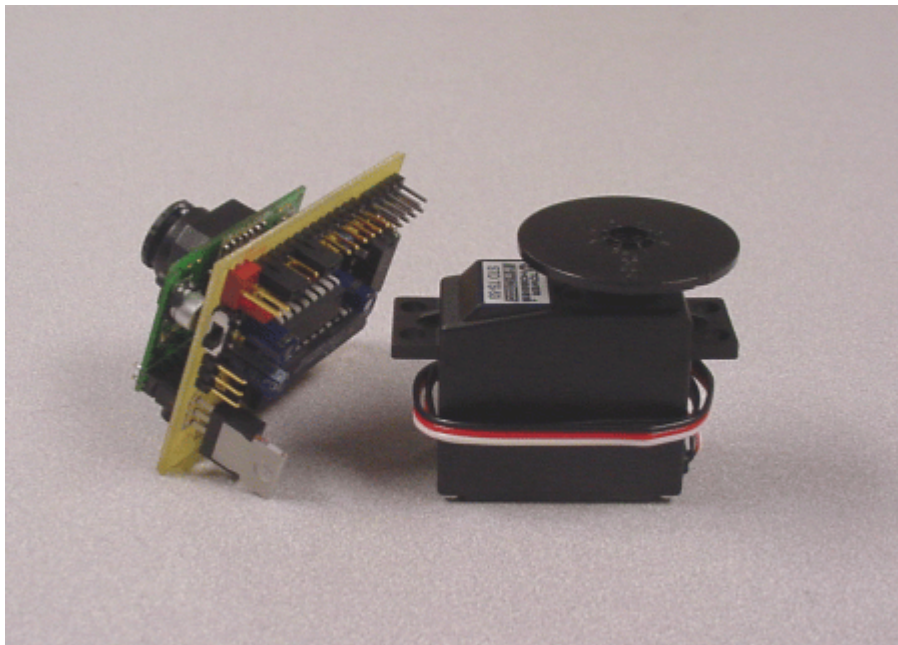


# CMUcam Vision Board



# User Manual

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This is the CMUcam Manual v1.15 for the CMUcam v1.12 firmware.  
For more information go to <http://www.cs.cmu.edu/~cmucam> or contact us at [cmucam@cs.cmu.edu](mailto:cmucam@cs.cmu.edu)  
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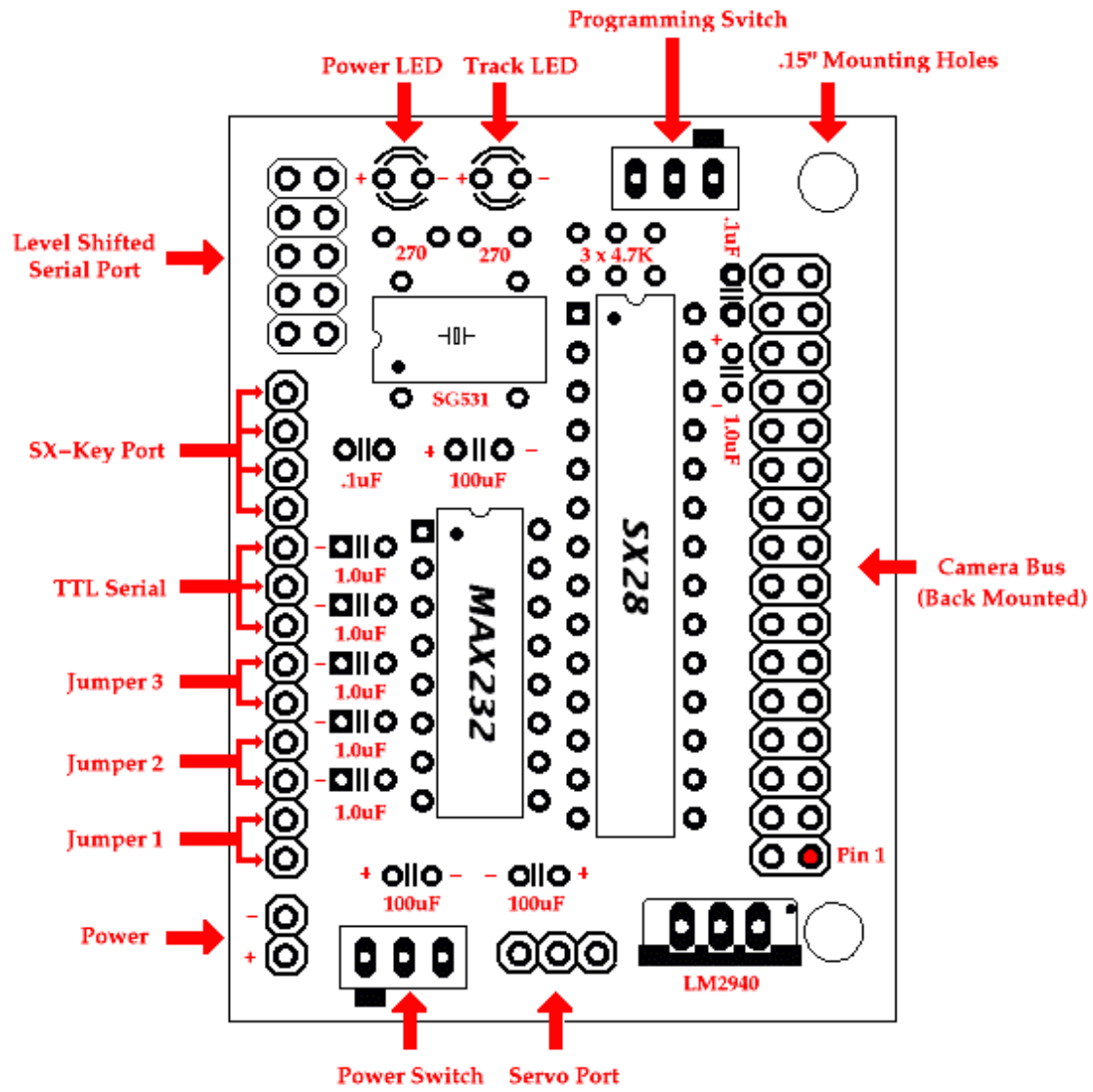
## Introduction

---

The CMUcam is a SX28 microcontroller ( <http://www.ubicom.com/products/processors/sx28ac.html> ) interfaced with a OV6620 Omnivision CMOS camera ( <http://www.ovt.com/omnicross.htm> ) on a chip that allows simple high level data to be extracted from the camera's streaming video. The board communicates via a RS-232 or a TTL serial port and has the following functionality:

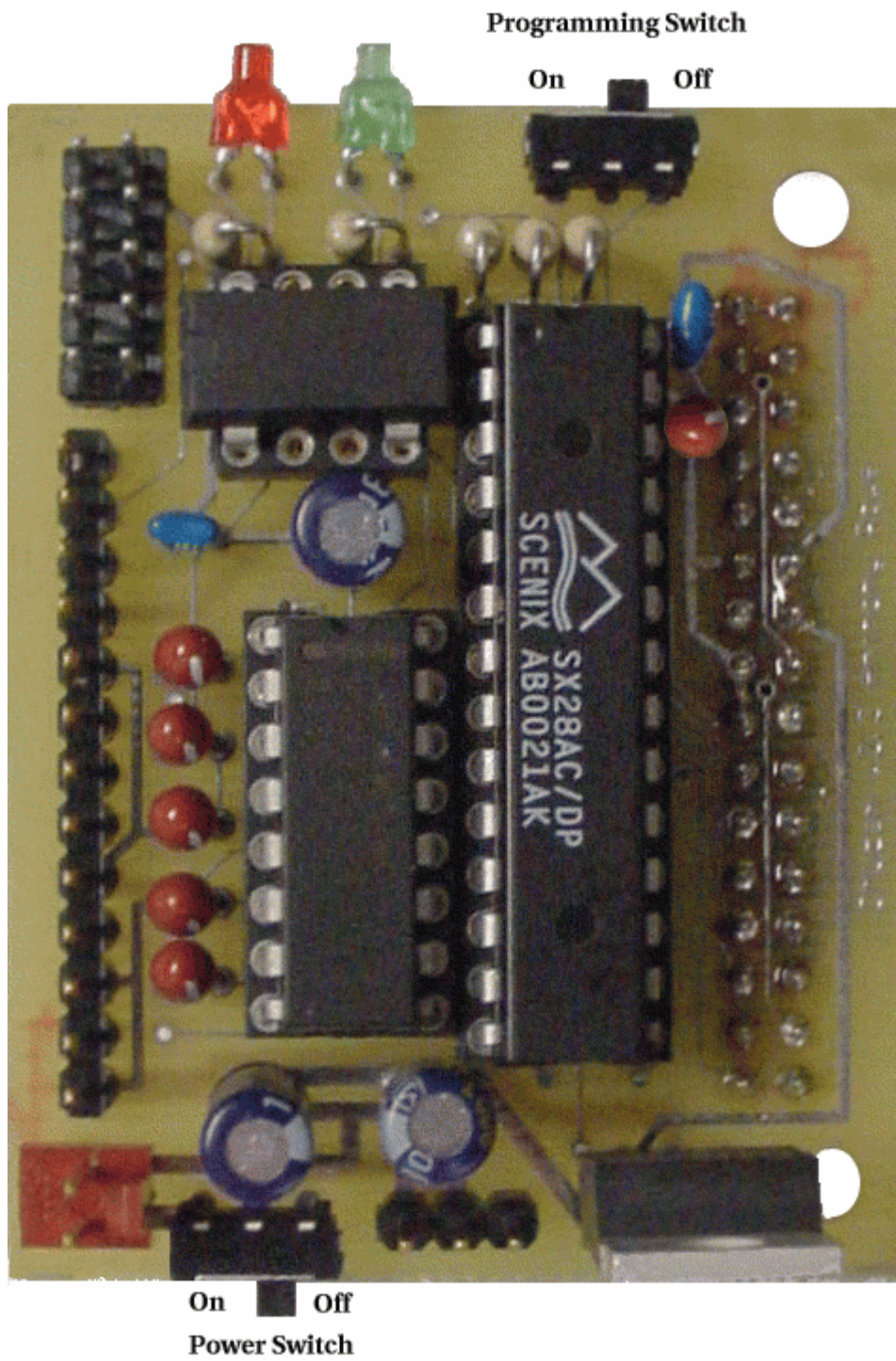
- Track user defined color blobs at 17 Frames Per Second
- Find the centroid of the blob
- Gather mean color and variance data
- Transfer a real-time binary bitmap of the tracked pixels in an image
- Arbitrary image windowing
- Adjust the camera's image properties
- Dump a raw image
- 80x143 Resolution
- 115,200 / 38,400 / 19,200 / 9600 baud serial communication
- Slave parallel image processing mode off a single camera bus
- Automatically detect a color and drive a servo to track an object upon startup
- Ability to control 1 servo or have 1 digital I/O pin

# Board Layout



## Assembled View

---

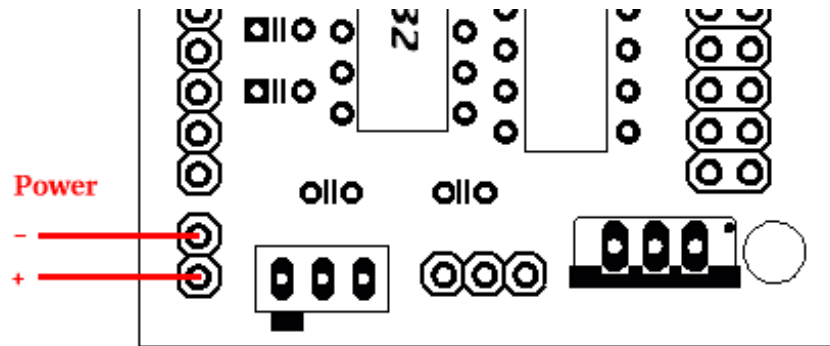


## Ports

---

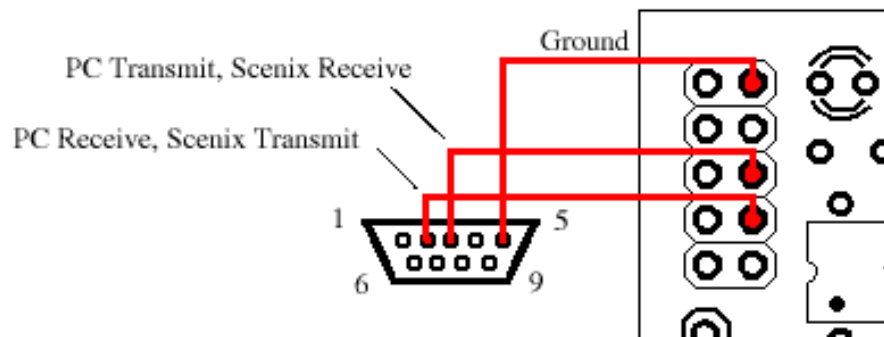
### Power

The input power to the board goes through a 5 volt regulator. It is ideal to supply the board with between 6 and 7 volts of DC power that is capable of supplying at least 200 milliamperes of current.



