SigmaStar
Camera Calibration User Guide

Version 1.6

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1. OVERVIEW

1.1. Overview

This article describes how to perform multi-camera calibration and stitching, as well as single-camera calibration by using CVTool. Based on the calibration image captured by user with multiple cameras or single camera, CVTool will help you calculate the stitching parameters required by the SOC.

2. CALIBRATION TOOL INSTALL ENVIRONMENT

To perform camera calibration, you need to install CVTool, which is developed by SigmaStar. As CVTool operates based on the runtime libraries of Microsoft Visual Studio, make sure you have installed the Visual Studio 2017 runtime libraries. You may download vc2017setup.exe and click Visual C++ Redistributable Package 2017, as Figure 1 shows, while unclick all other options, and then click Next Step for installment.

Figure 1: Install Visual Studio Runtime Library

3. CAMERA CALIBRATION

3.1. Before Calibration

3.1.1 AE/AWB Synchronization

Most of the stitching devices in the current market feature multi-channel image signal processors, which are independent of each other. This leads to different brightness, color, and contrast between images coming from different sensors. Such differences appear much more apparent when light source is uneven. Therefore, AE/AWB synchronization should be prioritized before performing camera calibration.

- AE Synchronization

  Auto Exposure (initialized as AE) refers to the camera mechanism that automatically adjusts exposure settings based on luminous intensity to avoid overexposure or underexposure, in a bid to prevent regional over-brightness or darkness in the picture. For stitching devices, adjacent cameras produce different pictures when they are placed at varying angles and distances away from objects, thus different exposure settings are required for the lens of each channel. Before stitching, therefore, AE synchronization must be done to the lens of every channel to avoid luminance discontinuity occurring at the edge of stitching. The different stitching results before and after AE Synchronization can be found in Figure 2. Please also refer to the setting of MI_ISP_SYNC3A_e in MI_ISP_API_V3.doc for SigmaStar AE Synchronization.

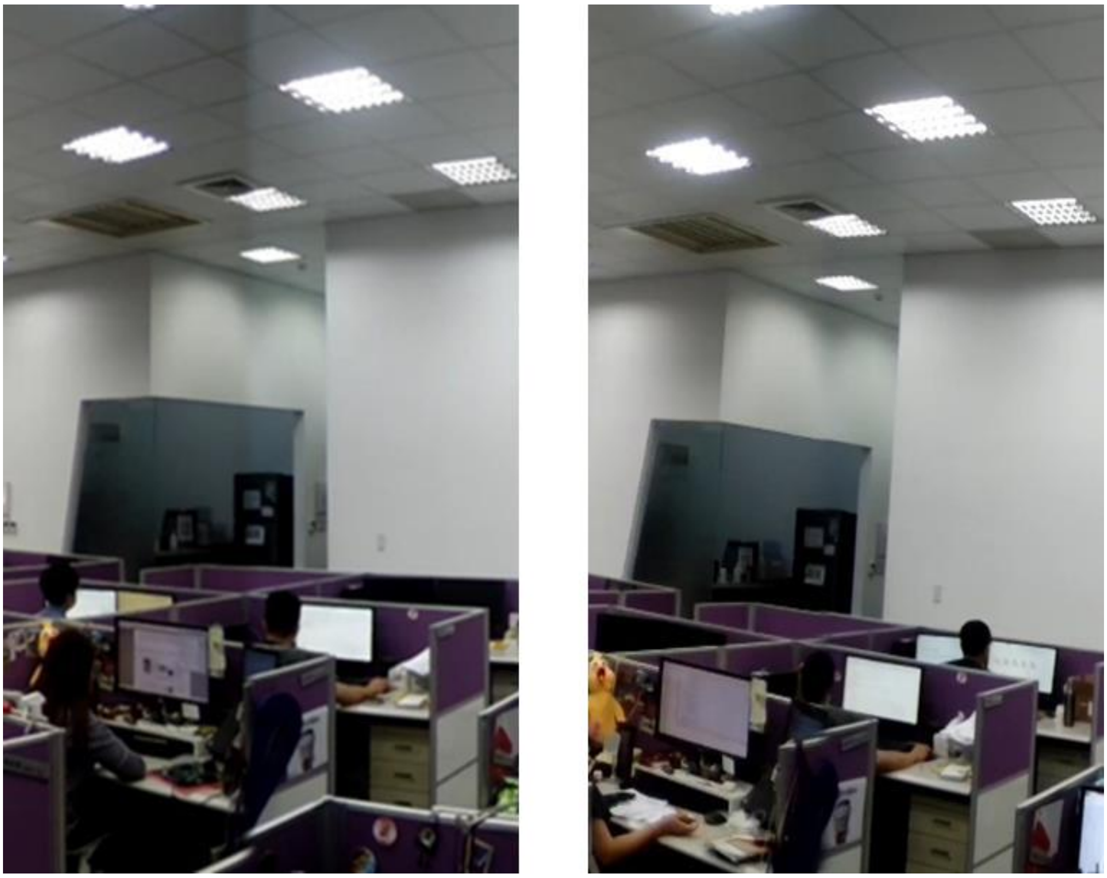


Figure 2: Different Stitching Results Before (Left) and After (Right) AE Synchronization

