

1.1. Subject

Overview of the Ladybug image stitching process

1.2. Applicable Product(s)

- Ladybug2 and Ladybug3 Spherical Vision cameras

1.3. Application Note Description

The purposes of this Technical Application Note are to:

- Explain how the Ladybug API creates a single panoramic image from six separate raw images that are output from a Ladybug2 or Ladybug3 camera.
- Explain why stitching is an imperfect process and how to work with stitching errors

1.4. Overview

The following diagram provides a high-level overview of the steps required to produce a panoramic image from Ladybug raw image output. The table below briefly explains the steps. The sections that follow explain the *Color Processing* and *Stitching* steps in more detail. The final section explains stitching errors and how to work with them.

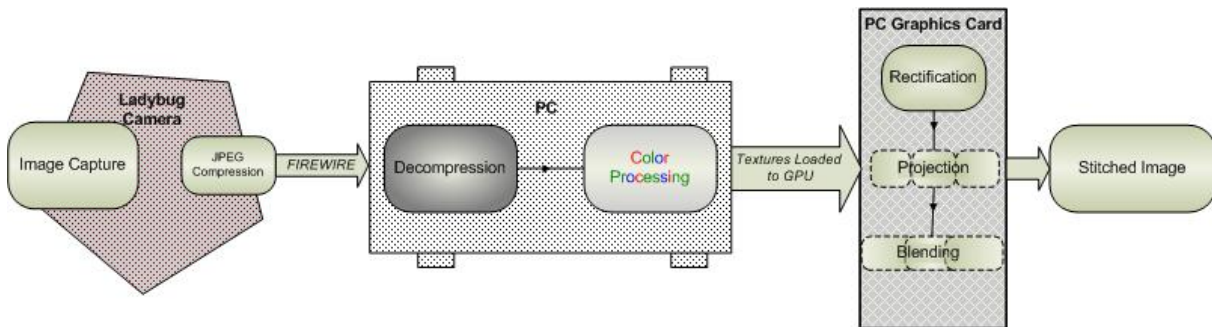


Figure 1: Ladybug Panoramic Imaging Process

Imaging Step	Description
Image Capture	Separate images are captured synchronously from each of the camera's six sensors and undergo image processing, including analog-to-digital conversion to raw (Bayer-tiled) format, gain, auto-exposure and white balance.
JPEG Compression	JPEG compression is optional. The purpose of this option is to allow for images to be transferred to the PC at a faster frame rate. If compression is disabled, the camera will transmit uncompressed images. If compression is enabled, each image is converted into JPEG compressed format before transmission. Images are transmitted to the PC via the FireWire cable.
Decompression	Images are decoded back into raw image format for further processing.
Color Processing	The raw Bayer-tiled images are interpolated to create a full array of RGB images. Following color processing, images are loaded onto the graphics card of the PC for rectification, blending and stitching.
Rectification	Rectification corrects the barrel distortion caused by the Ladybug lenses.
Projection	Image textures are mapped to a single 2- or 3-dimensional coordinate system, depending on the projection that is specified.
Blending	Pixel values in each image that overlap with the fields of adjacent images are adjusted to minimize the effect of pronounced borders. The result is a single, stitched image.

Table 1: Ladybug Imaging Process Steps

1.5. Color Processing

After raw (Bayer-tiled) images are received from the camera, and decompressed if necessary, they are processed into RGB images using one of the color interpolation methods specified. Most of the color processing algorithms available in the Ladybug API are explained in [Knowledge Base Article 33](#). An additional algorithm, "down sampling," scales the textures of each image to half their size in dimension (and quarter-size in data), making it the fastest of all the algorithms. However, due to the nature of scaling down, image resolution is reduced.

Also during color processing, an alpha mask value is assigned to each pixel of each image. This value represents the opaqueness of the pixel and is used in the blending stage. Alpha mask values, in turn, are computed based on the *Blending Width* value that is specified when the application is first started. This value specifies the pixel width on the border of each image within which blending should take place. Alpha mask values for each image are saved as .pgm files in the \Point Grey Research\PGR Ladybug\bin directory. Adjusting the blending width after an application starts results in the creation of new alpha mask files, which can take some time, depending on the configuration of your PC.