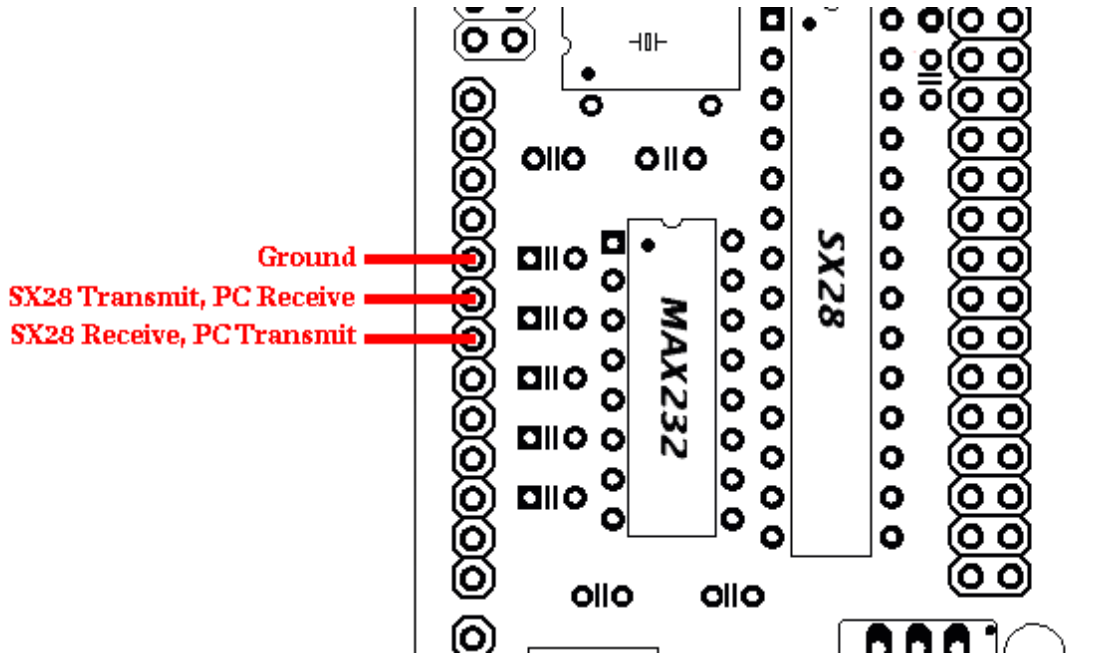
### Level Shifted Serial Port

This port provides full level shifting for communication with a computer. Though it only uses 3 of the 10 pins it is packaged in a 2x5 pin configuration to fit standard 9 pin ribbon cable clip-on serial sockets and 10 pin female clip on serial headers that can both attach to a 10 wire ribbon cable.



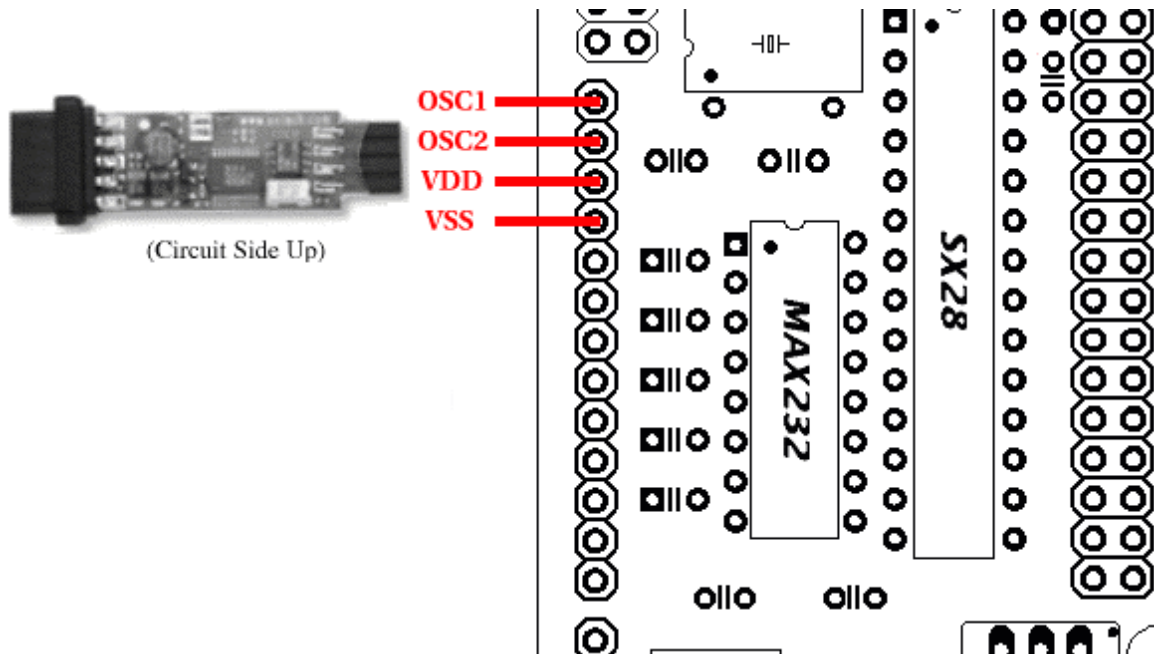
### TTL Serial Port

This serial port taps into the serial I/O before it goes through the MAX232 chip. This port may be ideal for communication with a microcontroller that does not have any built in level shifting. Note that, it may be necessary to remove the max232 chip.



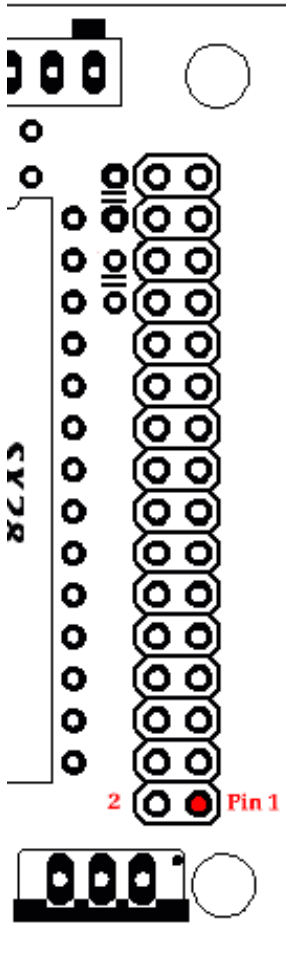
### Programming Port

The programming port allows the firmware to be downloaded to the SX28 using a SX-Key / Blitzer or equivalent programmer. These can be purchased from [Parallax Inc.](http://www.parallaxinc.com) (www.parallaxinc.com).



## Camera Bus

This bus interfaces with the CMOS camera chip. The CMOS camera board is mounted parallel to the processing part of the board and connects starting at pin 1. The female camera header should be soldered on the back of the board. (See assembled view) For information about the Video Analog Output port see page 11.