- AWB Synchronization

  Under the light sources in different color temperatures, color deviation often appears on the image of the same white object. For example, a slightly red hue may appear on the image of white object in lower color temperature, while a slightly blue hue may appear in higher color temperature. Due to potential assembly error, AWB parameters may also slightly vary from one camera to another of the same model. To ensure stitching quality, it is necessary to synchronize AWB parameters of the lens of each channel. AWB Synchronization shares the same adjustment flow with AE Synchronization, please refer to the setting of MI_ISP_SYNC3A_e in MI_ISP_API_V3.doc for SigmaStar AWB Synchronization.

3.1.2 Lens Shading Calibration

Due to manufacturing techniques and optical characteristics of lens, shading may appear on the margins of lens and lead to vignetting, a phenomenon of brightness reduction toward the periphery compared to the center in the picture. In multi-channel stitching cases, vignetting often lead to different brightness levels in the overlapping areas of stitched images. To ensure the stitching effect is smooth and natural, we suggest that you conduct lens shading correction for each camera.

3.1.3 Check, Tune, and Load Applicable IQ (Image Quality) bin

Before calibration, you should check, tune, and load applicable IQ (Image Quality) bin files for calibration to the board. The IQ bin, after adjustment, should be able to detect corner points as precise as possible, in order to enhance the quality of camera calibration images. Figure 3 and Figure 4 shows the calibration image before and after IQ is adjusted. The applicable adjustments for camera calibration is as follows:

1. Enhance Black and White Contrast: By adjusting the YUV Gamma to a slightly S-shaped curve, corner points will become more apparent.
2. Adjust WDR_LCE Module: By fine-tuning relevant parameters of this module, you may increase the contrast between black and white (by increasing Num and Filter, or increasing the strength of detail darkening / brightening enhancement) in a bid to increase the pixel intensity of corners as compared to surrounding pixels, highlighting the corners.
3. Adjust YEE Module: In cases where adjusting medium-low (ML) or high (H) frequency alone or adjusting directional (D) or non-directional (UD) frequency only does not make apparent impact upon corner point detection, you may increase EdgeGain, Edgekillut, and OverShootGain, in a bid to enhance checkerboard clarity.
4. Do not overly sharpen white edges.
5. Increase brightness and exposure time: The occurrence of strong noise in the picture may cause certain impacts upon corner point detection. You may reduce noise by increasing brightness and exposure time.

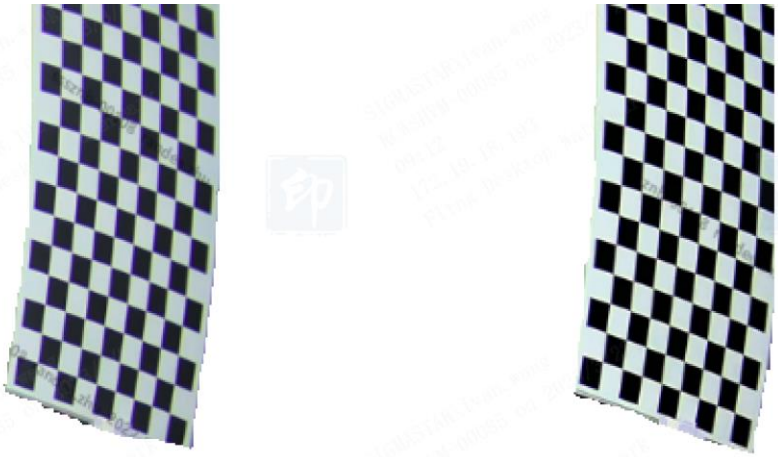


Figure 3: Calibration Images Before (Left) and After (Right) IQ Adjustment

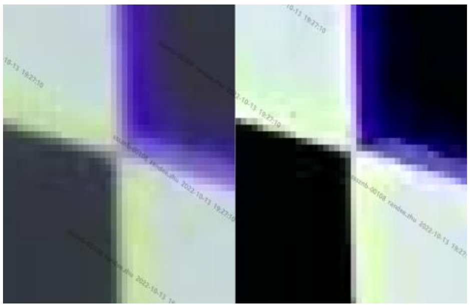


Figure 4: Black Diagonal Checkerboard Corners Before (Left) and After (Right) IQ Adjustment

In Figure 3, the image on the left represents the pre-adjusted calibration image, while the image on the right represents the calibration image after making adjustments according to the above suggestions. Compared with the image on the left, the checkerboard on the right shows greater clarity and stronger black-and-white contrast. Zooming in the image on the right, you will be able to see the corner points in pixel-level with much clarity, as the right image in Figure 4 shows.

