Hardware Documentation

March 25, 2014

Contents

1 Flea3 USB3 Camera

In our project, we are using Flea3 USB 3.0 cameras (FL3-U3-32S2C-CS) from PointGrey Research product.

Figure 1: FL3-U3-32S2C-CS

1.1 Camera Specifications and Imaging Performance

These cameras provide features like enhanced opto-isolated GPIO, an on-camera frame buffer; non-volatile flash memory for user data storage, new trigger modes and improved imaging performance. These are colored, 3.2 megapixels cameras with 1/3", 3.63 μm Sony IMX035 CMOS image sensors and rolling shutter with global reset. Maximum achievable resolution is 2080×1552 at 60 FPS. Figure 2 lists the imaging performance of the camera and Figure 3 refers to technical specifications.

Specification	Mode 0
Full Well Depth	14300 e- at zero gain
Dynamic Range	60 dB
Read Noise	9.4 e- at zero gain
Measurements taken at maximum resolution	

Quantum Efficiency	
Peak QE Wavelength	Red 600 nm, Green 530 nm, Blue 460 nm
Peak QE Value	Red 37%, Green 45%, Blue 40%

Figure 2: Imaging Performance

A/D Converter	12-bit (FL3-U3-13S2, FL3-U3-32S2, FL3-U3-88S2) / 10-bit (FL3-U3-13Y3, FL3-U3-13E4)
Image Data Output	8, 12, 16 and 24-bit digital data
Image Data Formats	Y8, Y16, Mono8, Mono12, Mono16 (all models) RGB8, YUV411, YUV422, YUV444, Raw8, Raw12, Raw16 (color models)
Partial Image Modes	Pixel binning and region of interest (ROI) modes
Image Processing	Gamma, lookup table, hue, saturation, and sharpness
Gain	Automatic*/Manual/One-Push* Gain modes (*Free running only)
	0 dB to 24 dB (FL3-U3-32S2, FL3-U3-88S2) / 0 db to 18 db (FL3-U3-13S2, FL3-U3-13Y3, FL3-U3-13E4)
Gamma	0.50 to 4.00
White Balance	Automatic/Manual modes, programmable via software
Color Processing	On-camera in YUV or RGB format, or on-PC in Raw format
Digital Interface	USB 3.0 interface with screw locks for camera control, data, and power
Transfer Rates	5 Gbit/s
GPIO	8-pin Hirose HR25 GPIO connector for power, trigger, strobe, PWM, and serial I/O: 1 opto-isolated input, 1 opto-isolated output, 2 bi-directional I/O pins
External Trigger Modes	IIDC Trigger Modes 0, 1 (excluding FL3-U3-13E4), and 15
Synchronization	via external trigger or software trigger
Shutter	Rolling Shutter (FL3-U3-13S2) / Global Reset (FL3-U3-32S2, FL3-U3-88S2) / Global Shutter (FL3-U3-13Y3, FL3-U3-13E4)
	Automatic*/Manual/One-Push*/Extended Shutter** modes (*Free running only) (**except FL3-U3-13Y3)
	0.008 ms to 1 second (FL3-U3-13S2) / 0.006 ms to 1 second (FL3-U3-13Y3) / 0.016 ms to 1 second (FL3-U3-13E4) / 0.01 ms to 32 seconds (FL3-U3-32S2) / 0.021 ms to 1 second (FL3-U3-88S2)
Image Buffer	32 MB frame buffer
Memory Channels	2 memory channels for custom camera settings
Flash Memory	1 MB
Dimensions	29 x 29 x 30 mm excluding lens holder (metal case)
Mass	Without optics: 35 g (FL3-U3-13S2, FL3-U3-32S2) / 41 g (FL3-U3-13Y3, FL3-U3-13E4, FL3-U3-88S2)
Power Consumption	5 V, <3 W, via GPIO or USB 3.0 interface
Camera Specification	IIDC v1.32
Camera Control	via FlyCapture SDK, CSRs, or third party software
Camera Updates	In-field firmware updates
Lens Mount	CS-mount (FL3-U3-13S2, FL3-U3-32S2) / C-mount (FL3-U3-13Y3, FL3-U3-13E4, FL3-U3-88S2)
Temperature	Operating: 0° to 45°C; Storage: -30° to 60°C
Emissions Compliance	CE, FCC, RoHS
Operating System	Windows, Linux (32- or 64-bit)
Warranty	Three years

Figure 3: Technical Specifications

1.2 System Requirements

Recommended system configurations for these cameras are -

- OS - Windows 7 32- or 64-bit

- CPU - Intel Core i3 3.1 GHz or equivalent
- RAM - 2 GB
- Video - NVIDIA GeForce6 128 MB RAM
- Ports - PCIe 2.0 compatible host controller with USB 3.0 connector
- Software - Microsoft Visual Studio 2005 SP1 and SP1 Update (to compile and run example code)

1.3 Camera Interface

The cameras are equipped with a USB 3.0 Micro-B connector that is used for data transmission, camera control and power. These cameras also have 8-pin GPIO connectors on the back, as shown in Figure 4.

Diagram	Pin	Function	Description
	1	IO0	Opto-isolated input (default Trigger in)
	2	IO1	Opto-isolated output
	3	IO2	Input/Output/serial transmit (TX)
	4	IO3	Input/Output/serial receive (RX)
	5	GND	Ground for bi-directional IO, V_{EXT}, +3.3 V pins
	6	GND	Ground for opto-isolated IO pins
	7	V_{EXT}	Allows the camera to be powered externally
	8	+3.3 V	Power external circuitry up to 150 mA
	To configure the GPIO pins, consult the General Purpose Input/Output section of your camera's Technical Reference Manual.		

