

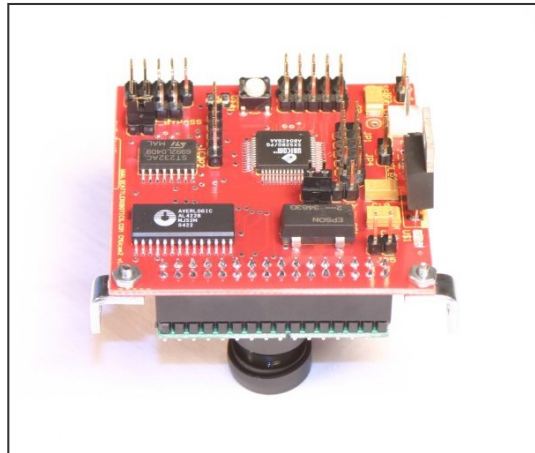
**Attaching Brackets to the CMUcam2 (CMUcam2 only)****Parts:**

- 1 CMUcam2 module
- 2 2-56 screws
- 2 brackets
- 2 2-56 nuts

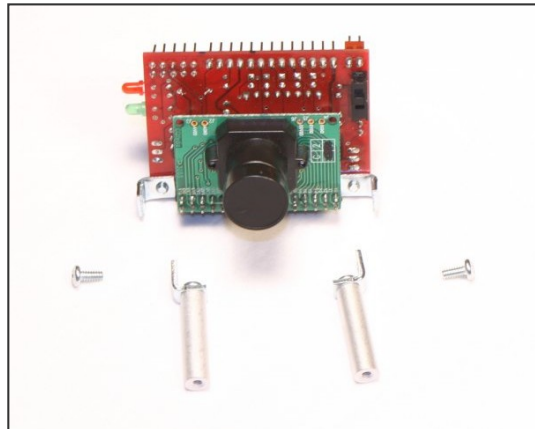


**Instructions:**

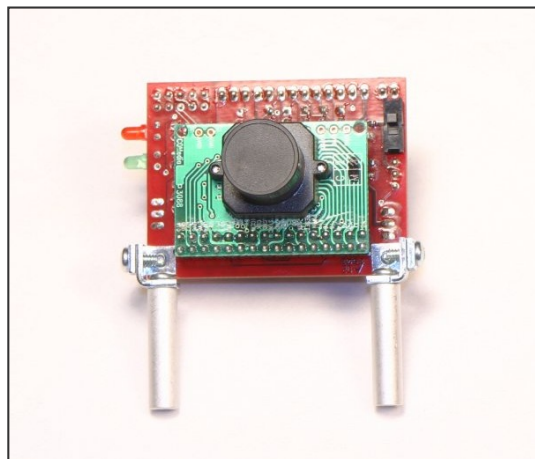
1. Insert a screw through the threaded hole from the inside of a mounting bracket. **Note: the screw does not thread into the bracket, it just goes through the threaded hole.**
2. Insert the screw with the bracket on it into a mounting hole from the lens side of the camera module.
3. Put a nut on the screw and tighten it.
4. Repeat steps 1 through 3 for the second bracket.

**Attaching Standoffs to the Camera Assembly****Parts:**

- 1 CMUcam or CMUcam2 assembly
- 2 standoff assemblies
- 2 4-40 screws

**Instructions:**

1. Insert a screw through the hole in a bracket attached to the camera.
2. Thread the screw into the bracket on the end of a standoff and tighten.
3. Repeat step 1 and 2 for the second standoff assembly.

