

APPLICATION NOTE



```
// Create an instant camera object with the first
Camera_t camera(CTlFactory::GetInstance().Create

// Register an image event handler that accesses
camera.RegisterImageEventHandler(new CSampleImage
Ownership_TakeOwnership);

// Open the camera.
camera.Open();
```

Merging Color Data of Basler 2D Cameras with Basler blaze Depth Data

Applicable to 2D color cameras and blaze cameras only

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Table of Contents

1	Introduction	2
2	Technical Setup	3
2.1	Selection and Assembly of Components	3
2.2	Sample System Setup	4
2.3	Software Installation	5
3	Displaying the Color Point Cloud	7
3.1	Calibration	7
3.2	Data Fusion: Overlaying 3D Points with Color Data	11
4	Conclusion	12
5	Further Reading	12

1 Introduction

This document describes how to use a Basler 2D color area scan camera and a Basler blaze 3D ToF camera to create a joint camera system that will allow you to combine the RGB color data of the 2D color camera with the depth data of the blaze camera. The result of such an operation, also known as data fusion, is shown in Figure 1. It shows a point cloud of the blaze camera where the right half has been colorized using the 2D camera's color data.

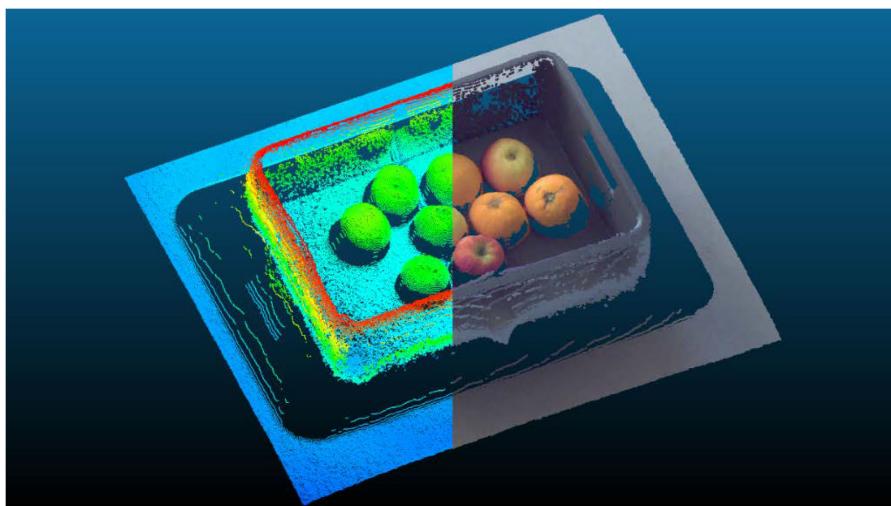


Figure 1: Point Cloud of the Basler blaze Colorized Using the Basler 2D Camera RGB Color Data

The Basler blaze provides 3D point clouds in real time. The point cloud represents the surface of an object as seen by the camera. In addition, the camera provides an infrared intensity image of the scene. For a large number of applications, this data is already sufficient. In some applications, however, it may be desirable to have additional high-resolution color data. For example, the appearance of objects under infrared lighting can differ from their appearance in visible light. It's also easier to analyze fine structures such as bar codes or labels in a higher-resolution color image. In addition, the neural networks used in machine learning are usually trained on color data in the visible range.

Use cases affected by these challenges may benefit from the data fusion techniques described in this document. Data fusion allows the merging of data from the point cloud of a Basler blaze camera with the RGB data from a 2D color camera with the aim of forming a single, combined data set. Adding high-resolution 2D images to 3D applications can improve pattern recognition or object detection algorithms.

The pylon Supplementary Package for blaze contains sample programs that demonstrate how to calibrate the joint camera system, how to perform the data fusion, and how to display the data stream in real-time. The sample programs use the open-source libraries OpenCV and Point Cloud Library for calibration, data fusion, and display.

2 Technical Setup

2.1 Selection and Assembly of Components

There are several aspects to consider when selecting components for the system.