Figure 4

Once the camera is powered, one can understand its status by looking at the color of the LED on the back of the camera, as shown in Figure 5.

LED Status	Description
Off	Not receiving power
Steady green	Camera receiving power (~3 seconds)
Flashing yellow	Initializing FPGA (~1 second)
Steady yellow	FPGA initialized (~1 second)
Steady yellow-green	Sensor powered
Steady bright green	Acquiring and transmitting images
Flashing bright, then brighter green	Camera registers being accessed (no image acquisition)
Steady red	Temporary camera problem
Slow flashing red	Serious camera problem

Figure 5

1.4 Camera Installation

The steps for camera installation are listed below -

- Install the Tripod Mounting Bracket.

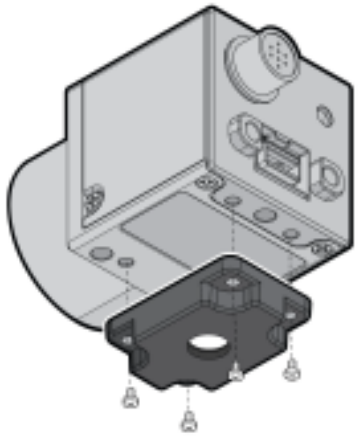

Figure 6

- Attach a suitable lens - We have used the Fujinon YV28x28SA-2 HD Vari-Focal Lens.

- Plug in the GPIO connector to provide external power, trigger, pulse width modulation, serial input output, and strobe.

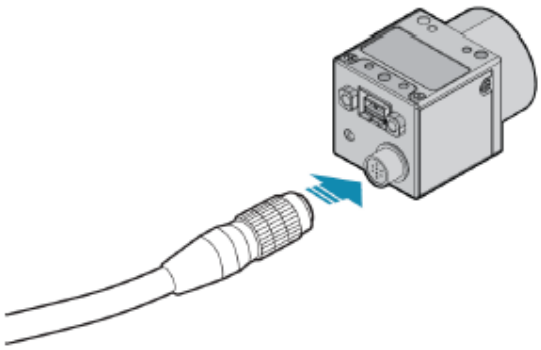

Figure 7

- Connect the USB 3.0 interface Cable into the host controller card of the camera.

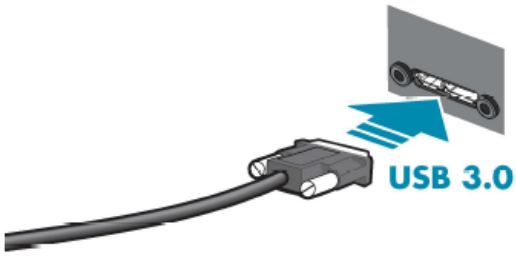

Figure 8

- Confirm successful installation by checking Device manager and verifying the camera is listed under "Point Grey Research Devices".

1.5 Physical Description

Figure 9 shows different camera parts.

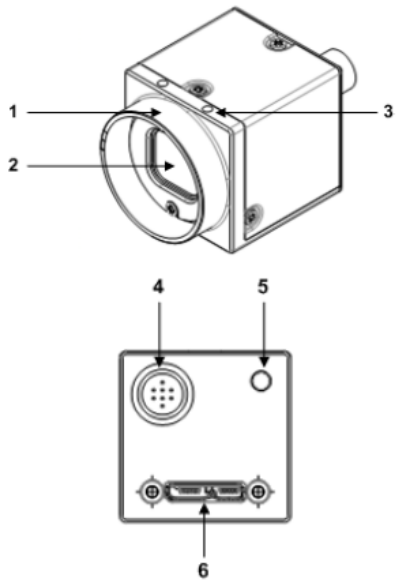

Figure 9

1. Lens holder
2. Glass/IR filter system
3. M2x2 mounting holes
4. General purpose I/O connector
5. Status LED
6. USB3 connector

More details about the cameras can be found in the Getting Started or Technical Reference Manual, provided in the ExtraDocs folder of Step01.

2 Lens Specifications

We are using Fujinon YV28x28SA-2 HD Vari-Focal Lens, shown in Figure 10. These are high image-quality monitoring lenses with optical performance supporting 3 megapixels. The lenses have 2.8mm width which results in achieving a horizontal field angle of 100 degrees (when used on 1/3 cameras). These compact and lightweight lenses are designed to maximize optical performance with high-accuracy aspheric lens, low-dispersion glass, and high refractive-index glass. Figure 11 gives a detailed overview about the technical specifications of this lens.

Figure 10

Focal Length (mm)			2.8~8 (2.8×)
Iris Range			F1.2 ~ Close
Operation	Zoom		Manual
	Focus		Manual
	Iris		Manual
Angle Of View (H×V)	1/3"	WIDE	100°00′ × 73°45′
		TELE	35°03′ × 26°18′
	1/4"	WIDE	73°45′ × 54°49′
		TELE	26°18′ × 19°44′
Angle Of View (H×V) Aspect Ratio 16:9	1/3"	WIDE	109°50′ × 59°51′
		TELE	38°11′ × 21°29′
	1/4"	WIDE	80°39′ × 44°38′
		TELE	28°39′ × 16°07′
Focusing Range (From Front Of The Lens) (m)			∞ ~ 0.3
Object Dimensions at M.O.D. (H×V) (mm)	1/3"	WIDE	744 × 468
		TELE	197 × 146
	1/4"	WIDE	468 × 323
		TELE	146 × 108
Object Dimensions at M.O.D. (H×V) (mm) Aspect Ratio 16:9	1/3"	WIDE	890 × 359
		TELE	216 × 118
	1/4"	WIDE	530 × 256
		TELE	159 × 88
Back Focal Distance (in air) (mm)			7.70
Exit Pupil Position (From Image Plane) (mm)			314
Filter Thread (mm)			—
Mount			CS
Mass (g)			50
Remarks			• With Metal Mount

Figure 11

This link can be referred for additional information.