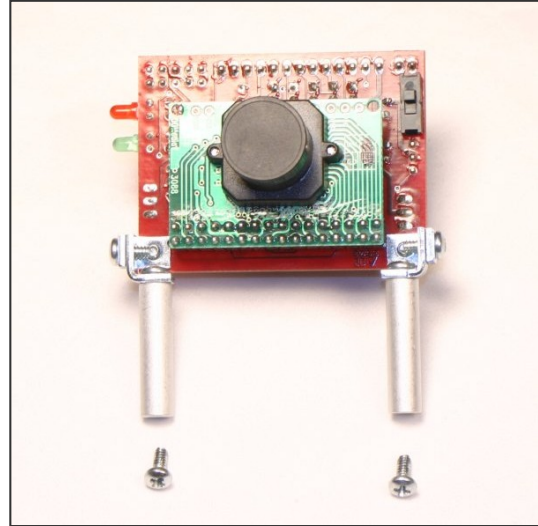




## Attaching the Camera Assembly to the IntelliBrain-Bot

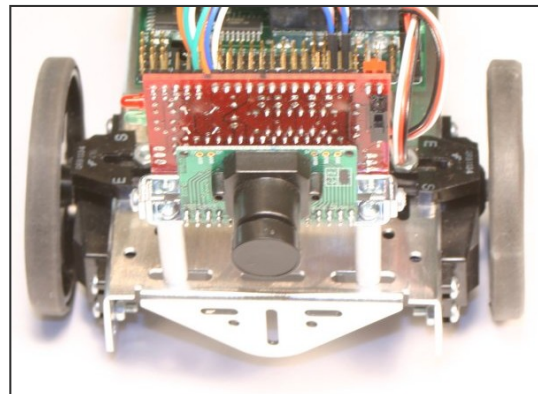
### Parts:

- 1 IntelliBrain-Bot
- 1 camera assembly
- 2 4-40 screws



### Instructions:

1. Insert a screw, from the bottom, through a slot near the front edge of the IntelliBrain-Bot chassis.
2. Thread the screw into the end of a standoff but do not tighten.
3. Repeat step 1 and 2 for the second screw.
4. Tighten both screws.



### Creating a Cable

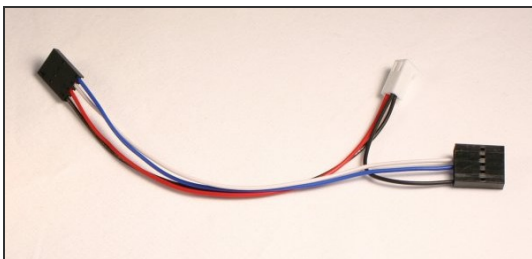


Figure 4 - CMUcam Cable

You will need a cable similar to the cable shown in Figure 4 to connect the CMUcam or CMUcam2 to the IntelliBrain controller.

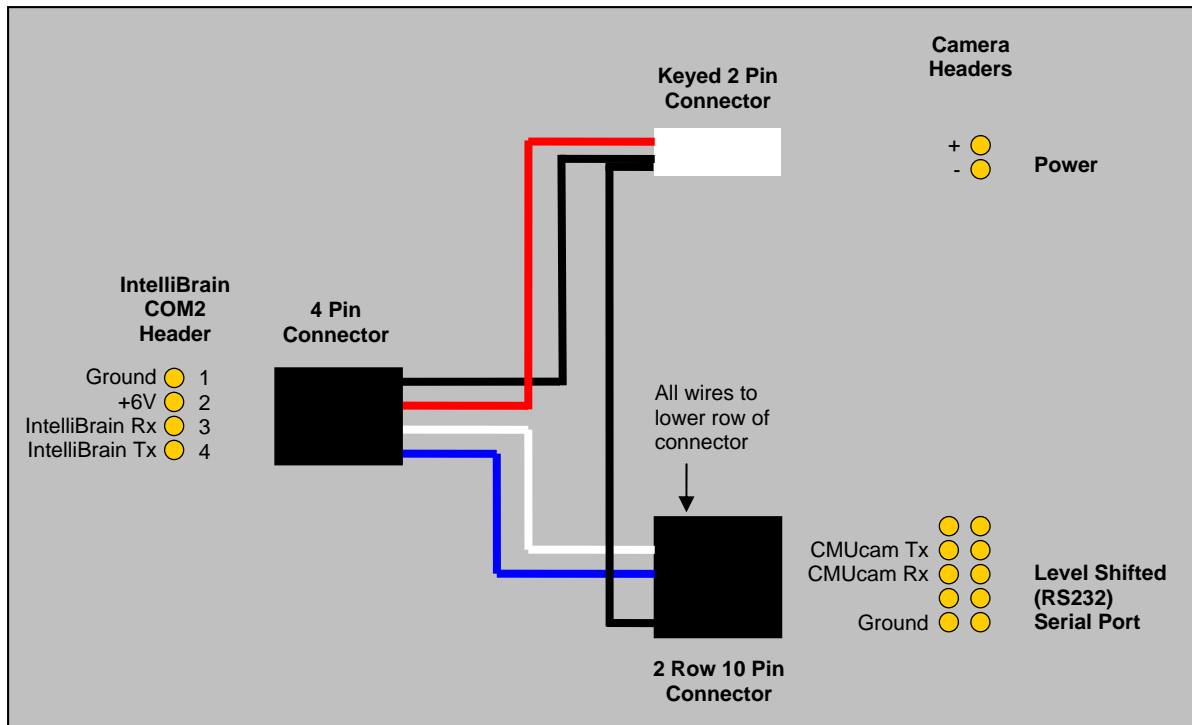
Table 3 lists the parts and tools you will need to create the cable.