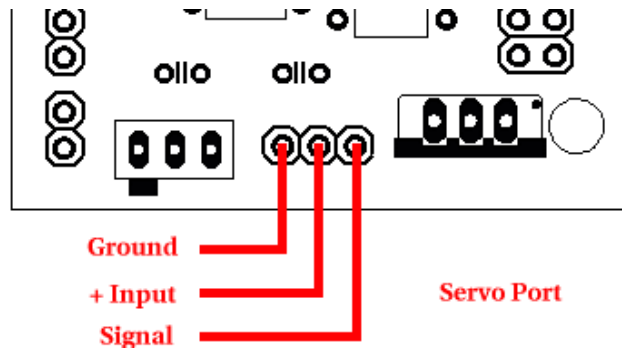


### Pin Description

1~8	Y0~Y7	Digital Output Y Bus
9	PWDN	Power Down Mode
10	RST	Reset
11	SDA	I2C Serial Data
12	FODD	Odd Field Flag
13	SCL	I2C Serial Clock
14	HREF	Horizontal Window Reference
15	AGND	Analog Ground
16	VSYN	Vertical Sync
17	AGND	Analog Ground
18	PCLK	Pixel Clock
19	EXCLK	External Clock
20	VCC	+5 VDC
21	AGND	Analog Ground
22	VCC	+5 VDC
23~30	UV0~UV7	Digital output UV bus
31	GND	Common Ground
32	VTO	Video Analog Output (75 Ohm)

## Servo Port

This is the output for the servo. The positive signal does not go through a regulator from the board's power input. Do not use a servo with the board if the board is being run off of more than 6 volts.





### Parallel Processing in Slave Mode (Jumper 1)

The CMUcam supports a mode of operation that allows multiple boards to process data from the same camera. If a PC104 style pass-through header is used instead of the standard double row female header, it is possible to rack multiple boards along the same camera bus. Upon startup, if jumper 1 is set, the camera becomes a slave. Slave mode stops the camera board from being able to configure or interfere with the CMOS camera's settings. Instead it just processes the format setup by the master vision board. When linking the buses together you must only have one master; all other boards should be setup to be in slave mode. In this current version of the system there is no message passing between boards other than the image data from the camera bus. This means you have to communicate to each slave board via a separate serial link. This communication to the board should be identical to using a single CMUcam. For example, you could have the master board tracking some color while the slave board could be told to get mean color data. Each board runs independently of one another and only the master can control camera registers.

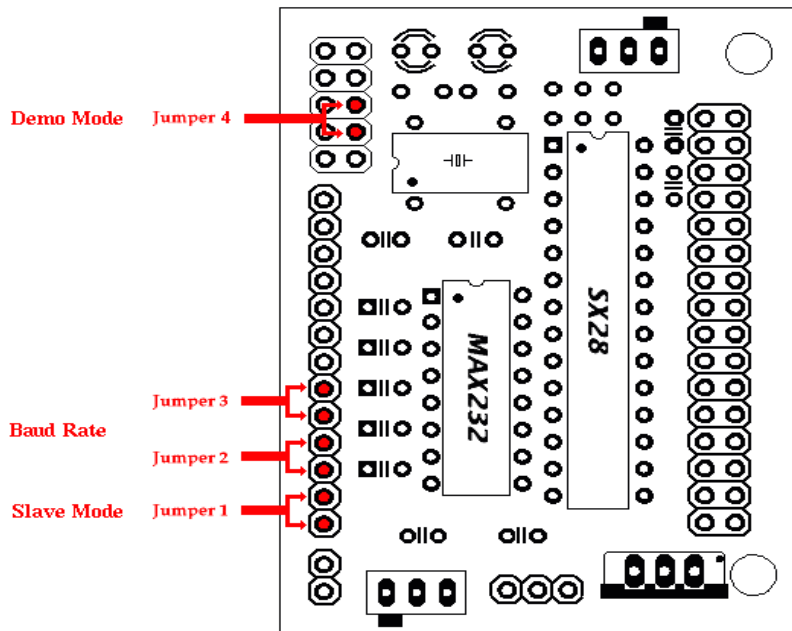
### Baud Rate (Jumpers 2 and 3)

115,200 Baud	Jumper 2 Open	Jumper 3 Open
38,400 Baud	Jumper 2 Set	Jumper 3 Open
19,200 Baud	Jumper 2 Open	Jumper 3 Set
9,600 Baud	Jumper 2 Set	Jumper 3 Set

Because of the extra time it takes to transmit data at lower rates, frames may be skipped resulting in a lower frame rate. The slower rate will also cause the bitmap mode and dump frame resolutions to shrink.

### Demo Mode (Jumper 4)

Jumper 4 puts the camera into a demo mode. Demo mode causes the camera to call the track window command and then begin outputting a standard hobby servo PWM signal from the servo output. The servo attempts to drive the camera mounted on it towards the middle mass of the color detected on startup. Note that upon powering up in this mode, the camera will wait for 5 seconds before grabbing a color and servoing. When it first starts up auto gain and white balance are both on. Then after they have stabilized for 5 seconds the camera turns them off and calls TW. (see pg 11) The servo tracking can be enabled manually, without the jumper, by sending the MM 2 command and then calling TW. If, when the servo is mounted on the camera, it appears to be tracking in the incorrect direction also set jumper 1. When jumper 1 and jumper 4 are set, the board does not go into slave mode; it runs demo mode and reverses the direction of the servo. Jumper 4 uses the UART port, which inhibits the use of the serial port while in Demo Mode.



## Testing the Board

---

Once you have set the board up and downloaded the firmware, a good way to test the system is to connect it to the serial port of a computer.

**Step 1:** Build a serial and power cable.

**Step 2:** Plug both of them in.

**Step 3:** Open the terminal emulator of your choice and set the communication protocol to 115,200 Baud, 8 Data bits, 1 Stop bit, no parity, local echo on, and if possible turn on "add line feed" (add `\n` to a received `\r`).

**Step 4:** Turn on the board; the Power LED should light up and the Track LED should not.

**Step 5:** You should see the following on your terminal emulator:

```
CMUcam v1.12
```

```
:
```

Once you have seen this, the board was able to successfully configure the camera and start the firmware.

**Step 6:** Type `gv` followed by the enter key. You should see the following:

```
:gv
```

```
ACK
```

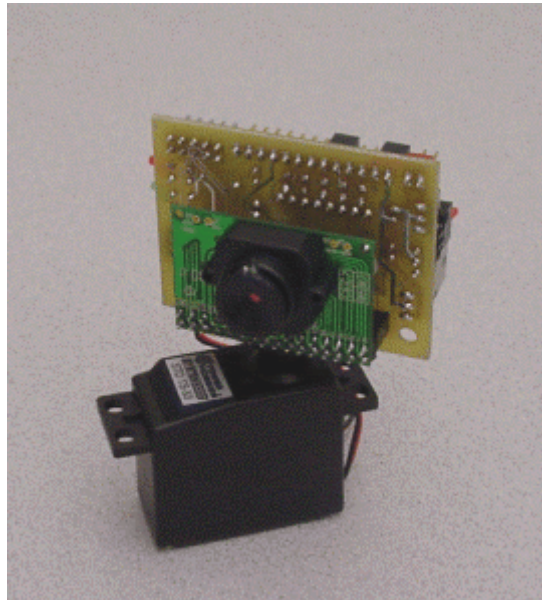
```
CMUcam v1.12
```

```
:
```

This shows the current version of the firmware. If this is successful, your computer serial port is also configured correctly.