Finally, falloff correction, if specified, is applied to the RGB image to compensate for the vignetting effect of the lenses. Vignetting refers to the boundary area of each image appearing dark relative to the center of the image, creating a shadow effect in the stitched image.

The six RGB-textured images are then transferred to the PC graphics card for stitching.

Related Ladybug API functions

```
ladybugConvertToMultipleBGRU32
ladybugGetColorProcessingMethod
ladybugSetColorProcessingMethod
ladybugSetAlphaMasking
ladybugInitializeAlphaMasks
ladybugSetAlphaMaskPathname
ladybugLoadAlphaMasks
```

1.6. Stitching

The PC graphics card maps the image textures onto polygon meshes. A polygon mesh is a projection of image textures onto polygons whose geometric vertices are arranged in a 2-dimensional or 3-dimensional coordinate system. If the application specifies a spherical view, the polygons are arranged in 3-dimensional coordinates. If the application specifies a panoramic or dome projection, the polygons are arranged in 2-dimensional coordinates.

The following figures are examples of polygon meshes. The first figure is a 2-dimensional mesh. The second figure is a 3-dimensional mesh (for clarity, only five of the six images are shown).

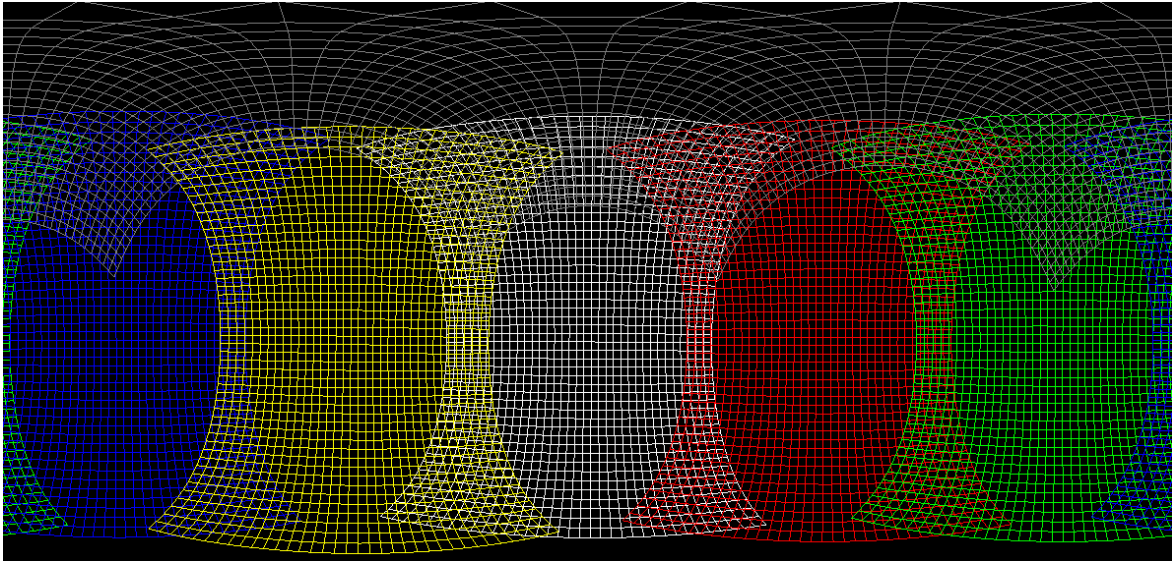


Figure 2: 2-D Polygon Mesh

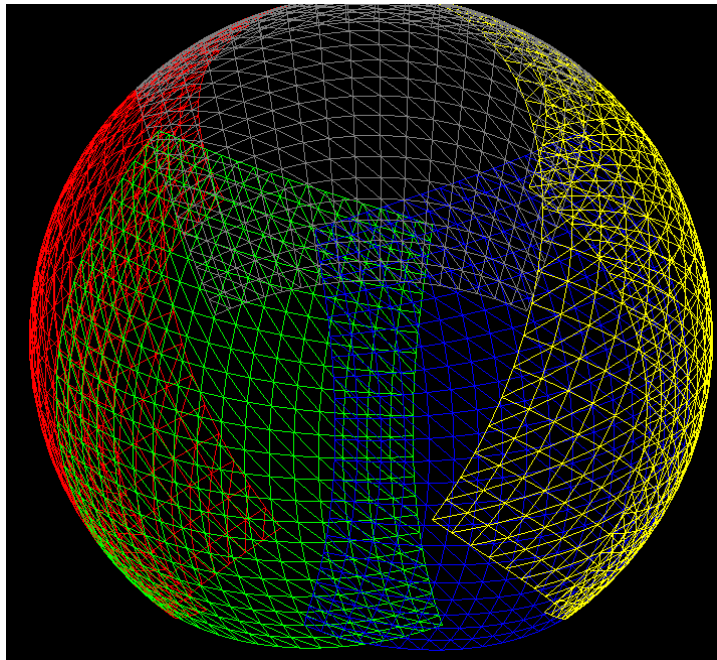


Figure 3: 3-D Polygon Mesh

The coordinates of the polygon meshes are calculated based on calibration data, which specifies how to rectify, rotate and translate images. Because the textures also reflect the alpha values in each pixel, blending from one image to the neighboring image appears smooth. The result is that by transferring image textures to the graphics card, a single, stitched image is produced without consuming any CPU resources.

Related Ladybug API Functions

Stitching is controlled in the Ladybug API by using functions defined in `ladybugrenderer.h`.

1.7. Understanding Stitching Errors

1.7.1. Stitching, Parallax and Calibration Distance

Mapping image textures to polygon meshes means that Ladybug stitching is performed completely based on geometry. There is no use of image content for the purpose of better-looking panoramas. (Methods have been developed that create panoramic images by matching image content. These methods usually generate better results, but are very computationally intensive and cannot be performed in real time.) As a result, Ladybug stitching is not perfect.

