Stereo Accuracy and Error Modeling

Technical Application Note TAN2004006
Revised August 30, 2012

1.1 Subject

Technical Application Note (TAN2004006): Stereo Accuracy and Error Modeling

1.2 Applicable Product(s)

- Stereo Vision Cameras

1.3 Application Note Description

The objective of this document is to give a reasonable approximation of stereo errors in 3D and to outline the methods customers can use to determine the tolerances themselves.

1.4 Stereo Errors, Validation, and Accuracy

There are two kinds of stereo errors: mismatch and estimation. Mismatch is where the disparity is just wrong. Estimation errors are where the correlation match was correct but there are some errors in estimating the position of the subpixel disparity value.

The purpose of validation is to remove mismatch errors only. We recommend the use of Texture Validation and Surface Validation as the most effective combination. In general, the default values for these validation methods will work well. Validation does not affect the accuracy of the valid stereo disparity pixels. It only throws out ones that it believes to be mismatch errors.

1.4.1 Stereo Accuracy – Numbers

The short answer: Larger stereo masks provide better accuracy but more smoothing of the 3D surface – mask size 11 is a good compromise mask size.

We have conducted an experiment to test the magnitude of stereo estimation errors. The results are summarized in Tables 1 and 2 below. The results indicate the standard deviation of the disparity matching for estimation errors.

The numbers are in pixels. For example, using stereo mask 11, edge mask 9 with 320 x 240 resolution images, the standard deviation on disparity values was 0.11 pixels. Since 2 standard deviations

should capture 95% of a Gaussian probability distribution, one can think of this as approximately ±0.22 pixels.

Table 1: Correlation accuracy results—Stereo Mask 11, Edge Mask 9

Resolution	Correlation Accuracy
160 x 120	0.10 pixels
320 x 240	0.11 pixels
640 x 480	0.10 pixels

Table 2: Correlation accuracy results for 320 x 240 resolutions—Range of mask sizes (edge mask was always set at *stereo$_m$ask* – 2)

Stereo Mask	Correlation Accuracy
5	0.18 pixels
7	0.18 pixels
9	0.14 pixels
11	0.11 pixels
13	0.10 pixels
15	0.10 pixels

1.4.2 Calculating the 3D Point Errors

We model our 3D stereo error on two parameters: the calibration error (*p* for "pointing error") and the correlation error (*m* for "matching error"). Calibration accuracy, *p*, can be requested from Point Grey Research for your camera by contacting Support, although almost all 640 x 480 cameras have a value of *p* between 0.06 and 0.08, and all 1024 x 768 cameras have a value of between 0.1 and 0.15. This value is for the maximum resolution of the camera. It should be divided by the reduction in resolution if the stereo is not being done at full resolution. (Example a 640 × 480 camera at 640 × 480 resolution would use *p* as given by PGR. For stereo at 320 × 240 you would use *p*/2).

Correlation accuracy, *m*, can be estimated from Tables 1 and 2.

The equations controlling XYZ determination are:

$$\frac{u}{f} = \frac{x}{z}; \quad \frac{v}{f} = \frac{y}{z}; \quad \frac{z}{f} = \frac{B}{d}$$

where *d* is disparity, (*u*, *v*) is the pixel position in the image relative to the image centre (i.e., *u* = *col* – *centreCol*, *v* = *row* = *centreRow*), *B* is the stereo baseline and *f* is the focal length. These are the equations implemented in the triclopsRCDToXYZ() family of functions.

For a given result of triclopsRCDToXYZ, you obtain (*x*, *y*, *z*). The tolerance in (*x*, *y*) are determined by the calibration error *p*. These are quite simple:

$$\Delta x = \frac{pz}{f}$$
$$\Delta y = \frac{pz}{f}$$

The accuracy in *z* is a little more complicated:

$$\frac{\partial z}{\partial d} = -\frac{fB}{d^2}$$

Substituting $\frac{fB}{z}$ for *d* we get:

$$\partial z = \frac{-z^2}{fB}\partial d$$

or

$$\partial \mathrm{z} = \frac{-z^2}{fB} m$$

since *m* is the uncertainty in disparity. Hence for a given expected error of *p* and *m* we can calculate the errors in (*x*, *y*, *z*).

As an example, say we have the following 3D point from stereo done at 320 × 240 with enhanced stereo and enhanced rectification. Typical results for a 4 mm camera would be:

$$\begin{aligned} p &= 0.04 \\ m &= 0.05 \\ f &= 250 \\ B &= 0.10 \\ d &= 20 \\ (x, y, z) &= (1.0, 0.5, 1.25) \end{aligned}$$

Then

$$\Delta x = \frac{(0.04)(1.25)}{250} = 0.002$$

$$\Delta y = \frac{(0.04)(1.25)}{250} = 0.002$$

$$\Delta z = \frac{1.25^2}{(250)(0.10)} 0.05 = 0.003$$

If *p* and *m* are a single standard deviation of error in the pointing and matching error distributions, then we can reasonably double these values, as two standard deviations cover 95% of an expected distribution. Consequently:

$$\begin{aligned} \Delta x &= \pm 0.4 \text{ mm} \\ \Delta y &= \pm 0.4 \text{ mm} \\ \Delta z &= \pm 6 \text{ mm} \end{aligned}$$

1.4.3 Your Mileage May Vary

These numbers are for a Color 640 × 480 4mm Digiclops camera. They give an indication of the magnitude of errors one can expect, but special circumstances such as different optics and different scenes will change the nature of the errors one experiences.

1.5 Additional Downloads and Support

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 Support section of our website.

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 and email address. To apply for a Customer Login Account go to the Downloads page.

Knowledge Base

Our Knowledge Base 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 page. 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.