3 Physical Set-Up

For this autonomous driving project, we have built a stereo set-up that can be mounted on the car, Figure 12.

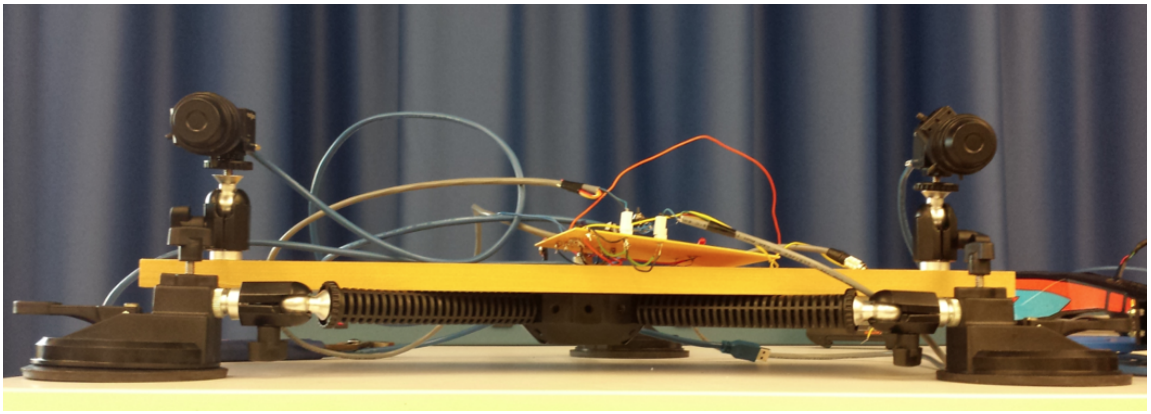

Figure 12

3.1 Equipment List

- Flea3 USB 3.0 cameras (FFL3-U3-32S2C-CS) from PointGrey Research product.
- Fujinon YV28x28SA-2 HD Vari-Focal Lens
- RoHS Circular 8PIN pre-wired GPIO Hirose Connector
- RoHS 3 METER USB3.0 CABLE, TYPE-A to MICRO-B (LOCKING)
- Camtree G - 21 Gripper Car Suction Mount - SKU383 (For details, refer here)
- Trigger circuit
- White beaglebone

3.2 Experimental Set-up

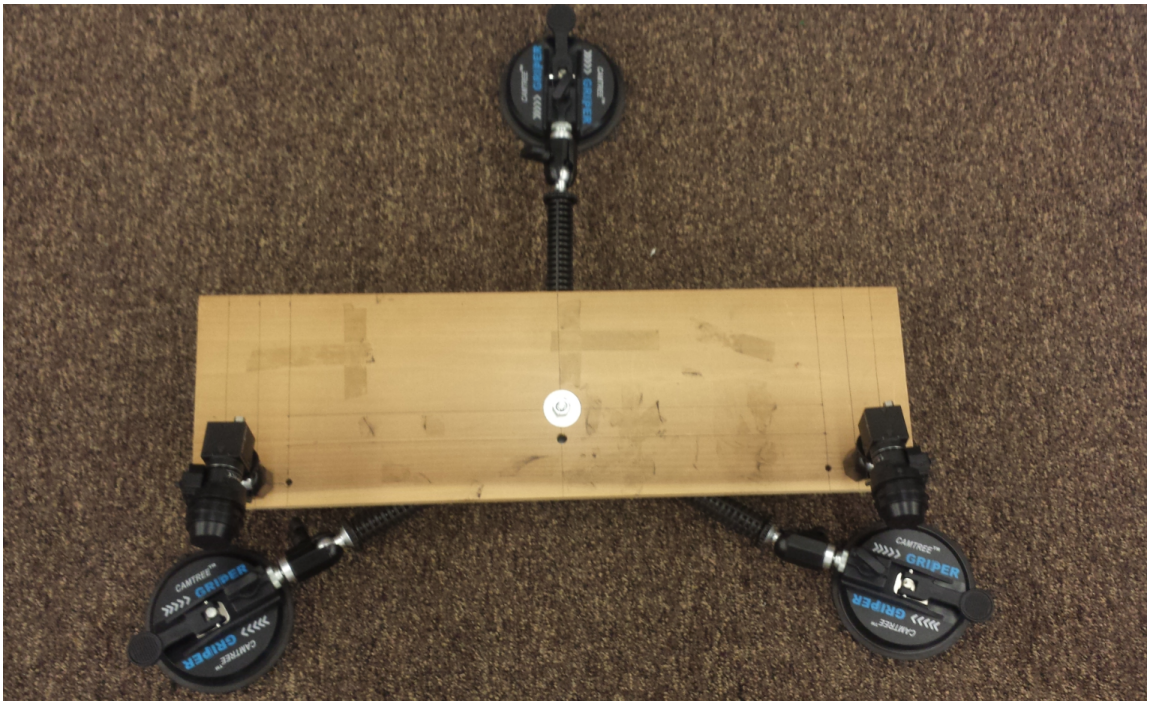

Figure 13: Top-view

Figure 13 shows the top-view and Figure 14 shows the front-view of our experimental set-up with the cameras and the mount. The average distance between the cameras is 50 cm. We acquire the images by setting the camera resolution to 1920×1080 at 15 FPS. The image are acquired synchronously by triggering our cameras externally through the 8-pin GPIO connectors.