The image on the left in Figure 4 represents the enlarged view of the image on the left in Figure 3, and the image on the right in Figure 4 represents the enlarged view of the image on the right in Figure 3. Compared with the image on the left, the diagonal black corner points in the image on the right shows smaller transitional area, and the pixel intensity of corner points compared to the surrounding pixels is strong, showing a much clearer view of checkerboard and allowing corner points to be detected easier.

The appendix shows calibration images with very bad IQ adjustments as well as exemplary IQ effects.

3.2. Calibration Flow

3.2.1 Model Calibration

During the stage of model calibration, product of each type only needs to be calibrated once. We suggest that you pick one product from the same batch for model calibration based on the idea of the three-sigma rule of thumb. During calibration, the product you picked will be used to take a great number of checkerboard pictures for the purpose of ensuring the accuracy and robustness of calibration result.

3.2.1.1. Checkerboard

Prepare a checkerboard for calibration purpose. The precision of checkerboard should be high, so we recommend that you should purchase a checkerboard for professional purposes. An example of checkerboard is illustrated in Figure 5, with the following specs: 12x9 squares, with 11x8 internal corners, as the red circles in Figure 5 shows, and the side length of checkerboard square is 95 mm (physical length).

> Note: The checkerboard should occupy a larger proportion of the picture, with the side length of each checkerboard square no smaller than 10 pixels. If your checkerboard occupies very few pixels in the picture, you may move it closer to the lens or use larger checkerboard instead. You may also reduce the number of squares in checkerboard — the smallest combination of internal corners being 4*3 — if necessary. In addition, the edge of checkerboard should be at least as wide as the side length of single checkerboard square, meaning that enough space in white should be reserved for the edge.

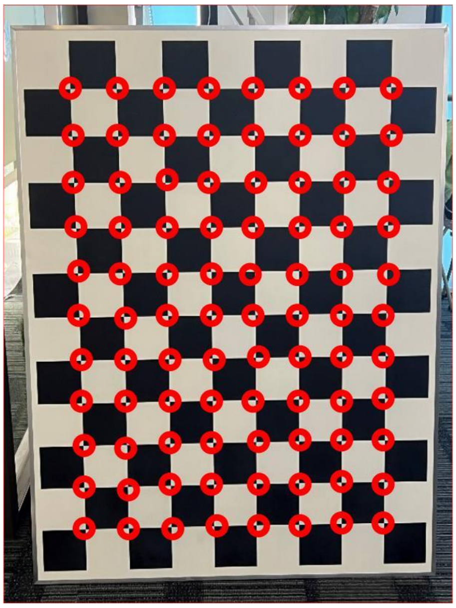


Figure 5: Example of Checkerboard Image for Calibration Purpose

3.2.1.2. Run cv server

- For product of Muffin, Maruko, and Opera series
  a) Modify the streaming json according to the board settings and the configuration instructions in Table 1, and put json in the common directory
  b) Put the common directory on the board side, such as /mnt/
  c) Set the environment variable to specify the json path `.export CV_SERVER_JSON_PATH=/mnt/`
  d) Enter the following command to run the demo: `./prog_cv_server`
- For product of Souffle series
  a) Modify the streaming json according to the board settings and the configuration instructions in Table 2.
  b) Put ./prog_cv_server_demo and json to the same directory on the board side
  c) Enter the following command to run the demo: `./prog_cv_server`

Note:
(1). cv_server and sdk must be matched.
(2). Please refer to muffin_json_sample.zip for the example of json for the chip in Muffin, Maruko, and Opera series.
(3). Please refer to souffle_json_sample.zip for the example of json for the chip in Souffle series.

muffin_json_sample.zip   souffle_json_sample.zip

Table 1: MUFFIN cv server json Configuration

Node	Configuration	Description	Note
stPadVifInfo	snrNum	The number of sensor for the current video streams	Set to 1 for grabbing images for calibration purpose.
	snrResW	The width of sensor resolution	The resolution should be supported by sensor.
	snrResH	The height of sensor resolution	The resolution should be supported by sensor.
	padId	SensorPad ID	
	GroupId	Vif Group ID	
	vifDevIdInGroup	The device number in VIF group	Normally not modified.
	vifPortId	The output port of VIF	Normally not modified.
stIqCfg	IqFilePath	Path to the IQ file	
stIspCfg	IspDevId	ISP device number	
	IspChnId	ISP channel number	
	IspOutPortId	ISP output port number	
	Isp3DNRLevel	ISP 3DNR level	
stSclCfg	SclDevId	SCL device number	
	SclChnId	SCL channel number	
	SclOutPortId	SCL output port number	
	SclOutPortW	SCL output width	Unit: pixel
	SclOutPortH	SCL output height	Unit: pixel
	SclHwId	SCL hardware ID	
stVencCfg	vencDev	Venc device number	
	u32VencChn	Venc channel number	
	eType	Encoding type	2: H264 3: H265 4: JPEG