- Positioning of the cameras

The data from the color camera is transformed into the coordinate system of the blaze camera. This works best if the optical axes of the cameras are aligned and they are as close to each other as possible.

- Resolution of the 2D color camera

The resolution of the 2D color camera should be at least the same as that of the blaze camera, preferably even higher. Basler recommends choosing a camera with at least 4 times the resolution of the blaze, i.e., 1.2 MP, to benefit from the higher-resolution color image.

- Field of view

The field of view of the 2D color camera should match that of the blaze camera, which is 67° x 51°. However, Basler recommends choosing a lens for the 2D color camera with a field of view about 5 % larger than that of the blaze. This ensures that color information is available for all points of the point cloud even if the positioning of the cameras isn't perfect.

To achieve the best possible match of the cameras' fields of view and to reduce occlusion, Basler recommends placing the 2D color camera as close as possible to the blaze's lens. This means installing it on the right-hand side of the blaze. To join the two cameras, a mounting bracket is required. This will ensure that the positioning of the cameras won't change during use.

2.2 Sample System Setup

This application note is based on a sample system that meets the above requirements. The components used for this are listed in Table 1. Basler offers a mounting bracket (as a bundle including various screws for installation as well as a heat sink) that has been designed specifically to join the ace camera to the blaze camera with optimum alignment of the optical axes and minimal distance between the cameras. Figure 2 shows an image of the assembled system (without the heat sink).



Basler strongly recommends using the heat sink included in the bundle if you use an ace 2 camera in your setup as this camera heats up significantly during operation and excessive temperatures will impair the accuracy of any distance measurements.

Description	Order Number
Camera, Basler blaze-101	107796
Camera, Basler acA1300-75gc	106757
Lens, Basler Lens C125-0418-5M-P f4mm	2000034830
Mounting Bracket Bundle	2200001176

Table 1: Materials Required for the Assembly of the Sample Camera System

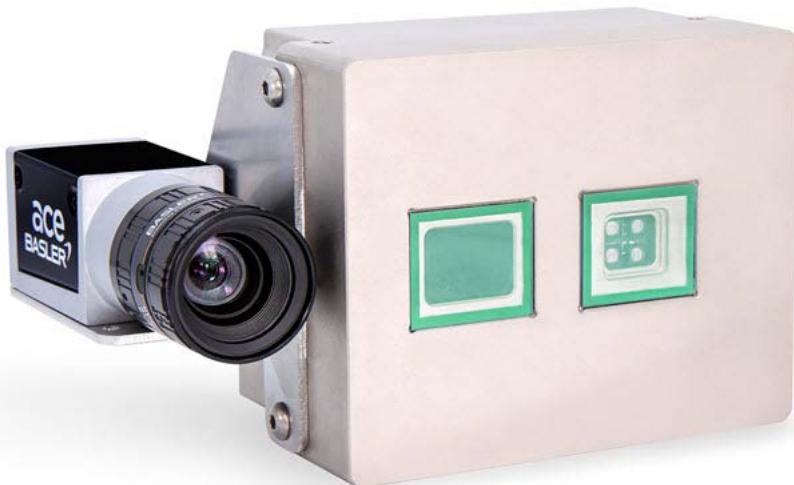


Figure 2: Assembled Sample Camera System

2.3 Software Installation

To run the sample program, a computer with Windows or Linux operating system is required. The camera assembly can be connected to the computer directly or via a switch. The following software components must be installed:

- pylon Camera Software Suite (version 6.2 or higher)
You can download the software from the Basler [website](#).
- pylon Supplementary Package for blaze
You can download the software from the Basler [website](#).
- OpenCV
For more information, visit <https://opencv.org/>.
- PointCloudLibrary (PCL) (Optional: Required only for visualization)
For more information, visit <http://pointclouds.org/>.

For information how to install the pylon Camera Software Suite and the pylon Supplementary Package for blaze, visit docs.baslerweb.com.