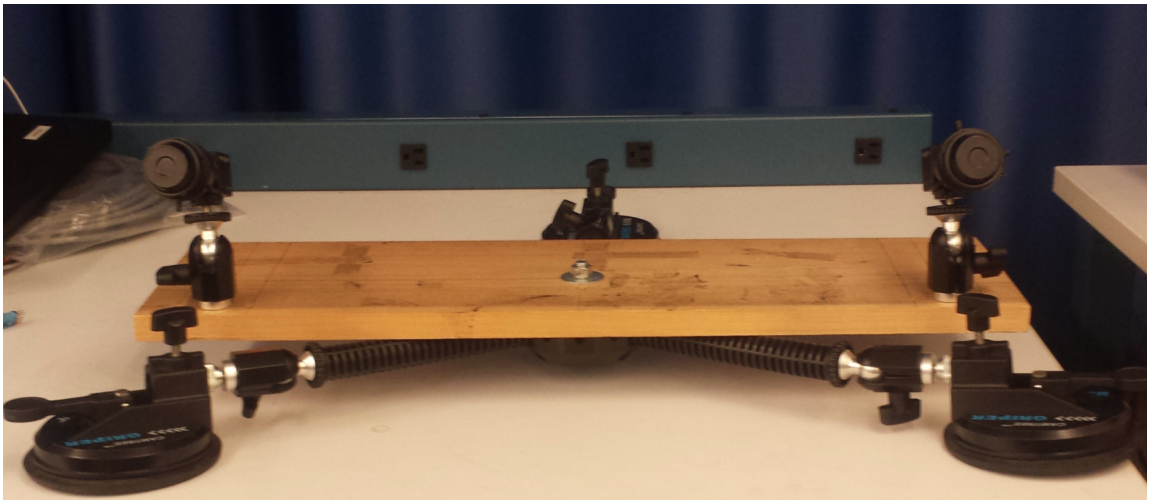

Figure 14: Front-view

3.3 Image Acquisition by External Triggering

These cameras can be synchronized by applying an external trigger. When a GPIO pin is put into GPIO Mode 0, it is configured to accept external trigger signals. One of the GPIO pins is configured as the external trigger source. For our camera model, the default trigger pin is Pin 1. In our experiment, the images are, thus, acquired by connecting the external 5V or 3.3V TTL synchronization signal to GPIO pin 1. Once the trigger is fired, images from the stereo cameras are grabbed simultaneously. For more external triggering information, consult Chapter 6 of the camera's Technical Reference Manual, listed in the ExtraDocs folder of Step01.

For our experiment, we have designed a triggering circuit which takes input of 3.3V from the beaglebone. We have written a shell script to make the beaglebone operate as a timer. The trigger code has been provided in the source code section. To learn more about beaglebone programming, refer to this website. Figure 15 is the schematic of our power supply circuit.

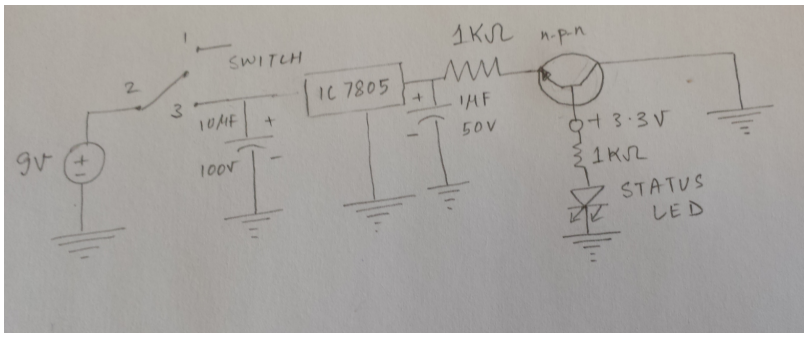

Figure 15

The circuit components are -

1. Voltage Regulator - IC L7805CV
2. NPN transistor
3. 9V battery
4. Two 1 KΩ resistors
5. 10 μF/ 100 V capacitor
6. 1 μF/ 50 V capacitor
7. 3-legged toggle switch
8. Status LED

This circuit provides 5V to the beaglebone, which in turn, outputs 3.3V to the cameras every time a trigger is fired. As we know, the maximum current supply for the IC L7805CV is 1.5A, we use a n-p-n power transistor for additional current requirement. The ground of the above circuit is connected to the beaglebone's DGND (pin 1 or 2 under the header P9). The input power goes to GPIO_37 (pin 22 under header P8). More details about the beaglebone's GPIO pins can be found here.

4 FlyCapture 2 SDK

The camera comes with a FlyCapture2 SDK which has different API examples and the FlyCap2 program. Users can monitor or control features of the camera through these examples or through the FlyCap2 Program. FlyCapture API examples are provided for C, C++, C#, and VB.NET languages. The package is compatible with both Microsoft Windows and Linux Ubuntu, and supports the ActiveX, DirectShow and TWAIN APIs. The software can be downloaded by logging in here.