Table 2: SOUFFLE cv server json Configuration

Node	Configuration	Description	Note
stVifCfg	snrResIdx	The index of sensor resolution mapping table.	
	padId	Sensor device number	
	GroupId	The device number in VIF group	
	vifPortId	The output port of VIF	Normally not modified.
stIqCfg	IqFilePath	Path to the IQ file	
stIspCfg	IspDevId	ISP device number	
	IspChnId	ISP channel number	
	IspOutPortId	ISP output port number	
	Isp3DNRLevel	ISP 3DNR level	
stSclCfg	SclDevId	SCL device number	
	SclChnId	SCL channel number	
	SclOutPortId	SCL output port number	
	SclOutPortW	SCL output width	Unit: pixel
	SclOutPortH	SCL output height	Unit: pixel
stVencCfg	VencDev	Venc device number	
	VencChn	Venc channel number	
	eType	Encoding type	2: H264 3: H265 4: JPEG

3.2.1.3. Photographing for Monocular Camera Calibration

The pictures taken in this session are used to calibrate the intrinsic parameters of camera. During the photographing session, try not to support the checkerboard by your hand, because a tiny hand movement would blur the internal corners, which is harmful to corner point detection. Now, place the checkerboard in front of the camera lens and constantly change the direction, distance, and position of the checkerboard in the picture, so that checkerboard positions cover the whole picture evenly. The following four scenarios should be included.

- Photographing in short distance and covering the whole picture with one checkerboard.
- Photographing in short distance and covering the whole screen with multiple images of checkerboard, which occupies 1/3 of the screen area.
- Photographing in mid-range distance and covering 1/6 of the screen with multiple images of checkerboard, which occupies 1/6 of the screen area.
- Photographing in long distance with multiple images of checkerboard, which rotates in different angles.

The actual distance for intrinsic parameter calibration is related to the FOV of monocular lens. The smaller the FOV of lens, the more distance should be increased for model calibration; the larger the FOV, the more distance should be decreased.

The naming rule of monocular camera calibration image is:

<fixed prefix><camera number>_<image number>.jpg/.yuv

For example, camera0_0.jpg represents the first image taken by the first camera, and camera0_1.jpg represents the second image taken by the first camera, while camera1_2.jpg represents the third image taken by the second camera.

A more detailed step-by-step photographing flow for monocular camera calibration is provided below.

Table 3: Photographing Calibration Image with Monocular Camera

Step	Objective	Calibration Method	Checkerboard Placement (Please refer to Figure 6)	Number of Images	Reference Distance
1	Photograph in short distance and cover the whole screen with one checkerboard.	The whole screen should be filled up by one checkerboard. Two photographs are required: Checkerboard facing the camera, and checkerboard rotating 10 degree using its central axis as the axis of rotation.	1. Fill up the whole screen with a checkerboard. 2. Based on the previous checkerboard placement, rotate the checkerboard by roughly 10° using its central axis as the axis of rotation.	2	N/A.
2	Photograph in short distance and cover the whole screen with multiple checkerboard images.	The whole screen should be filled up by multiple images of checkerboard — by placing checkerboard in the four corners and the center of the picture, in a total of five positions. The checkerboard should occupy 1/3 of the screen area in every picture, and two photographs should be taken in each position: one with checkerboard facing the camera, the other with checkerboard tilted 10 degree, with the four corners forming a trapezium.	1. Place the checkerboard in the center of the screen. 2. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation. 3. Place the checkerboard on the lower left corner of the screen. 4. Tilt the checkerboard by roughly 10° toward the camera using its length as the axis. 5. Place the checkerboard on the lower right corner of the screen. 6. Tilt the checkerboard by roughly 10° toward the camera using its length as the axis. 7. Place the checkerboard on the upper right corner of the screen. 8. Tilt the checkerboard by roughly 10° toward the camera using its length as the axis. 9. Place the checkerboard on the upper left corner of the screen.	10	1500 mm

Step	Objective	Calibration Method	Checkerboard Placement (Please refer to Figure 6)	Number of Images	Reference Distance
			10. Tilt the checkerboard by roughly 10° toward the camera using its length as the axis.		
3	Photograph in mid-range distance and cover the whole screen with multiple checkerboard images.	Increase the distance between checkerboard and lens by two times, place the checkerboard in the four corners and the center of the picture, in a total of five positions. The checkerboard should occupy 1/6 of the screen area in every picture, and two photographs should be taken in each position: one with checkerboard facing the camera, the other with checkerboard tilted 10 degree based on the first photograph.	1. Place the checkerboard in the center of the screen. 2. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation. 3. Place the checkerboard on the lower left corner of the screen. 4. Tilt the checkerboard by roughly 10° toward the camera using its length as the axis. 5. Place the checkerboard on the lower right corner of the screen. 6. Tilt the checkerboard by roughly 10° toward the camera using its length as the axis. 7. Place the checkerboard on the upper right corner of the screen. 8. Tilt the checkerboard by roughly 10° toward the camera using its length as the axis. 9. Place the checkerboard on the upper left corner of the screen. 10. Tilt the checkerboard by roughly 10° toward the camera using its length as the axis.	10	3000 mm
4	Photograph in long distance and from different angles.	Increase the distance between checkerboard and lens again by two times, and take two photographs in each position: the other one should be tilted by 10 degrees compared with the first photograph. There is no regulation regarding the checkerboard position, but the two photographs	1. Place the checkerboard in the center of the screen. 2. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation. 3. Place the checkerboard on the lower right corner of the screen. 4. Tilt the checkerboard by roughly 10° toward the camera using its width as the axis. 5. Place the checkerboard on the upper right corner of the screen. 6. Tilt the checkerboard by roughly	6	5000mm