The pylon Supplementary Package for blaze includes the *C++ Programmer's Guide* with instructions for compiling and running the samples. For calibration and data fusion, use the following sample programs in the **Samples\blaze\cpp\MultiCam\ColorAndDepth** folder:

- **Calibration** sample: This illustrates how to calibrate a system consisting of a Basler GigE color camera and a Basler blaze camera. It can be used to generate the calibration information and intrinsic camera parameters that are required for running the **ColorAndDepthFusion** and **RgbdCamera** samples. The calibration information is stored in the **CalibrationData** folder.
- **ColorAndDepthFusion** sample: This illustrates how to merge color data acquired from a Basler GigE color camera and depth data acquired from a Basler blaze camera. In this sample, the cameras are triggered using software triggers. With software triggers you can't achieve the maximum possible frame rate and the two cameras won't be triggered exactly simultaneously. It requires the information about the relative positions of the cameras to each other that is produced by the **Calibration** sample.
- **RgbdCamera** sample: This is an alternative to the **ColorAndDepthFusion** sample. In this sample, the cameras are triggered using the PTP (IEEE 1588 protocol) and Synchronous Free Run feature to run the cameras synchronously.
Prerequisites for using the sample are a color camera that supports PTP and the Synchronous Free Run feature and a network configuration where both cameras are connected to the same network interface via a network switch. Part of the sample is the **RgbdCamera** class that is intended for RGB-D camera setups where synchronizing the cameras using the Synchronous Free Run feature is possible. The **RgbdCamera** class matches related 2D and 3D data by using timestamps and delivers combined depth and color data sets.
It requires the information about the relative positions of the cameras to each other that is produced by the **Calibration** sample.

In addition, sample scripts for calibration and data fusion written in Python are available in the **Samples\blaze\Python\ColorAndDepthFusion** folder. The **calibration.py** script demonstrates the calibration of a system consisting of a Basler GigE color camera and a Basler blaze camera. The **fusion.py** script uses the calibration information and the color camera data to display a colored point cloud.



For more information about PTP clock synchronization and the Synchronous Free Run feature in Basler cameras, visit [docs.baslerweb.com/synchronous-free-run-\(blaze\)](https://docs.baslerweb.com/synchronous-free-run-(blaze)) and [docs.baslerweb.com/precision-time-protocol-\(blaze\)](https://docs.baslerweb.com/precision-time-protocol-(blaze)).

3 Displaying the Color Point Cloud

The fusion of depth and color information by means of the projective geometry is based on the pinhole camera model. Here, the depth data is projected into the coordinate system of the 2D color camera using the intrinsic and extrinsic parameters. The relationship obtained in this process can be used to merge the data. Because the 2D color camera is attached to the blaze camera in a rigid setup, the rotation and translation between the cameras are fixed and must only be determined once.

3.1 Calibration

The purpose of the calibration is to determine the relative transformation between the 2D color camera and the blaze camera. Furthermore, the intrinsic parameters, i.e., the focal length and distortion of the 2D color camera are determined.

To perform the calibration, a calibration target is required. The folder containing the sample programs also includes a printable calibration target (**chessboard.pdf**, shown in Figure 3). The target has a chessboard pattern that defines its own coordinate system. The OpenCV library contains the `findChessboardCorners()` function, which is able to detect the corners of the chessboard in an image and to return the image coordinates of every corner point. If both cameras are “looking” at the target, corresponding points can be identified using the target coordinates, which are the same for both cameras.

To use the target, print it in its original size on a DIN A3 (297 x 420 mm) sheet. For the target to work correctly, i.e., the accuracy of the calibration, the printing accuracy should be at least 0.1 mm.

To verify whether your printed target is accurate enough, check whether the dimensions of the squares in the chessboard are 40 mm by 40 mm each.

Targets printed on 6-mm aluminum Dibond (an economical choice available through many online outlets) provide good results. For initial experiments, inkjet or laser prints may suffice if carefully glued to a flat surface, such as an aluminum plate or a piece of thick cardboard.