In our project, we are using the FlyCap2 demo program from the FlyCapture SDK to acquire images and videos. The FlyCap2 application is a streaming image viewer that allows you to view a live video stream from the camera, save individual images, adjust the various video formats, frame rates, properties and settings of the camera, and access camera registers directly. FlyCap has two primary interfaces - the **Main Window** and the **Camera Control Window**. The main window allows users to view live video stream, save individual images and get information of the captured images such as, time-stamp, mode, resolution, etc. Some of the functions of the camera control windows are setting various camera parameters, viewing information about the selected camera, handling software/external triggers, etc.

To run FlyCap from the **Start menu**, select **Program Files>FlyCapture2 SDK>FlyCap2**. The **Camera Selection** window opens. This window lists all the currently connected cameras, across all buses, and allows the users to select any camera from the list.

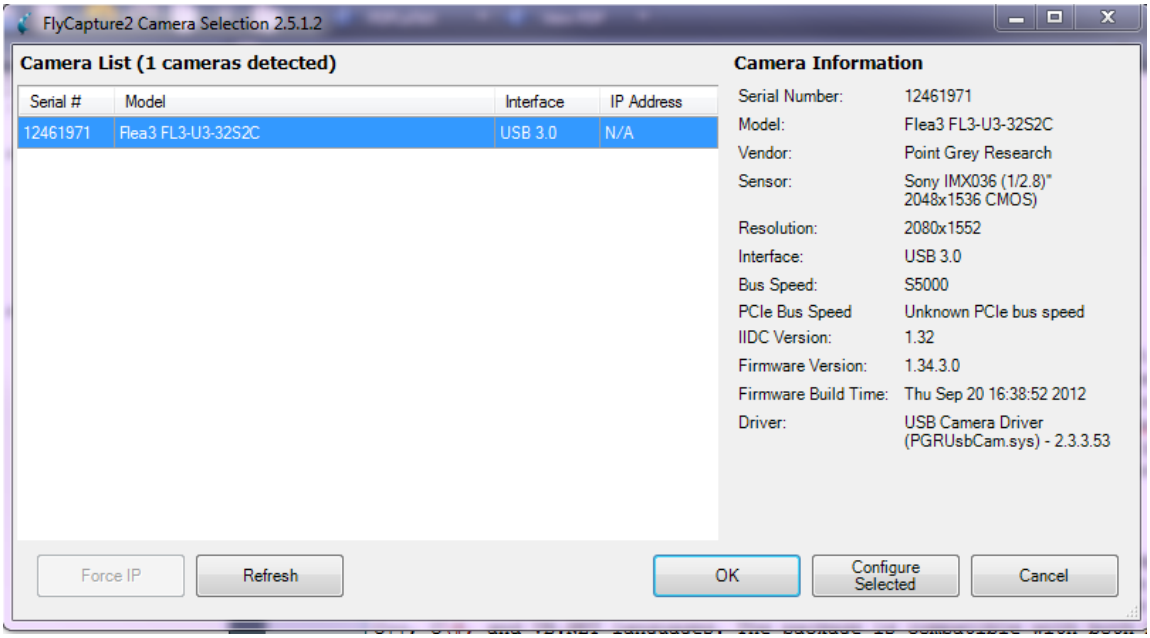

Figure 16

One can start grabbing images by selecting a camera and clicking **OK**. The FlyCap **Main Window** opens. One can also open multiple instances of the FlyCap Main Window to grab images from multiple cameras simultaneously. However, the number of active cameras is limited by the bandwidth of the bus. Users can also select a camera and click **Configure Selected** to access **camera Control** window prior to grabbing images.