Step	Objective	Calibration Method	Checkerboard Placement (Please refer to Figure 6)	Number of Images	Reference Distance
		from the same distance should be taken from different angles.	10° toward the camera using its width as the axis.		

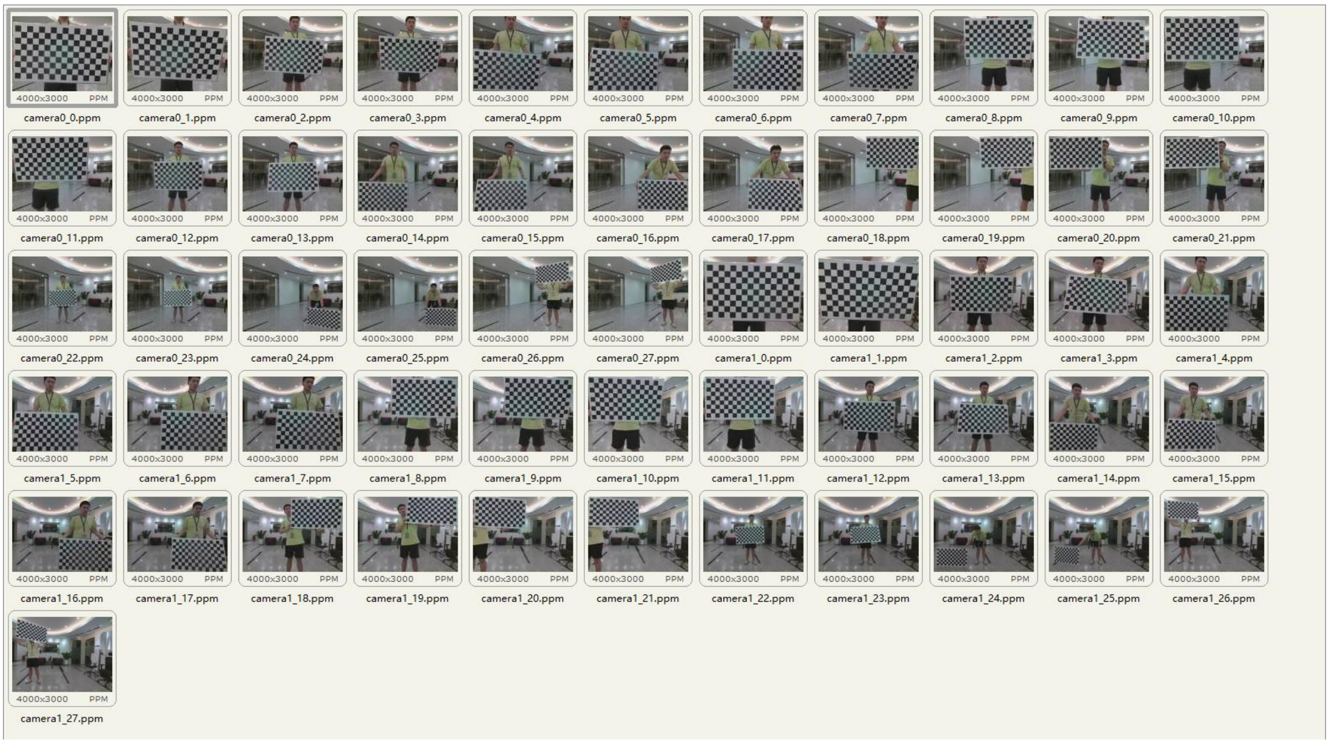


Figure 6: Example of Monocular Camera Calibration Images

- Photographing Tools
  1. You may use third-party tool, such as VLC or Potplayer, to observe real-time stitching effect, or
  2. Use CV Tool developed by SigmaStar and grab images after connecting to prog_cv_server.
     a) Run prog_cv_server on the board, please contact our FAE for how to run this demo.
     b) Connect to prog_cv_server by following Step 1 to Step 3, as shown in Figure 7.
     c) Click "Start" Buttom and start previewing, as shown by Step 4 in Figure 7.
     d) Grab images by following Step 5 to Step 9, as shown in Figure 7.