**Table 3 – CMUcam Cable Parts and Tools**

Qty	Description	Part Number	Source
7	Crimp Terminals	WM2555-ND	<a href="http://www.digikey.com">www.digikey.com</a>
1	4 Circuit Housing	WM2802-ND	<a href="http://www.digikey.com">www.digikey.com</a>
1	2 Row 10 Circuit Housing	WM2522-ND	<a href="http://www.digikey.com">www.digikey.com</a>
2	Crimp Terminals	WM2200-ND	<a href="http://www.digikey.com">www.digikey.com</a>
1	2 Circuit Keyed Housing	WM2000-ND	<a href="http://www.digikey.com">www.digikey.com</a>
	26 AWG stranded wire, black, red, blue and white	A3049x-100-ND	<a href="http://www.digikey.com">www.digikey.com</a>
1	Universal Crimp Tool	WM9999-ND	<a href="http://www.digikey.com">www.digikey.com</a>
1	Wire Cutter and Stripper		

Figure 5 provides the details of how you should wire the cable and make connections to the IntelliBrain controller and the CMUcam or CMUcam2.

**Note: the power and serial port headers on the camera are positioned differently on the CMUcam2 than on the CMUcam, but the same cable may be used for either sensor.**



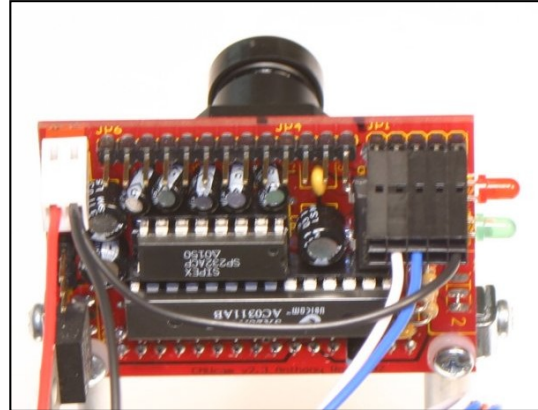
**Figure 5 - CMUcam or CMUcam2 Cable and Connections**



### Connecting the Cable to the CMUcam (CMUcam only)

#### Instructions:

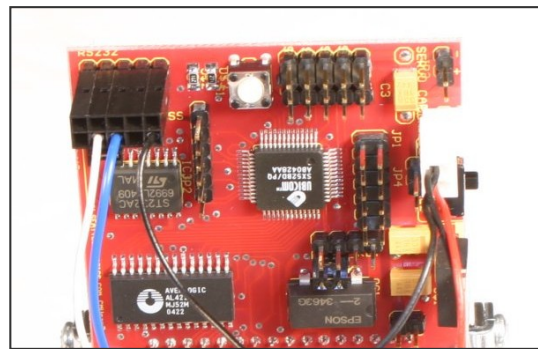
1. Attach the keyed power connector to the power header on the upper left of side of the CMUcam. **Be sure to attach the red power wire to the pin nearest the left edge of the board.**
2. Attach the 2 x 5 pin serial port connector to the header on the upper right. **Be sure to attach the black ground wire to the pin on the lower right of the header.**



### Connecting the Cable to the CMUcam2 (CMUcam2 only)

#### Instructions:

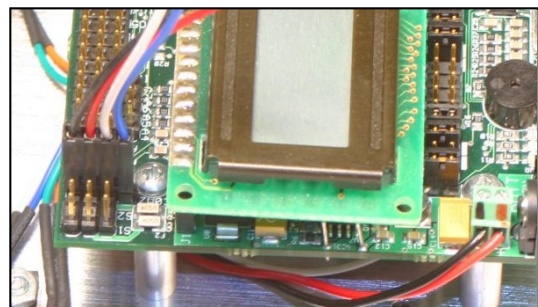
1. Attach the keyed power connector to the power header on the right edge of the CMUcam2, just above the power switch. **Be sure to attach the red power wire to the pin nearest the power switch.**
2. Attach the 2 x 5 pin serial port connector to the header on the upper left. **Be sure to attach the black ground wire to the pin on the lower right of the header.**