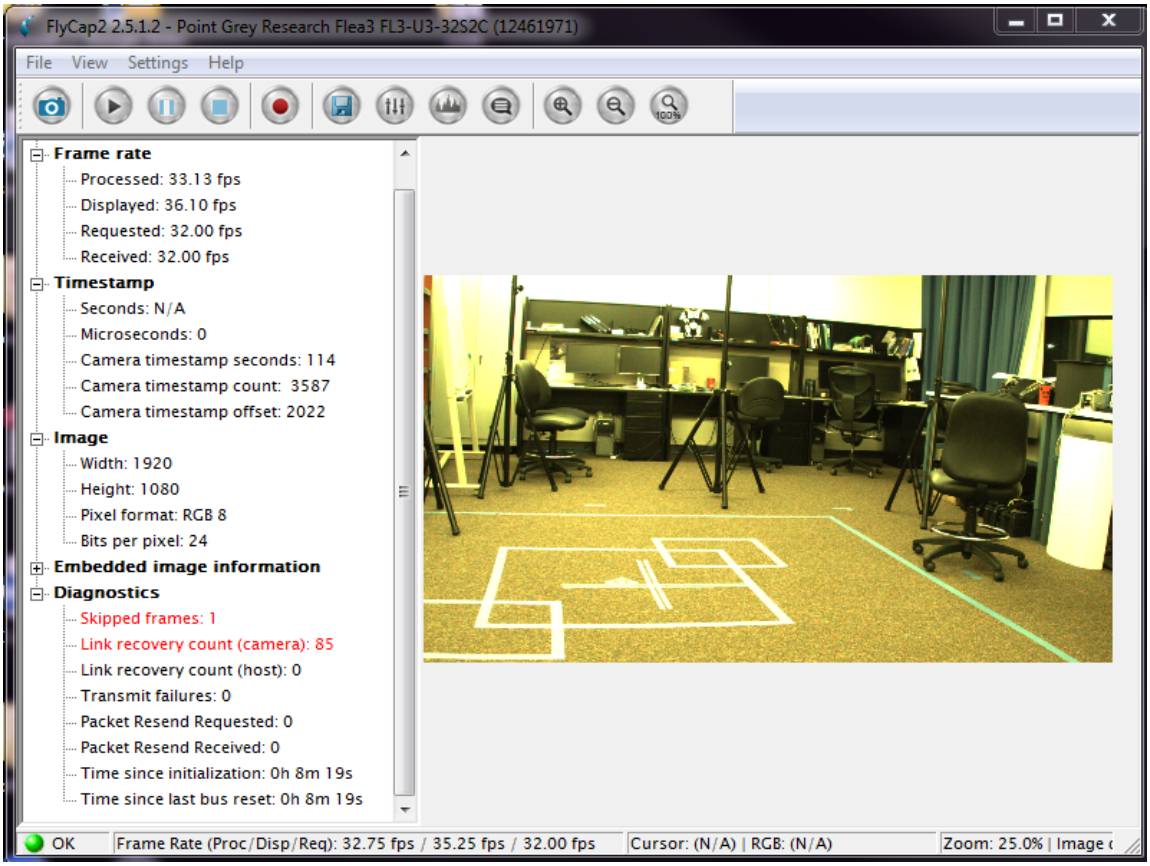

Figure 17

The **Main Window** has the following components -

1. Title Bar - Displays camera model and serial number.
2. Menu Bar - Displays **file**, **view**, **settings** and **help**.

File	• **New Camera**: (Ctrl+N) Stops the current camera and opens the Camera Selection Dialog. • **Start image transfer**: Re-starts the camera after it has been stopped. • **Stop image transfer**: Stops the camera. • **Save As**: (Ctrl+S) Opens a dialog to save the current image. For more information, see Recording Video and Saving Images. • **Capture Video or Image Sequence**: (F9) Opens a dialog for recording video or image sequences. • **Exit:**(Ctrl+Q) Closes FlyCapture.
View	• **Graphic Mode** – Three choices: ○ **GDI**: If selected, images are rendered to screen using the Windows Graphics Device Interface (GDI). ○ **OpenGL**: If selected, images are rendered to screen using the Open Graphics Library (OpenGL) interface. Using OpenGL on supported systems may improve rendering performance. However, in some cases OpenGL may interact poorly with other system processes and produce unexpected behavior. ○ **Direct 2D**: This is available on Windows 7 only. If selected, images are rendered to screen using Direct 2D. If using Direct 2D and the FlyCap example program, you must use the Visual Studio 2010 version found at: FlyCapture2 SDK/Examples/C++ Examples/VS2010 Solutions/FlyCap2.sln • **Draw Image**: When selected, allows image streaming. When unselected, pauses streaming. • **Draw Crosshair**: (F7) If **Draw Image** is selected, inserts a crosshair in the center of the image pane. • **Change Crosshair Color**: Opens the **Color Selection**dialog to change the crosshair color. • **Show Toolbar**: (F8) If selected, displays the Toolbar. See below for more information. • **Show Information Panel**: (F11) If selected, displays the Information Panel. See below for more information. • **Show Status Bar**: If selected, displays the Status Bar. See below for more information. • **Stretch To Fit** If selected, adjusts the image dimensions to fit the size of the current window. This setting does not affect the resolution or size of any saved images. • **Fullscreen**: (F12) Changes the size of the FlyCap Main Window to fit the entire screen.
Settings	• **Color Processing Algorithm**: Sets the color processing algorithm used to interpolate raw Bayer-tile images into full color. For more information about color processing algorithms, refer to Knowledge Base Article 33. • **Toggle Camera Control Dialog**: Opens or shifts focus to the Camera Control Dialog.
Help	Displays **About FlyCapture2** ; or opens the **Online Help**.

Figure 18: Menu Bar

3. Tool Bar - Displays buttons to performs functions like choosing new camera, stopping camera, saving images,etc.

	Choose new camera - stops the current camera and opens the Camera Selection Dialog.
	Re-starts the camera after it has been stopped.
	Stops the camera.
	Opens a dialog for recording video or image sequences.
	Saves the current image. For more information, see Recording Video and Saving Images.
	Opens the Camera Control dialog.
	Opens the FlyCapture Histogram dialog. This dialog provides statistical information about the representation of values in the current image, including grey, red, green and blue channel values, hue, saturation and lightness. Only greyscale values are represented on monochrome cameras, or color cameras streaming in a monochrome format.
	Opens the Event Statistics dialog.
	Zooms in and out on the image display, or restores to 100%.

Figure 19: Tool Bar

4. Information Pane - Displays information about the frames received.
5. Status Bar - Displays the frame rate, cursor position, etc.

In this document, we have mentioned some **Camera Control** functions which have been used

extensively in our experiment. Firstly, **Camera Settings** allow users to adjust image acquisition settings, such as shutter, gain, brightness, exposure, white balance and others.