**Step 7:** Using the CMUcam java GUI or by graphically interpreting the Dump Frame Packet yourself, focus the camera lens. Usually the lens is focused when it sits a few rotations out from its closest position to the CMOS array. Turning the lens and re-dumping the frame incrementally should provide a good feel for when the image is sharpest.

**Step 8:** Try running the camera in demo mode.



## About the Camera

---

From power up, the camera can take up to 6 seconds to automatically adjust to the light. Drastic changes in the environment, such as lights being turned on and off, can induce a similar readjustment time. When using the camera outside, due to the sun's powerful IR emissions, even on relatively cloudy days, it will probably be necessary to use either an IR filter or a neutral density 3 camera filter to decrease the ambient light level. The field of view depends on the lens attached to the camera. It is possible to special order the camera with wider or narrower lenses. Individual lenses can be purchased separately.

The functions provided by the camera board are meant to give the user a toolbox of color vision functions. Actual applications may greatly vary and are left up to the imagination of the user. By being able to change the viewable window, grab color / light statistics and track colors can be interwoven by the host processor to create higher level functionality.

### Analog Video Output

Pin 32 on the camera bus is a black and white analog output pin. It is possible to connect the analog output to a TV or multi-sync monitor. Due to the clock rate of the camera, the analog output does not correctly synchronize with standard NTSC or PAL systems. If you have some system that can synchronize with a non-standard signal, it may be possible to monitor the video while processing. First, it is required that you cut the connection on the CMUcam board between camera bus pins 31 and 32. Then connect the central line on a 75 Ohm coax input plug to pin 32 on the camera bus. Next, connect the outer shield to the camera's common ground (pin 31 on the camera bus). Finally, power up the camera and adjust the frame rate until you see the best results. Most standard TVs can at least see a skewed flickering image when the frame rate clock divider is set to 0 (CR 17 0).

### A Note on Demo Mode: Better Tracking with Auto-gain and White Balance

Auto-gain is an internal control that adjusts the brightness level of the image to best suit the environment. It attempts to normalize the lights and darks in the image so that they approximate the overall brightness of a hand adjusted image. This process iterates over many frames as the camera automatically adjusts its brightness levels. If for example a light is turned on and the environment gets brighter, the camera will try and adjust the brightness to dim the overall image.

White balance on the other hand attempts to correct the camera's color gains. The ambient light in your image may not be pure white. In this case, the camera will see colors differently. The camera begins with an initial guess of how much gain to give each color channel. If active, white balance will adjust these gains on a frame-by-frame basis so that the average color in the image approaches a gray color. Empirically, this "gray world" method has been found to work relatively well. The problem with gray world white balance is that if a solid color fills the camera's view, the white balance will slowly set the gains so that the color appears to be gray and not its true color. Then when the solid color is removed, the image will have undesirable color gains until it re-establishes its gray average.

When tracking colors, like in demo mode, you may wish to allow auto-gain and white balance to run for a short period and then shut them off. While on for a period of about 5 seconds, the camera can set its brightness gain and color gains to what it sees as fit. Then turning them off will stop the camera from unnecessarily changing its settings due to an object being held close to the lens or shadows etc. If auto-gain and white balance were not disabled and the camera changed its settings for the RGB values, then the new measured values may fall outside the originally selected color tracking thresholds.

## Serial Command Set

---

The serial communication parameters are as follows:

- 115,200 Baud
- 8 Data bits
- 1 Stop bit
- No Parity
- No Flow Control (Not Xon/Xoff or Hardware)

All commands are sent using visible ASCII characters (123 is 3 bytes "123" ). Upon a successful transmission of a command, the ACK string should be returned. If there was a problem in the syntax of the transmission, or if a detectable transfer error occurred, a NCK string is returned. After either an ACK or a NCK, a \r is returned. When a prompt ('\r' followed by a ':') is returned, it means that the camera is waiting for another command in the idle state. White spaces do matter and are used to separate argument parameters. The \r (ASCII 13 carriage return) is used to end each line and activate each command. If visible character transmission exerts too much overhead, it is possible to use varying degrees of raw data transfer. (See Raw Mode)

\r

This command is used to set the camera board into an idle state. Like all other commands, you should receive the acknowledgment string "ACK" or the not acknowledge string "NCK" on failure. After acknowledging the idle command the camera board waits for further commands, which is shown by the ':' prompt. While in this idle state a /r by itself will return an "ACK" followed by \r and : character prompt.

*Example of how to check if the camera is alive while in the idle state*

```
:  
ACK  
:
```

**CR** [ reg1 value1 [reg2 value2 ... reg16 value16] ]\r

This command sets the Camera's internal **R**egister values directly. The register locations and possible settings can be found in the Omnivision documentation. All the data sent to this command should be in decimal visible character form unless the camera has previously been set into raw mode. It is possible to send up to 16 register-value combinations. Previous register settings are not reset between CR calls; however, you may overwrite previous settings. Calling this command with no arguments resets the camera and restores the camera registers to their default state.

Useful Settings:

<u>Register</u>	<u>Values</u>
5 Contrast	0-255
6 Brightness	0-255
18 Color Mode	36 YCrCb* Auto White Balance On 32 YCrCb* Auto White Balance Off 44 RGB Auto White Balance On 40 RGB Auto White Balance Off (default)
17 Clock Speed	2 17 fps (default) 3 13 fps 4 11 fps 5 9 fps 6 8 fps 7 7 fps 8 6 fps 10 5 fps 12 4 fps
19 Auto Exposure	32 Auto Gain Off 33 Auto Gain On (default)

*Example of decreasing the internal camera clock speed (default speed is 2)*

```
:CR 17 5  
ACK  
:
```

\*The red channel becomes Cr which approximates r-g, The green channel becomes Y which approximates intensity, the blue channel becomes Cb which approximates b-g

RGB -> CrYCb

$Y = 0.59G + 0.31R + 0.11B$

$Cr = R - Y$

$Cb = B - Y$

## DF\r

This command will **D**ump a **F**rame out the serial port to a computer. This is the only command that will by default only return a non-visible ASCII character packet. It dumps a type F packet that consists of the raw video data column by column with a frame synchronize byte and a column synchronize byte. (This data can be read and displayed by the CMUcamGUI java application. ) Since the data rate required to send the raw video greatly exceeds the maximum serial port speed, only one column per frame is sent at a time. This allows you to see a slowly updating view of what the camera sees. To get the correct aspect ratio, double each column of pixels. The camera is able to dump a full resolution frame at full speed (17 columns per second) only at 115,200 baud. At lower baud rates, or 115,200 baud with added delays the frame rate must be decreased in order to see a full resolution image. With auto-gain on and at lower frame rates, the image at first may appear much brighter than usual. This is because the camera is getting frames slower than usual and takes longer to adapt. Try manually setting the brightness and contrast.