Firstly, the various images that are combined into the panorama are not obtained from exactly the same viewpoint, but from slightly offset viewpoints caused by the physical separation of the individual camera lenses. This effect is known as parallax.

Second, in order to perfectly stitch images together, a range to the physical scene is required. However, since the Ladybug does not do range estimation, we do not have this value. To remove this unknown, we assume all points in the scene are at the same radius from the camera, effectively forcing the real world onto a sphere surrounding the camera. Current Ladybug2 and Ladybug3 cameras are calibrated using a sphere radius of 20 meters. When the true range is different from the sphere radius, a stitching error results. This error depends upon the separation of the lenses, the sphere radius and the true range. For ranges from 10 meters to infinity, a 20-meter sphere generally results in a parallax error less than 1 pixel in width, and therefore it is a good radius selection for most outdoor scenes.

Stitching errors manifest themselves as a 'double image' or 'image offset' effect on the border areas between images. Typically, these errors are most noticeable on objects that are very close to the camera. For example, a 'double image' effect can be seen in the following picture:



Figure 4: Image Offset Stitching Error

Before July 2006, Ladybug2 cameras were calibrated with a sphere of 5 meters. The change to 20 meters was based on the high amount of outdoor use for these cameras. Any concerns about the sphere radius on your camera should be forwarded to the Point Grey Research support team.

Slight errors in camera calibration can also contribute to stitching errors.

1.7.1.1. Calculating Stitching Error

You can use the following equation to determine the pixel width within which a stitching error will occur, given the distance between the camera and the subject:

$$stitching_error(pixels) = \left| \frac{1}{Z} - \frac{1}{Z_c} \right| K$$

Where:

Z = distance to an object (m)

Z_c = calibration distance (m)

K = A constant value determined by the distance between the adjacent camera lenses, focal length and the number of pixels on the sensor. For the side cameras on the Ladybug2, K is approximately 22. For the Ladybug3, K is approximately 45.

For example, if the calibration distance is 20 meters, the stitching error that results when an object is an infinite distance from a Ladybug3 camera is 2.2 pixels.