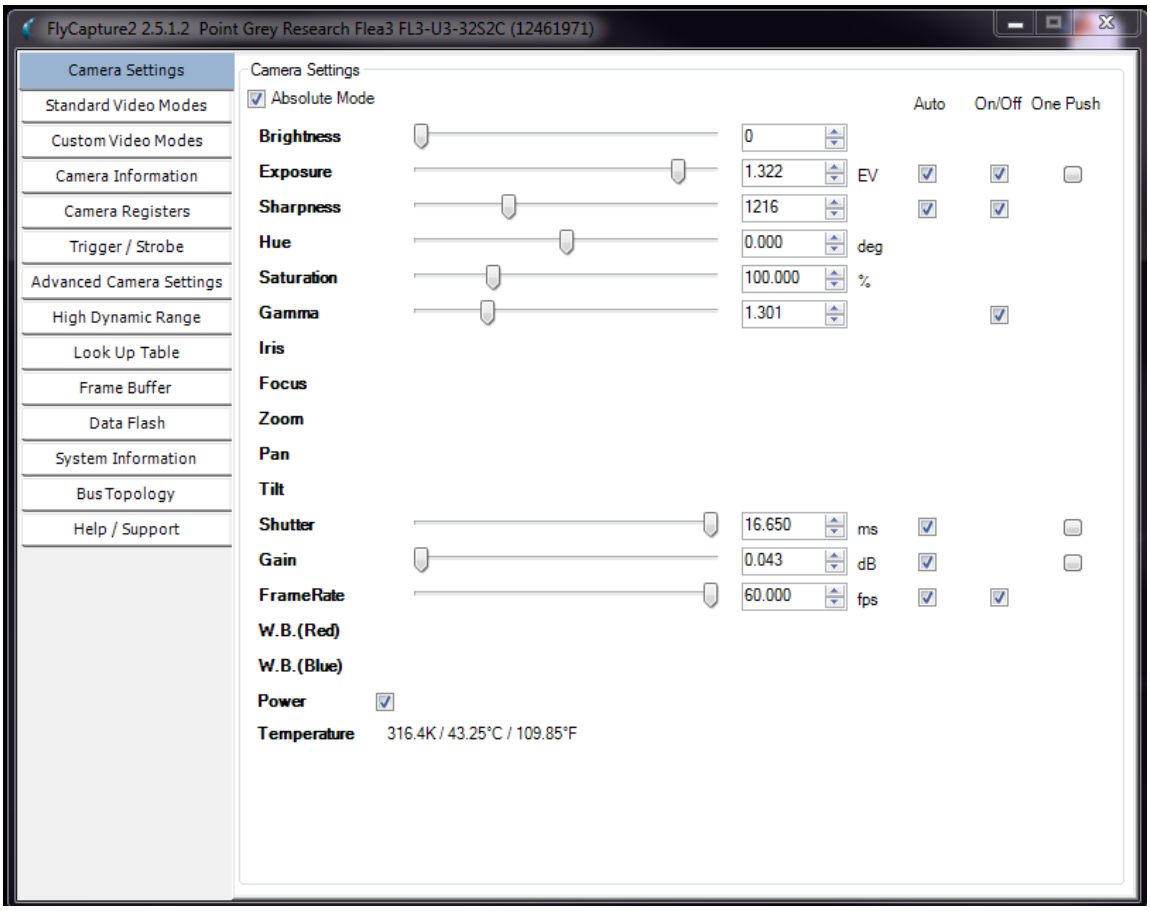

Figure 20

Standard Video Modes set standard pixel formats, resolutions, and frame rates, whereas, **Custom Video Modes** set custom image modes and modes for GigE Vision cameras.