Type F data packet format

- 1 - new frame
- 2 - new col
- 3 - end of frame

RGB (CrYCb) ranges from 16 - 240

*1 2 r g b r g b ... r g b r g b 2 r g b r g b r ... r g b r g b ...*

*Example of a Frame Dump from a terminal program*

*(WARNING: This may temporarily interfere with a terminal program by sending non-visible characters)*

*:DF*

*ACK*

*maKP(U A\$IU AL<>U A\$L\*YL%\*L L (G AUsonthAYA(KMAy098a34ymawvk...*

## DM value\r

This command sets the **D**elay before packets that are transmitted over the serial port. The value should be set between 0 and 255. A value of 0 (default) has no delay and 255 sets the maximum delay. Each delay unit correlates to approximately the transfer time of one bit at the current baud rate.

## GM\r

This command will **G**et the **M**ean color value in the current image. As with the TC command this function only operates on a selected region of the image. The mean values will be between 16 and 240. It will also return a measure of the average absolute deviation of color found in that region. The mean together with the deviation can be a useful tool for automated tracking or detecting change in a scene. In YCrCb mode RGB maps to CrYCb.

Type S data packet format

*S Rmean Gmean Bmean Rdeviation Gdeviation Bdeviation\r*

*Example of how to grab the mean color of the entire window*

*:SW 1 1 40 143*

*ACK*

*:GM*

*ACK*

*S 89 90 67 5 6 3*

*S 89 91 67 5 6 2*

## **GV**\r

This command **G**ets the current **V**ersion of the firmware from the camera. It returns an **ACK** followed by the firmware version string.

*Example of how to ask for the firmware version*

```
:GV  
ACK  
CMUcam v1.12
```

## **HM** *active*\r

This command puts the camera into **H**alf-horizontal resolution **M**ode for the **DF** command and the **LM** command when dumping a bitmap image. An *active* value of 1 causes only every odd column to be processed. The default value of 0 disables the mode.

## **I1** \r

This command uses the servo port as a digital **I**nput. Calling **I1** returns either a 1 or 0 depending on the current voltage level of the servo line. The line is pulled high; because of this it is only required to pull it low or let it float to change it's state. The servo line can also be used as a digital output. ( See **S1** command)

*Example of how to read the digital value of the servo line*

```
:I1  
ACK  
1
```

## **L1** *value*\r

This command is used to control the tracking **L**ight. It accepts 0, 1 and 2 (default) as inputs. 0 disables the tracking light while a value of 1 turns on the tracking light. A value of 2 puts the light into its default auto mode. In auto mode and while tracking, the light turns on when it detects the presence of an object that falls within the current tracking threshold. This command is useful as a debugging tool.

*Example of how to toggle the Tracking Light on and then off*

```
:L1 2  
ACK  
:L1 0  
ACK
```

## LM active

This command turns on **Line Mode** which uses the time between each frame to transmit more detailed data about the image. It adds prefix data onto either **C**, **M** or **S** packets. This mode is intended for users who wish to do more complex image processing on less reduced data. Since the frame rate is not compromised, the actual processing of the data put out by the vision system must be done at a higher rate. This may not be suitable for many slower microcontrollers.

Line mode's effect on TC and TW:

When line mode is active and TC or TW is called, line mode will send a binary bitmap of the image as it is being processed. It will start this bitmap with an 0xAA flag value (hex value AA not in human readable form). The value 0xAA will not occur in the data stream. This is followed by bytes each of which contains the binary value of 8 pixels being streamed from the top-left to the bottom-right of the image. The vertical resolution is constrained by the transfer time of the horizontal data so lines may be skipped when outputting data. In full resolution mode, the resulting binary image is 80x48. The binary bitmap is terminated by two 0xAA's. This is then followed by the normally expected standard **C** or **M** data packet (processed at that lower resolution).

*Example of TC with line mode on*

*:LM 1*

*:TC*

*(raw data: AA XX XX XX .... XX XX XX AA AA) C 45 72 65 106 18 51*

*(raw data: AA XX XX XX .... XX XX XX AA AA) C 46 72 65 106 18 52*

Line mode's effect on GM:

When line mode is active and GM is called, line mode will send a raw (not human readable) mean value of every line being processed. These packets are started with an 0xFE and terminate with an 0xFD. Each byte of data between these values represents the corresponding line's mean color value. Similarly to the bitmap mode the vertical resolution is halved, because of the serial transfer time. At 17 fps 115,200 baud every other line is skipped. At any slower frame rate (still 115,200 baud) no lines will be skipped.

*Example of GM with line mode on*

*:LM 1*

*:GM*

*(raw data: FE XX XX XX ... XX XX XX FD) M 45 56 34 10 15 8*

*(raw data: FE XX XX XX ... XX XX XX FD) M 45 56 34 10 15 8*



### **MM mode**\r

This command controls the **Middle Mass** mode which adds the centroid coordinates to the normal tracking data. A *mode* value of 0 disengages middle mass, a value of 1 (default) engages middle mass and a value of 2 engages the mode and turns on the servo PWM signal that tries to center the camera on the center of color mass (see the Demo Mode Jumper description). This mode is good if you want a single point representation of where the object is or if there is too much small background noise to get a good bounding box. To switch the direction of the servo it is necessary to set the 2<sup>nd</sup> bit (counting from 0 i.e. bitwise OR in the value 4) of the mode value. If the 3<sup>rd</sup> bit is set (bitwise OR in the value 8), then tracking a color will return a type N packets that is identical to a type M packet, only it contains the current servo position as its first return value (see Output Data Packet Description section).

*Example of how to disable Middle Mass mode*

```
:MM 0
ACK
:TC
ACK
C 38 82 53 128 35 98
C 38 82 53 128 35 98
C 38 82 53 128 35 98
```

### **NF active**\r

This command controls the **Noise Filter** setting. It accepts a Boolean value 1 (default) or 0. A value of 1 engages the mode while a value of 0 deactivates it. When the mode is active, the camera is more conservative about how it selects tracked pixels. It requires 2 sequential pixels for a pixel to be tracked.

*Example of how to turn off noise filtering*

```
:NF 0
ACK
:
```

### **PM mode**\r

This command puts the board into **Poll Mode**. Setting the mode parameter to 1 engages poll mode while 0 (default) turns it off. When poll mode is engaged only one packet is returned when an image processing function is called. This could be useful if you would like to rapidly change parameters or if you have a slow processor that can't keep up with a given frame rate.