Figure 7: Grabbing Images in CVTool for Monocular Camera Calibration

Please refer to the following table for the description of CVTool configuration.

Table 4: Description of CVTool Configuration

Configuration	**Description**	**Note**
Chip	Chip Type.	
Host Name	The IP of prog_cv_server to run the board.	Fill in the address in accordance with prog_cv_server.
Port	The listening port of prog_cv_server.	The default is 9527.
Camera Num	The number of camera.	Fill in the number in accordance with the preview number created by prog_cv_server.
Save Directory	The directory for saving images.	Use English only; space, decimal point, or any other special characters are not allowed in the path.
Node	Select a node in the entire chain and grab the images from that stage. (Five nodes are available for	To select VENC, RTSP preview support is the only requirement. For other nodes, please set up

Configuration	Description	Note
	selection: VIF, ISP, LDC, SCL, VENC.)	alongside prog_cv_server.
Type	Image type.	Single: Grabbing images for monocular camera calibration Stereo: Grabbing images for binocular camera calibration.
Stereo Option	The numbering of two cameras for binocular camera calibration.	The number should correspond to the setting of Index.
Prefix	The prefix for the name of image file.	Fill in "camera" for Prefix, for instance, the image will be named as cameraX_Y.jpg.
Index	The indext number of camera.	This number will directly be used in the naming of images. In "cameraX_Y.jpg", for instance, X represents the camera number.
Snap	Enable image grabbing.	Only after Snap is checked will camera supports image grabbing.
Capture	Capture image.	
Start	Preview captured image.	

3.2.1.4. Photographing for Binocular Camera Calibration

The pictures taken in this session are used to calibrate the extrinsic parameters of camera. During the photographing session, **NEVER** support the checkerboard by your hand (Note the difference from photographing for monocular camera calibration), because binocular camera calibration requires two cameras simultaneously taking pictures, so that the overlapping area is guaranteed to be photographed by both cameras at the same time. This way, every data point in the overlapping area of the two cameras corresponds to its counterpart, and the accuracy of binocular camera calibration can be ensured.

The naming rule of binocular camera calibration image is:

<Fixed Prefix><Camera Number>_<Camera Number 1><Camera Number 2>_<Image Number>.jpg/.yuv

For example, camera0_01_0.jpg represents the first image taken by the first lens, and camera0_01_1.jpg represents the second image taken by the first lens, while camera1_01_3.jpg represents the fourth image taken by the second lens.

Each set of binocular cameras should take at least 18 pairs of photographs. Before the photographing session starts, make sure that two cameras are placed next to each other, and that both of them can photograph simultaneously. Now, place the checkerboard inside the overlapping area and as close as possible to the lens, until a complete view of checkerboard can be seen by the adjacent cameras, and take the first set of photographs. After that, slightly rotate the checkerboard by 10 degree and take another set of photographs. Then, change the position of checkerboard inside the overlapping area little by little and repeat photographing, until the checkerboard positions have covered the overlapping area completely. Finally, place the checkerboard further away from cameras and take several sets of photographs.

For binocular camera calibration, three different distances between checkerboard and lens should be included.

- Photographing in short distance and partially covering the overlapping area (80%).
- Photographing in mid-range distance and partially covering the overlapping area (60%).
- Photographing in long distance and partially covering the overlapping area (40%).

The calibration distance of extrinsic parameter is related to the FOV of overlapping area. The smaller the FOV of overlapping area, the more distance should be increased for model calibration of extrinsic parameter.

Table 5: Photographing Calibration Image with Binocular Camera

Step	Objective	Calibration Method	Checkerboard Placement (Please refer to Figure 8)	Number of Images	Reference Distance
1	Photograph in short distance and partially covering the overlapping area (80%).	Place the checkerboard as close as possible to the lens, until a complete view of checkerboard can be seen by the adjacent cameras. Starting by placing the checkerboard at the top of the overlapping area, and take a pair of photographs. After that, slightly rotate the checkerboard by roughly 10° and take another set of photographs. Then, lower the position of checkerboard and repeat photographing, until the checkerboard positions have reached the bottom of the overlapping area. At least three positions should be included (the top,	1. Place the checkerboard at the top of the overlapping area; 2. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation; 3. Move the checkerboard to the center of the overlapping area; 4. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation; 5. Keep moving the checkerboard to the bottom of the overlapping area; 6. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation.	6	2000 mm