If the dimensions of the squares in your print aren't 40 mm by 40 mm, you can modify the sample program accordingly to ensure accurate calibration. To do this, change the value of the `m_fieldSize` parameter from 40.0 to the value of the squares in your print:

```
float m_fieldSize = 40.0; // mm corner size
```

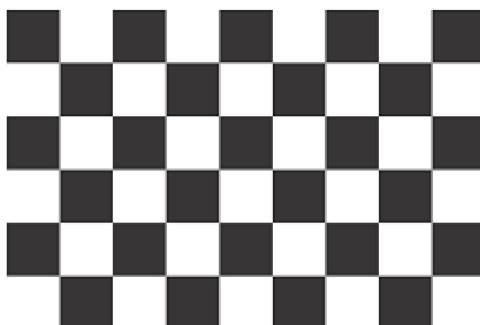


Figure 3: Calibration Target

To perform the calibration, start the **Calibration** sample program and take several images of the chessboard by pressing the **S** key. For the calibration, take 10 to 15 images of the chessboard at different positions covering the entire field of view of both cameras. The chessboard must always be completely visible by both cameras (see Figure 4). Figure 5 shows a variety of target positions that are suitable for performing the calibration.

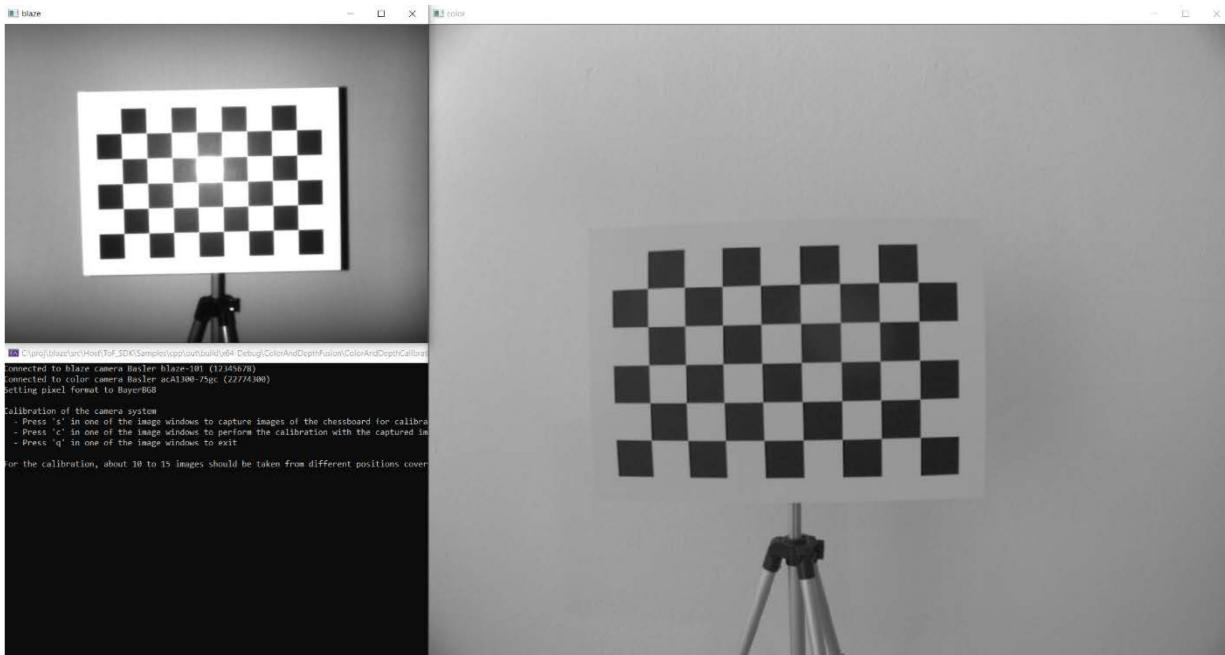


Figure 4: Performing the Calibration of the Camera System

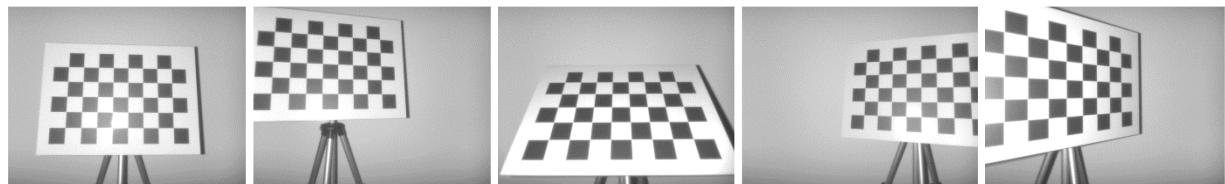


Figure 5: Examples of Chessboard Positions Suitable for Performing the Calibration

After you have taken the images, start the calibration by pressing the **C** key. During calibration, the intrinsic parameters of the 2D color camera as well as the relative transformation between it and the blaze camera are determined. The intrinsic parameters of the blaze have already been determined during manufacturing and can be read out. All the resulting data is stored in an XML file in the **CalibrationData** folder. The following section shows an example of the result of a camera system calibration.

```
<?xml version="1.0"?>
<opencv_storage>
<colorCameraMatrix type_id="opencv-matrix">
<rows>3</rows><cols>3</cols><dt>d</dt>
<data>
    8.53e+02 0.       6.62e+02
    0.       8.53e+02 5.00e+02
    0.       0.       1.
</data>
</colorCameraMatrix>
<colorDistortion type_id="opencv-matrix">
<rows>1</rows><cols>5</cols><dt>d</dt>
<data>-2.43e-01 9.85e-02 0. 0. 0.</data>
</colorDistortion>
<blazeCameraMatrix type_id="opencv-matrix">
<rows>3</rows><cols>3</cols><dt>d</dt>
<data>
    5.0887e+02 0.       3.1844e+02