*Example of how to get one packet at a time*

```
:PM 1
ACK
:TC 50 20 90 130 70 255
ACK
C 38 82 53 128 35 98
:
```

## **RM** *bit\_flags*\r

This command is used to engage the **R**aw serial transfer **M**ode. It reads the bit values of the first 3 (lsb) bits to configure settings. All bits cleared sets the default visible ascii mode. If bit 0 is set, then all output from the camera is in raw byte packets. The format of the data packets will be changed so as not to include spaces or be formatted as readable ASCII text. Instead you will receive a 255 valued byte at the beginning of each packet, followed by the packet and the packet identifying character (i.e. C for a color packet). There is no \r sent after each packet, so you must use the 255 to synchronize the incoming data. Any 255 valued bytes that may be sent as part of the packet are set to 254 to avoid confusion. If bit 1 is set, the “ACK\r” and “NCK\r” confirmations are not sent. If bit 3 is set, input will be read as raw byte values, too. In this mode, after the two command byte values are sent, send 1 byte telling how many arguments are to follow. (i.e. DF followed by the raw byte value 0 for no arguments) No \r character is required.

If bit 0 is enabled, then output to the camera is in raw bytes

If bit 1 is enabled, then the “ACK\r” and “NCK\r” confirmations are suppressed

If bit 2 is enabled, then input to the camera is in raw bytes

*Example of the new packet for Track Color with Raw Mode output only*

*(WARNING: This may temporarily interfere with a terminal program by sending non visible characters)*

*:RM 1*

*ACK*

*:TC 50 20 90 130 70 255*

*ACK*

*C>%k(ai Ck\$&,.L*

## **RS** \r

This command **Re**Sets the vision board. Note, on reset the first character is a /r.

*Example of how to reset the camera*

*:rs*

*ACK*

*CMUcam v1.12*

*:*

## **S1** *position* \r

This command lets you **Set** the position of servo 1. 0 turns the servo off and holds the line low. 1-127 will set the servo to that position while it is tracking or getting mean data. Any value 128 and higher sets the line high. In order for the servo to work, the camera must be in either a tracking loop or mean data gather loop. Values 0 and 128 can be useful if you wish to use the servo port as a digital output. The port can also be used as a digital input (see I1 command). The “MM” command can enable or disable the automatic servo tracking.

### **SM** *value* \r

This command is used to enable the **Switching Mode** of color tracking. When given a 0 it is in its default mode where tracking will return its normal C or M color packet. If the value is set to 1, the tracking commands will alternate each frame between color packets and S statistic packets. Each statistic packet is only being sampled from an area one quarter the size of the bounded area returned from the tracking command. If no object was bounded, then no S statistic packets are returned. This can be useful for adaptive tracking or any type of tracking where you would like to get feedback from the currently bound target. After the first tracking packet is returned, the window gets set back to full size for all future packets. Note, you will get only half the number of actual color packets per time interval.

*Example of how to Track Color with SM*

```
:SM 1
ACK
:TC 200 255 0 30 0 30
ACK
C 2 40 12 60 10 70
S 225 20 16 2 3 1
C 5 60 20 30 12 100
S 225 19 17 1 2 1
C 0 0 0 0 0 0
C 0 0 0 0 0 0
C 0 0 0 0 0 0
C 5 60 20 30 12 100
S 225 19 17 1 2 1
```

### **SW** [x y x2 y2] \r

This command **Sets the Window** size of the camera. It accepts the x and y Cartesian coordinates of the upper left corner followed by the lower right of the window you wish to set. The origin is located at the upper left of the field of view. **SW** can be called before an image processing command to constrain the field of view. Without arguments it returns to the default full window size of 1,1,80,143.

*Example of setting the camera to select a mid portion of the view*

```
:SW 35 65 45 75
ACK
:
```

**TC** [*Rmin Rmax Gmin Gmax Bmin Bmax*]\r

This command begins to **Track a Color** . It takes in the minimum and maximum RGB (CrYCb) values and outputs a type M or C data packet (set by the MM command). The smaller type C packet encodes a bounded box that contains pixels of the currently defined color, the number of found pixels (scaled: actual value is (pixels+4)/8 ) that fall in the given color bounds and a confidence ratio. The default type M packet also includes the center of mass of the object. The resolution of the processed image is 80x143. The X values will range from 1 to 80 and the y values will range from 1 to 143. A packet of all zeros indicates that no color in that range was detected. The confidence value is a ratio of the pixels counted within the given range and the area of the color bounding box. It returns a value which ranges from 0 to 255. Under normal operations any value greater than 50 should be considered a very confident lock on a single object. A value of 8 or lower should be considered quite poor. With no arguments, the last color tracking parameters will be repeated.

Type M packet

*M mx my x1 y1 x2 y2 pixels confidence\r*

Type C packet

*C x1 y1 x2 y2 pixels confidence\r*

*Example of how to Track a Color with the default mode parameters*

*:TC 130 255 0 0 30 30*

*ACK*

*M 50 80 38 82 53 128 35 98*

*M 52 81 38 82 53 128 35 98*

*M 51 80 38 82 53 128 35 98*

**TW** \r

This command will **Track** the color found in the central region of the current **Window**. After the color in the current window is grabbed, the track color function is called with those parameters and on the full screen. This can be useful for locking onto and tracking an object held in front of the camera. Since it actually calls track color, it returns the same type of C or M color packet. Note, your set window will only be used for grabbing the color to track and then the window will return to 80x143.

*Example of how to use Track Window:*

*:TW*

*ACK*

*S 240 50 40 12 7 8*

*C 2 40 12 60 10 70*

*C 3 41 12 61 11 70*

*C 2 40 12 60 13 70*

*C 3 42 12 62 9 70*

*C 4 45 12 60 8 70*

## Output Data Packet Descriptions

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All output data packets are in ASCII viewable format except for the F frame and prefix packets.

### ACK

This is the standard acknowledge string that indicates that the command was received and fits a known format.

### NCK

This is the failure string that is sent when an error occurred. The only time this should be sent when an error has not occurred is during binary data packets.

### Type C packet

This is the return packet from a color tracking command.

*x1* - The left most corner's x value

*y1* - The left most corner's y value

*x2* - The right most corner's x value

*y2* -The right most corner's y value

*pixels* -Number of Pixels in the tracked region, scaled and capped at 255:  $(pixels+4)/8$

*confidence* -The (# of pixels / area)\*256 of the bounded rectangle and capped at 255

*C x1 y1 x2 y2 pixels confidence\r*

### Type F data packet format

1 - new frame 2 - new col 3 - end of frame

RGB (CrYCb) ranges from 16 - 240

RGB (CrYCb) represents a two pixels color values. Each pixel shares the red and blue.

176 cols of R G B (Cr Y Cb) packets (forms 352 pixels)

144 rows

To display the correct aspect ratio, double each column so that your final image is 352x144

It does not begin with an "F" and only sends raw data!