1.7.2. Stitching and Blending Width

When stitching errors occur, a high blending width value generally results in a more pronounced 'double image' effect. A low blending width value, in the presence of stitching errors, generally results

in a more pronounced 'image offset' effect. When there are no stitching errors—indicating the scene and calibration distance are well-matched—the blending width value has little impact.

In the following series, blending widths of 0, 20, and 100 are applied on images of a nearby subject—approximately three meters from the camera. In the first image, a blending width of 0 renders the border between the stitched images very obvious, which, in turn, makes the offset effect more pronounced. In the second image, a blending width of 20 is specified. This setting still produces an offset error, but it is mitigated somewhat by the blending effect. The third figure specifies a blending width of 100. This setting enhances the offset error, resulting in a 'double image' effect.



Figure 5: Blending Width=0



Figure 6: Blending Width=20



Figure 7: Blending Width=100

So, when capturing nearby objects, there is a trade-off between blending width and the stitching error effect that you are willing to tolerate in your image. But when capturing distant objects, no parallax-related stitching errors occur, and therefore there is no tradeoff. As seen in the following series of images taken of the sky at blending widths of 0, 20, and 100, the maximum blending width of 100—which is the camera's default—is clearly the best choice.



Figure 8: Blending Width=0



Figure 9: Blending Width=20



Figure 10: Blending Width=100

Related Ladybug API Functions

```
ladybugSetBlendingParams  
ladybugGetBlendingParams
```

1.7.3. Stitching and Vignetting

As discussed above, vignetting happens when the boundary area of each image appears dark relative to the center of the image, creating a shadow effect in the stitched image. If you enable falloff correction, the brightness of each image is adjusted so that equally-lit images appear flat in brightness. The side effects of falloff correction are slower processing time due to additional computation, and an amplification of noise in the image.

The following images show the effect of falloff correction. In the first image, falloff correction is disabled; in the second image, falloff correction is enabled.



Figure 11: Falloff Correction Off



Figure 12: Falloff Correction On

Related Ladybug API Functions

```
ladybugSetFalloffCorrectionFlag  
ladybugGetCorrectionAttenuation  
ladybugSetCorrectionAttenuation
```

1.8. Related Knowledge Base Articles

Article	Title	Address
33	Different Color Processing Algorithms	http://www.ptgrey.com/support/kb/index.asp?a=4&q=33
222	How does changing the compression level affect the quality of Ladybug2 images?	http://www.ptgrey.com/support/kb/index.asp?a=4&q=222
227	How does the Ladybug2 rectification process work?	http://www.ptgrey.com/support/kb/index.asp?a=4&q=227
250	Overview of the Ladybug image stitching process	http://www.ptgrey.com/support/kb/index.asp?a=4&q=250
251	Improved calibration process for Ladybug cameras	http://www.ptgrey.com/support/kb/index.asp?a=4&q=251

1.9. Additional Downloads and Support

Access more Technical Application Notes on the web at www.ptgrey.com/support/downloads.

Point Grey Research Inc. endeavors to provide the highest level of technical support possible to our customers. Most support resources can be accessed through the Product Support section of our website: www.ptgrey.com/support.

Creating a Customer Login Account

The first step in accessing our technical support resources is to obtain a Customer Login Account. This requires a valid name, e-mail address, and camera serial number. To apply for a Customer Login Account go to www.ptgrey.com/support/downloads/.

Knowledge Base

Our on-line knowledge base at www.ptgrey.com/support/kb/ contains answers to some of the most common support questions. It is constantly updated, expanded, and refined to ensure that our customers have access to the latest information.

Product Downloads

Customers with a Customer Login Account can access the latest software and firmware for their cameras from our downloads site at www.ptgrey.com/support/downloads. We encourage our customers to keep their software and firmware up-to-date by downloading and installing the latest versions.

Contacting Technical Support

Before contacting Technical Support, have you:

1. *Read the product documentation and user manual?*
2. *Searched the Knowledge Base?*
3. *Downloaded and installed the latest version of software and/or firmware?*

If you have done all the above and still can't find an answer to your question, contact our Technical Support team at www.ptgrey.com/support/contact/.