Step	**Objective**	**Calibration Method**	**Checkerboard Placement (Please refer to Figure 8)**	**Number of Images**	**Reference Distance**
		the center, the bottom).			
2	Photograph in mid-range distance and partially cover the overlapping area (60%).	Increase the distance by two times. Starting by placing the checkerboard at the bottom of the overlapping area, and take a pair of photographs. After that, slightly rotate the checkerboard by roughly 10° and take another set of photographs. Then, move the checkerboard upward and repeat photographing, until the checkerboard positions have reached the top of the overlapping area. At least three positions should be included (the top, the center, the bottom). The photographing session does not have to follow the upward moving direction.	1. Place the checkerboard at the center of the overlapping area; 2. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation; 3. Move the checkerboard downward to the bottom of the overlapping area; 4. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation; 5. Move the checkerboard upward to the top of the overlapping area; 6. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation.	6	4000 mm
3	Photograph in long distance and partially cover the overlapping area (40%).	Move the checkerboard further away from the lens. Starting by placing the checkerboard at the	1. Place the checkerboard further away at the center of the overlapping area; 2. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation;	6	5000mm

Step	Objective	Calibration Method	Checkerboard Placement (Please refer to Figure 8)	Number of Images	Reference Distance
		lower center of the overlapping area, and take a pair of photographs. After that, slightly rotate the checkerboard by 10 degree and take another set of photographs. Then, move the checkerboard upward to the center as well as the upper center position of the overlapping area and repeat photographing.	3. Move the checkerboard downward to the lower center of the overlapping area; 4. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation; 5. Move the checkerboard upward to the upper center of the overlapping area; 6. Rotate the checkerboard by roughly 10° using its central axis as the axis of rotation.		

Note: As Figure 8 illustrates, the numbering corresponds to the document name, where camera0 and camera1 indicate different lenses, 0_01_0, 0_01_1 …, 0_01_17 indicate different calibration images of the same lens. 0_01_n and 1_01_n ("n" indicates index number) represent the same pair of calibration images of each lens in a pair.