    0.       5.0887e+02 2.3244e+02
    0.       0.       1.
</data>
</blazeCameraMatrix>
<blazeDistortion type_id="opencv-matrix">
<rows>1</rows><cols>5</cols><dt>d</dt>
<data>0. 0. 0. 0. 0.</data>
</blazeDistortion>
<rotation type_id="opencv-matrix">
<rows>3</rows><cols>3</cols><dt>d</dt>
<data>
    9.9997e-01 -3.8126e-03 -5.1768e-03
    3.8790e-03  9.9990e-01  1.2873e-02
    5.1273e-03 -1.2893e-02  9.9990e-01
</data>
</rotation>
<translation type_id="opencv-matrix">
<rows>3</rows><cols>1</cols><dt>d</dt>
<data>-4.1266e+01 3.8105e-01 -1.6245e+00</data>
</translation>
<colorCameraSerialNumber>"22774300"</colorCameraSerialNumber>
<depthCameraSerialNumber>"23577102"</depthCameraSerialNumber>
</opencv_storage>
```

During the first step of the calibration, the intrinsic camera parameters of the 2D color camera are determined. In the sample program, this is done using the `calibrateCamera()` function from the OpenCV software library. The result is a 3×3 matrix of the intrinsic camera parameters. This matrix is called **colorCameraMatrix** in the result file. Furthermore, a 5-element vector is determined that contains the distortion coefficients of the 2D color camera's lens. This is called **colorDistortion** in the result file.

The corresponding parameters of the blaze camera, i.e., **blazeCameraMatrix** and **blazeDistortion**, don't have to be calculated, but can be read directly from the camera. The distortion coefficients are zero for the blaze since the distortion is already corrected internally in the camera.

During the second step of the calibration, the relative transformation between 2D color camera and blaze camera is determined. This information is required to project the 3D points of the blaze into the 2D color image to determine the corresponding color information of the 3D points. To determine the transformation, the `stereoCalibrate()` function from the OpenCV software library is used. This function returns the rotation and translation between the two cameras. In the result file, these are a 3×3 rotation matrix and a 3-element vector describing the translation.