### Connecting the Cable to the IntelliBrain Controller

#### Instructions:

1. Connect the cable to the IntelliBrain controller's COM2 port. **Be sure to connect the black ground wire to the pin nearest the IntelliBrain controller board's edge.**



## Tracking Colored Objects with the CMUcam

The CMUcam sensor tracks a uniquely colored object in its field of view by using the built-in microcontroller to scan each video frame pixel by pixel. The microcontroller compares the individual color components of each pixel – red, green and blue, or Cr, Y, Cb – with a range you specify for each of these color components. While doing this, the microcontroller generates tracking information which includes:

- the smallest rectangle that includes all pixels that are within the color range you specified,
- the middle of the mass of pixels that match the color range,
- the total number of pixels that match the specified color range, and
- a measure of the confidence that the camera has identified the intended object.

The middle mass (centroid) measurement roughly identifies the center of the object the camera is tracking, provided you choose the color range carefully to include the colors of the tracked object while excluding colors in other objects that may be in the camera's field of view. You can use the position of the middle mass in the field of view to enable your robot to track or navigate toward an object by programming the robot to steer such that the middle mass is centered horizontally in the field of view. In addition, the height of the middle mass in the field of view can be used to estimate the robot's distance from an object. By aiming the camera down slightly, the object being tracked will appear high in the field of view when it is distant and lower in the field of view when it is near.

Once the statistics for the frame have been collected, the sensor transmits them over the serial link to the robotics controller. By sending only the statistics rather than entire video frames, the CMUcam off-loads video processing tasks from the IntelliBrain robotics controller preserving its computing power for other tasks.

The trickiest aspect of using the CMUcam sensor is determining the color component ranges to track. Variations in lighting produce significant variations in the color components the camera senses. The sensor works most effectively if the object your robot is tracking is a bold, solid color that can be easily distinguished from other colors in the background. This may seem fairly easy to achieve, but in reality it can be difficult, especially if the environment the robot operates in contains a variety of colors and lighting conditions. Fortunately, the CMUcam sensors provide a number of features that provide effective color tracking: automatic color balance adjustment, automatic white balance adjustment and an alternate color mapping space. Automatic color balancing and white balancing allows the camera sensor to automatically adapt to the actual lighting conditions. The alternate color space, CrYCb – as opposed to RGB (Red-Green-Blue) – represents each pixel by an illumination component, Y, and two color components, Cr and Cb, which do not vary greatly with moderate

changes in lighting. By choosing this color space, you can then specify a narrow range for each of the two color components, Cr and Cb, and wider tracking range for the illumination component, Y, allowing the sensor to track an object over a range of lighting conditions.

### Choosing Objects to Track

The color tracking method the CMUcam employs works most effectively if the objects the sensor is to tracking are bold, solid colors that are distinct from other colors in the robot's operating environment. Brightly colored twelve-ounce plastic drink cups, as shown in Figure 6, are convenient and inexpensive objects to track and use as navigation landmarks.



Figure 6 - Colored Cup Landmarks as Viewed by the CMUcam

### Determining Tracking Parameters for a Particular Object

Finding an effective set of tracking parameters – value ranges for Y, Cr and Cb or R, G and B – is one of the more difficult aspects of using the CMUcam. The ranges must be narrow enough that the sensor can distinguish your tracking object from the background and wide enough that variations in lighting and color don't cause the sensor to overlook the object.

Although there are many ways you can determine the color components ranges to use, perhaps the easiest is to use the PC-based CMUcamGUI or CMUcam2GUI utility, which comes with the camera. You can do this using the following procedure:

1. Detach the 10 pin serial port connector of the IntelliBrain interface cable from the camera.
2. Attach the ribbon cable that came with the camera to the serial port on the camera and to a serial port on the PC, following the directions in the CMUcam user guide.
3. Power the CMUcam by switching both the IntelliBrain controller power switch and the CMUcam power switch on.
4. Start the CMUcamGUI – CMUcam2GUI for CMUcam2 – following the directions in the CMUcam user guide.
5. Focus the camera as described in the user guide.
6. Adjust the lighting and background conditions to be as close to your robot's operating environment as possible.