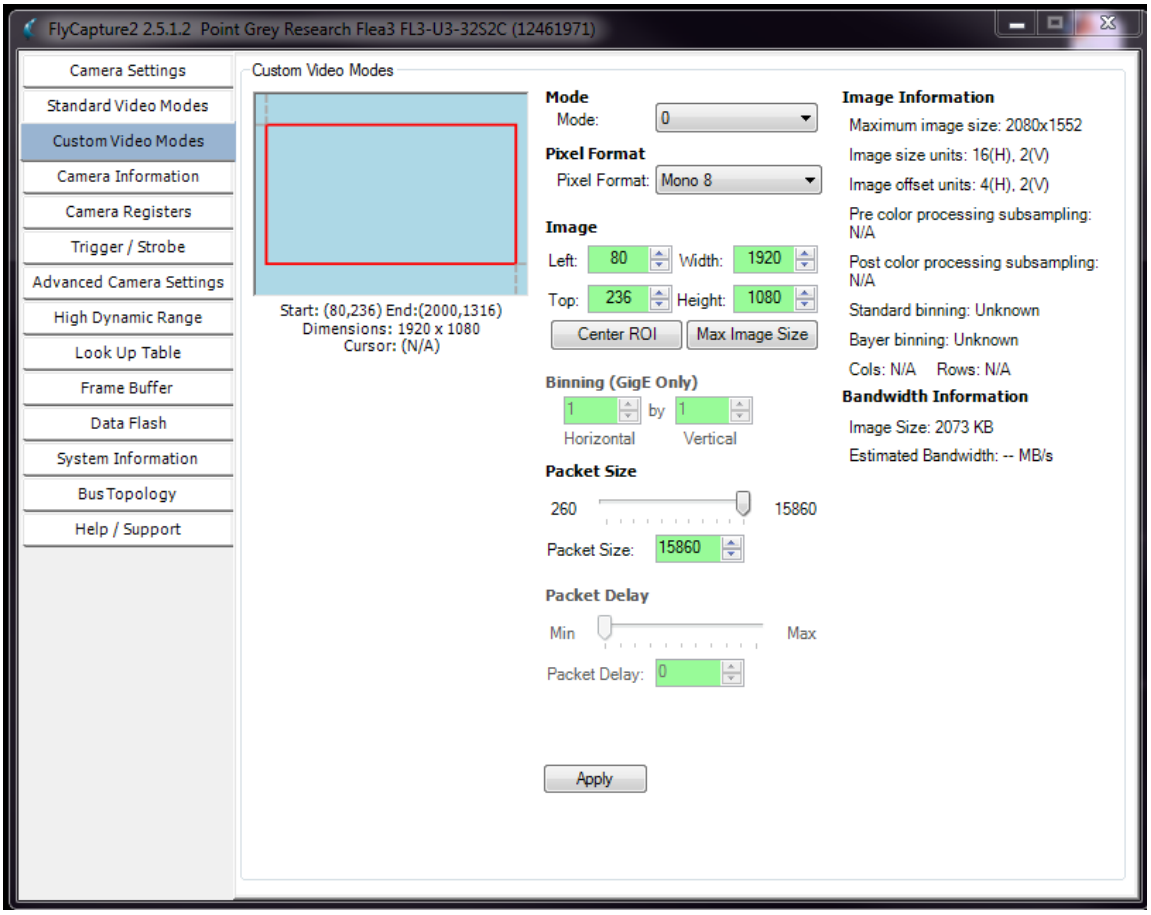

Figure 21

The **Trigger/Strobe** control dialog provides control over the general purpose input/output (GPIO) capabilities of the camera. In our experiment, we have used the trigger control dialogue extensively to synchronize image acquisition from our stereo set-up. When the **Enable/disable Trigger** box is checked, it allows the camera to respond to external triggers, or that an internal (software) trigger can fire. When unchecked, external trigger functionality is off, and only output (strobe) functionality is supported.

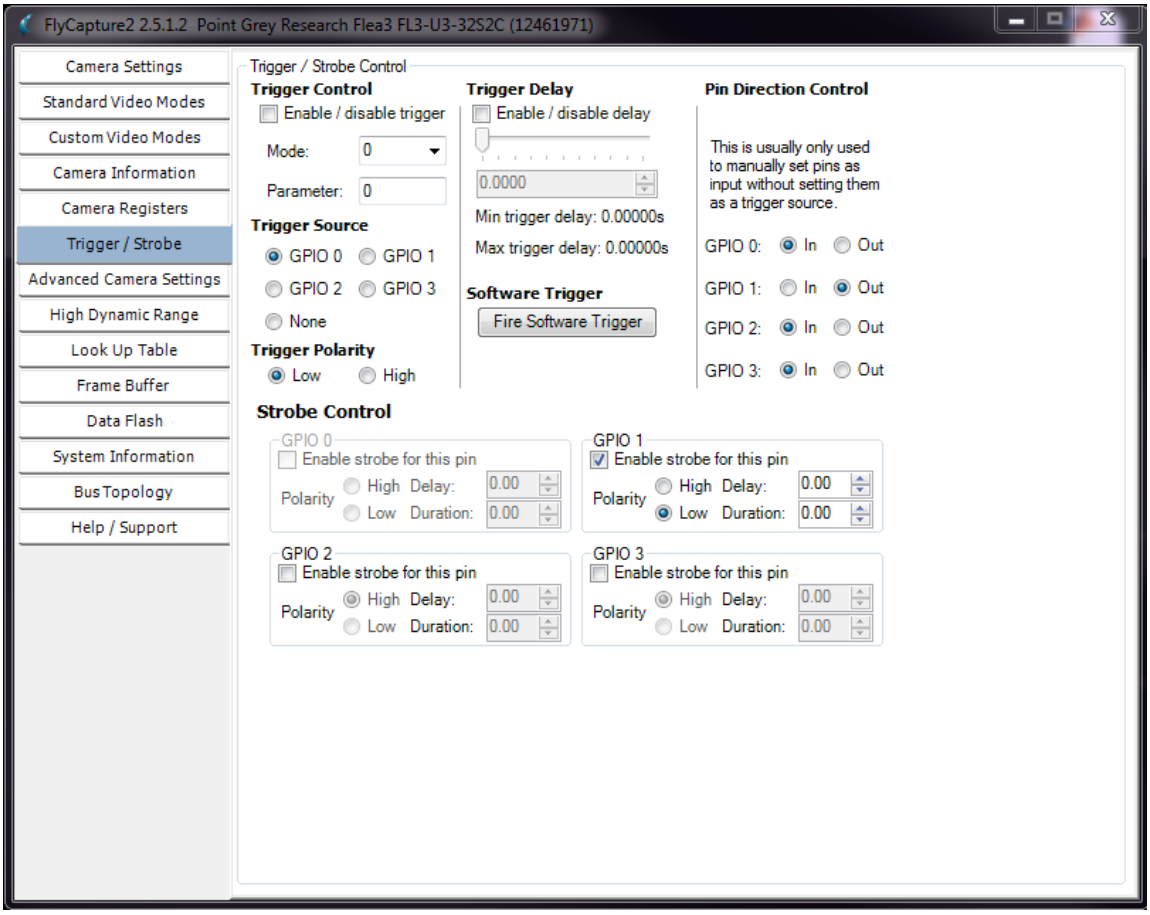

Figure 22

There are several other functions of the FlyCap2 API. Please refer to the **FlyCapture2SDKHelp.chm** folder, provided in the ExtraDocs folder of Step01 for a detailed information.