*1 2 r g b r g b ... r g b r g b 2 r g b r g b ... r g b r g b ...*

### Type M packet

This is the return packet from a color tracking command with Middle Mass mode on.

*mx* - The middle of mass x value

*my* - The middle of mass y value

*x1* - The left most corner's x value

*y1* - The left most corner's y value

*x2* - The right most corner's x value

*y2* -The right most corner's y value

*pixels* -Number of Pixels in the tracked region, scaled and capped at 255:  $(pixels+4)/8$

*confidence* -The (# of pixels / area)\*256 of the bounded rectangle and capped at 255

*M mx my x1 y1 x2 y2 pixels confidence\r*

### Type N packet

This is identical to a type M packet with an added value for the servo position.

*spos* - The current position of the servo

*N spos mx my x1 y1 x2 y2 pixels confidence\r*

## Type S data packet format

This is a statistic packet that gives information about the camera's view

*Rmean* - the mean Red or Cr (approximates r-g) value in the current window

*Gmean* - the mean Green or Y (approximates intensity) value found in the current window

*Bmean* - the mean Blue or Cb (approximates b-g) found in the current window

*Rdeviation* - the \*deviation of red or Cr found in the current window

*Gdeviation*- the \*deviation of green or Y found in the current window

*Bdeviation*- the \*deviation of blue or Cb found in the current window

*S Rmean Gmean Bmean Rdeviation Gdeviation Bdeviation*\r

\*deviation: The mean of the absolute difference between the pixels and the region mean.

## Binary bitmap **Line Mode** prefix packet

This packet is in raw byte form only. It starts off with the hex value 0xAA and then streams bytes, with each byte containing a mask for 8 pixels, from the top-left to the bottom-right of the image. (Each binary bit in the byte represents a pixel) The bitmap is then terminated with two 0xAAs. 0xAA is never transmitted as part of the data, so it should be used to signify termination of the binary bitmap. After the binary bitmap is complete, a normal tracking packet should follow.

(raw data: AA XX XX XX .... XX XX XX AA AA) C 45 72 65 106 18 51

(raw data: AA XX XX XX .... XX XX XX AA AA) C 46 72 65 106 18 52

## Get mean **Line Mode** prefix packet

This packet prefix outputs the mean color of each row being processed. These packets are started with an 0xFE and terminate with an 0xFD. Each byte of data between these values represents the corresponding line's mean color value. Due to the serial transfer time, the vertical resolution is halved. After all rows have been completed, a normal tracking packet should follow.

(raw data: FE XX XX XX ... XX XX XX FD) M 45 56 34 10 15 8

(raw data: FE XX XX XX ... XX XX XX FD) M 45 56 34 10 15 8

## Firmware

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Once the board has been assembled and powered up, the firmware can be downloaded using the SX-Key downloading program. The SX-Key downloader and manual are available at:

[www.parallaxinc.com/html\\_files/downloads/downloads\\_sx.htm](http://www.parallaxinc.com/html_files/downloads/downloads_sx.htm)

The firmware for the camera can be found at:

<http://www.cs.cmu.edu/~cmucam/downloads.html>

## Downloading The Firmware

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After downloading and installing the SX-Key software, it is necessary to load the CMUcam.hex firmware to the board.

- step 1: Turn on the board's power.
- step 2: Ensure that the programming switch is in the program mode (pushed towards the LEDs see Assembled view)
- step 3: Plug in the SX-key, text side facing away from the board. (for more details see the hardware port section)
- step 4: Open up the SX-Key software
- step 5: Select "Device" from under the "Run" menu
- step 6: Click on the "Load Hex" button
- step 7: Go to the directory of the CMUcam.hex file and type its name into the dialog box. (It may not be visible)
- step 8: Press "Open" to load it
- step 9: Press the "Program" button
- step 10: Once programming has finished, turn off the power to the board
- step 11: Unplug the SX-Key and switch the programming switch into the run position
- step 12: Once the power switch is turned on again the firmware should be running and will greet you with

*CMUcam v1.12*

:

## Troubleshooting

If, when you tried to program, you see or experience:

*SX-Key not found*

-Make sure the comm port is set correctly and power is going to the camera

*Vpp Generation Failed*

-Ensure that the program switch is in the correct position

*Programming Failed*

- Try it again and if it still occurs consult the SX-Key manual

*No response*

-Make sure you switched the board out of program mode. Try power cycling the board.

*In Demo Mode, the light turns on for a second and then everything stops*

-When both the camera and servo are active, the power required is greater. Try using a battery or voltage source rated at a higher current.

## Hardware

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The following is a list of parts needed to assemble the CMUcam.

Qty	Item	Part no. (Digi-key)	Schematic Label	Unit Price
1	75 MIPS Uicom SX28	SX28AC75/DP-ND	IC1	5.18
1	OV6620 Eval Board *	BB048*		57.95
1	Maxim 232 Level Shifter	MAX232CPE-ND	IC3	3.31
1	SG-531 75.00 MHz crystal osc	SE2911-ND	QG1	5.85
1	5 Volt Regulator	LM2940CT-5.0-ND	IC2	1.80
3	4.7 Kohm 1/4 Watt Resistor	4.7KQBK-ND	R2 R3 R4	0.06
2	220 ohm 1/4 Watt Resistor	220QBK-ND	R1	0.06
6	1.0 uF Capacitor	P2105-ND	C1 C2 C3 C4 C5 C6	0.42
2	SPST Switch	EG1847-ND	S1 S2	1.11
1	3mm red LED	67-1125-ND	LED3MM	0.16
1	3mm green LED	67-1127-ND	D1	0.16
2	0.1uF Capacitor	P4923-ND	C9 C10	0.55
3	100 uF Capacitor	P5138-ND	C7 C8 C11	0.28
2	14 pin IC socket (to form a 28 pin socket)	AE8914-ND	IC1	0.32
1	8 pin IC socket **	ED3308-ND	QG1	0.42
1	16 pin IC socket	ED3316-ND	IC3	0.83
1	Double row female header	929852-01-36	JP5	3.35
1	Single row male header	929647-09-36-ND	JP1x2 JP3 JP4 JP7	1.83
(1)	Polarized 2 pin terminal housing	WM2700-ND		0.25
(2)	Crimp terminals	WM2200-ND		0.13
(1)	Polarized 2 pin terminal header	WM2000-ND		0.25
(1)	Female serial ribbon cable head	AFS09G-ND		6.14
(1)	Serial ribbon cable socket connector	ASC10G-ND		1.11

\*Order Code BB048 at <http://www.electronics123.com>. Ask them for an evaluation board with an OV6620 from Omnivision and an IR coated lens.

\*\*Use this for the oscillator by cutting off the inner 4 legs

( ) accessories that make interfacing easier, but are not required for functionality



# CMUcam Schematic