7. Place the objects you want the camera to track in view of the camera a few feet away.
8. Using the GUI, put the camera in the following modes: YUV (YCrCb for CMUcam2), automatic white balance on, and automatic color balance on.
9. Wait at least 5 seconds.
10. Use the Dump Frame feature of the GUI to see the camera's view and verify the lighting and color balance are good.
11. Disable automatic white balance and automatic color balance, but leave the camera in YUV mode.
12. Place the tracking object close enough to the camera that it just fills the entire field of view. You can use the Dump Frame feature to find the correct distance.
13. Keeping the tracking object at the same distance from the camera, use the Get Mean feature to get the mean values and deviations for the three color components. Note: Cr, Y, and Cb are labeled as Red, Green, and Blue, respectively, in the GUI.
14. Calculate the tracking range for the two color components, Cr and Cb, such that it starts at one deviation below the mean and extends to one deviation above the mean. For the CMUcam2, the deviation value is not provided by the GUI, so you will need to guess an approximate value for the deviation. The CMUcam2 user guide suggests 30.
15. Calculate the tracking range for the illumination component, Y, using the same method but 1.5 deviations above and below the mean.
16. Enter these values into the GUI's track color fields.
17. Put the camera in color tracking mode.
18. Move the tracking object around in front of the camera and observe the middle mass indicator and the tracking rectangle displayed in the GUI. These should be stable and follow the object as you move it around. If the tracking rectangle is not stable, you will need to use trial and error to adjust the tracking parameters to get it to be stable.
19. Reconnect the CMUcam serial port to the IntelliBrain controller.
20. Use the tracking values in your robot control program.

### **Communicating with the CMUcam**

The RoboJDE class library included with the IntelliBrain robotics controller includes Java classes to manage low-level communication with the CMUcam. The CMUcam class takes care of communicating with the CMUcam over the serial link and provides an easy to use set of methods which allow you to control the CMUcam sensor and receive tracking data from it. This will allow you to focus on making use of the tracking data to control our robot rather than getting bogged down in the details of interfacing directly with the sensor.

The following programming example illustrates how to set the CMUcam up to track the blue cup shown in Figure 6. This program displays the tracking data on the IntelliBrain's LCD display. You can use this program to verify your robot's

ability to track an object by adjusting the tracking parameters to appropriate values for your object, camera and lighting conditions. Move the object around in front of the camera and view the data displayed on the LCD screen to verify the camera is able to track the object.

### *Programming Example*

```
import com.ridgesoft.robotics.sensors.CMUcam.*;
import com.ridgesoft.io.Display;
import com.ridgesoft.intellibrain.IntelliBrain;

public class CMUcamTest {
    public static void main(String args[]) {
        try {
            Display display = IntelliBrain.getLcdDisplay();
            display.print(0, "CMUcamTest");
            display.print(1, "Starting");
            CMUcam camera = new CMUcam(IntelliBrain.getCom2(), 115200);
            camera.open();
            camera.setRGBMode(false); // switch to CrYCb mode
            camera.setWhiteBalance(true);
            camera.setAutoExposure(true);
            Thread.sleep(5000); // let the sensor adjust
            camera.setWhiteBalance(false); // disable further adjustment
            camera.setAutoExposure(false);
            // tracking parameters vary based on the specific object being
            // tracked, the camera's characteristics and the lighting conditions
            camera.trackColor(64, 94, 22, 94, 223, 243); // blue cup, CMUcam
            while (true) {
                Thread.sleep(1000);
                CMUcamTrackingData trackingData = camera.getTrackingData();
                if (trackingData != null) {
                    display.print(0, "mx: " + trackingData.mx +
                        " my: " + trackingData.my);
                    display.print(1, "c: " + trackingData.confidence +
                        " p: " + trackingData.pixels);
                }
                else {
                    display.print(0, "No camera data");
                    display.print(1, "");
                }
            }
        }
        catch (Throwable t) {
            t.printStackTrace();
        }
    }
}
```