With the help of the rotation matrix and the translation vector, points in the coordinate system of the blaze camera can be transformed to points in the coordinate system of the 2D color camera. In technical terms, a change of basis is performed. Due to its duality, the tuple of rotation matrix and translation vector is equivalent to the position of the blaze camera with respect to the coordinate system of the 2D color camera.

Note that the calibration must be repeated every time the relative position or the optical setup of the cameras changes, e.g., when changing the focus of the cameras.

3.2 Data Fusion: Overlaying 3D Points with Color Data

Merging the 3D data from a Basler blaze camera with the color image from a 2D color camera adds color information to the points of the point cloud. This is achieved by matching a given 3D point from the blaze camera with the pixel of the 2D color camera onto which this point is projected. The sample program needs the **calibration_blazeSN_colorSN.xml** file that was created during calibration for this because it contains the necessary intrinsic camera parameters as well as the relative transformation between the cameras.

For the projection of the points, the `projectPoints()` function from the OpenCV software library is used. The red, green, and blue (RGB) color information of this pixel is then set as the color of the point in the point cloud. The result is a color point cloud.

To create the color point cloud, a transformation of the P_{blaze} 3D points of the blaze camera into the camera coordinate system of the 2D color camera is performed first using the $R_{\text{blaze} \rightarrow \text{ace}}$ rotation and $T_{\text{blaze} \rightarrow \text{ace}}$ translation.

$$P_{\text{ace}} = [R_{\text{blaze} \rightarrow \text{ace}} \mid T_{\text{blaze} \rightarrow \text{ace}}] \cdot P_{\text{blaze}}$$

Next, the projection into the 2D pixel coordinate system of the 2D camera is done using the K_{ace} intrinsic camera parameters.

$$p = K_{\text{ace}} \cdot [I \mid 0] \cdot P_{\text{ace}}$$

The blaze camera and the color camera don't have the same optical center. This can cause occlusion problems when mapping the color data. Such effects can be eliminated, for example, by an additional processing step that uses the z-buffer algorithm (<https://en.wikipedia.org/wiki/Z-buffering>). The z-buffer algorithm saves the depth values for each pixel of the color image. If a pixel of the color image is assigned to multiple pixels of the depth image, only the pixel closest to the camera is colored.

The color point cloud generated in this way is then displayed using the PCLVisualizer from the PCL software library. Figure 6 shows the input images of the blaze camera and the 2D color camera as well as the color 3D point cloud generated from them. The additional color information allows the red and green boxes to be recognized clearly. In the depth image alone, they are almost indistinguishable.



Figure 6: Depth Image of the blaze and Color Image of the 2D Camera as Well as the Resulting Color 3D Point Cloud

4 Conclusion

The data fusion process detailed in this document allows you to combine the depth data of a blaze camera with the color data of a 2D color camera. This way you can generate a high-resolution color image of the scene in addition to the depth image. Merging these data sets can help you with image processing and interpretation. Also, the color image can be used to generate a color point cloud that can make understanding the 3D scene easier, especially for human users.

5 Further Reading

A thorough discussion of homogeneous transforms, camera calibration, and stereo techniques is beyond the scope of this document. Comprehensive overviews of the principles of computer vision can be found in the following publications:

- Richard Hartley, Andrew Zisserman: *Multiple View Geometry in Computer Vision*, Cambridge University Press 2004
- Richard Szeliski: *Computer Vision: Algorithms and Applications*, Springer 2011

For further information about the library functions mentioned in this text, please refer to the OpenCV online documentation of the **Camera Calibration** and **3D Reconstruction** modules (<https://opencv.org>) and the documentation of the Point Cloud Library (<https://pointclouds.org>).

For comprehensive information about Basler cameras, their features, and other Basler products, visit docs.baslerweb.com.

Revision History

Document Number	Date	Changes
AW00166501000	28 Jan 2021	Initial release version of this document.
AW00166502000	9 Aug 2021	Updated the software requirements.
AW00166503000	27 Jun 2022	Updated information regarding sample programs throughout the document. Removed information about the 3D-printed mounting bracket throughout the document. Added the Basler ace 2 to blaze Mounting Bracket in Table 1.