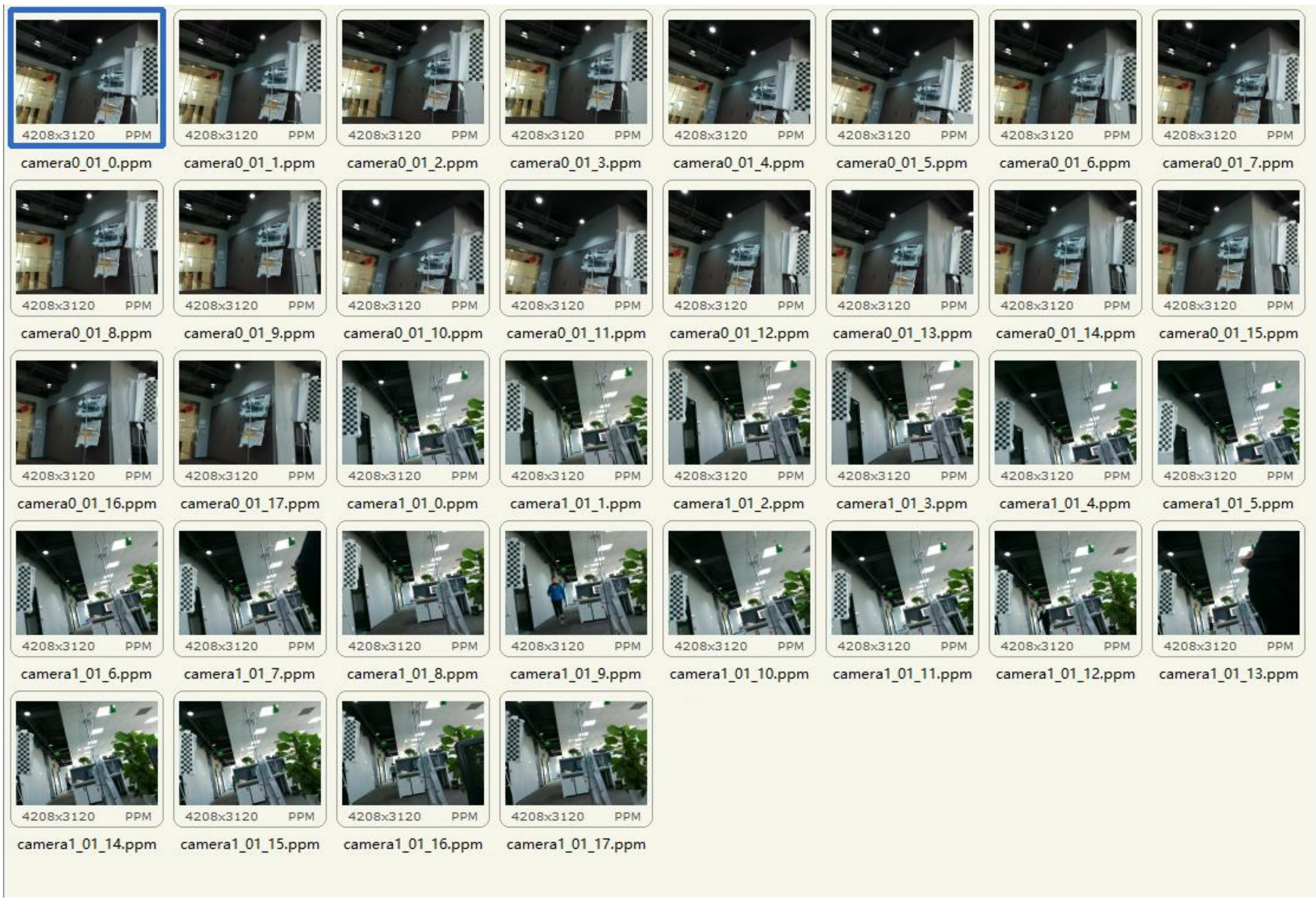


Figure 8: Example of Monocular Camera Calibration Images

Figure 6 and Figure 8 illustrate the suggested size, position, and the rotation of checkerboard in calibration images. These two figures serve the purpose of illustration only and do not have to be strictly followed. To achieve the effects of calibration, you may adjust the distance between lens and checkerboard, as well as the photographing angle, based on the actual cameras in use.

- Photographing Tools
  Please refer to the section in **Photographing for Monocular Camera Calibration**, but set Type to Stereo in CV Tool and configure Stereo Option.
- Precautions
  a) The calibration environment should be bright, and illumination should be evenly distributed, otherwise the environmental noises may affect calibration effects (as seen in the Appendix).
  b) Visible glare or shadow that may cause uneven brightness should not appear on checkerboard, otherwise checkerboard corners may fail to be detected. You may avoid glare and shadow by adjusting the relative positions of lens, checkerboard, and light source.
  c) Checkerboard size should not be too small in the picture. Generally, the side length of checkerboard square should not be smaller than 10 pixels. If checkerboard occupies very few pixels in the picture, checkerboard corners may fail to be detected, or the detection result will not be accurate. You may consider moving the checkerboard closer to the lens or replacing it with a larger checkerboard.

Reducing the number of checkerboard squares is also possible. (the minimum number of checkerboard corners being 4x3.)

d) Multiple checkerboards or objects with checkerboard patterns should not appear in the picture, otherwise corner detection may fail. If such things happen, you should remove those checkerboard objects away beforehand, or you may remove the objects manually in photo-editing tools.

e) Each checkerboard square must be completely included in the picture, otherwise checkerboard corners may fail to be detected.

f) The image of checkerboard squares must be clear in the picture, and blurring should be avoided. If checkerboard images are not clear enough, the detected coordinates of corner pixel will be imprecise, causing unsatisfactory calibration precision. Make sure that the lens is clean and focal length will not be affected if lens should be cleaned. Also, make sure that the camera focus is sharp, with a proper depth of field. No focal adjustment or magnification change is allowed during the calibration process, otherwise the calibrated parameters will all become ineffective and the whole calibration flow will have to be started all over again.

g) Do not touch checkerboard squares during the photographing session, and the squares should not be covered, either. Otherwise, checkerboard corners may fail to be detected.

h) All positions of the checkerboard in photographs should completely cover the whole picture. For binocular camera calibration, the whole overlapping area should be covered.

i) After all the required calibration photographs have been captured, you can set the best stitching distance.

3.2.1.5. Photographing for Offline Stitching Images

The offline stitching images are used to verify the results and to display the rendering after calibration is completed. These pictures serve testing purpose only and have nothing to do with calibration. During shooting, use the same set of calibrated cameras to take pictures that correspond to the number of stitching channels.

The naming rule of offline stitching picture is:

<fixed prefix><camera number>_stitch.jpg/.yuv

For instance: camera0_stitch.jpg

Figure 9: Example of Offline Stitching Images

3.2.1.6. Calibration

a) Create an empty main directory, and create three empty directories: intr, extr, and stitch in the main directory. After that, create an empty directory pair_i_i+1 in the extr directory, where "i" represents the number of the camera.

b) Create various directories for offline effect pictures. For stitching purpose, for instance, create "stitch" directory; for lens distortion correction, create "ldc" directory; for near-infrared light fusion, create "nir" directory; for deep learning processor unit, create "dpu" directory.

c) Put the pictures taken for single camera calibration into the intr directory.

d) Put the pictures taken for binocular camera calibration into the pair_i_i+1 directory of the extr directory.

e) Put the pictures used for stitching rendering examination into stitch/ldc/nir/dpu directory.

f) Configure the corresponding parameters according to the steps in Figure 8. The meaning of the parameters is shown in the following Table. If the parameters cannot meet the requirements, you can enter the Advance Mode.

g) Click Run to start calibration.

h) If calibration succeeds, offline stitching rendering will be displayed. The parameter file calib_out.json required for camera stitchin, calib_parameter.txt(used for mi ldc) and parameter folder calib_para (used for production line calibration) will be generated in the Image directory. Among them, calib_out.json is automatically generated in the main directory after successful calibration, and calib_para is a folder automatically generated in the main directory at the same point. The folder calib_para contains ori_model_intr.yml and ori_model_extr.yml files, which store the internal and external calibration of the camera respectively.

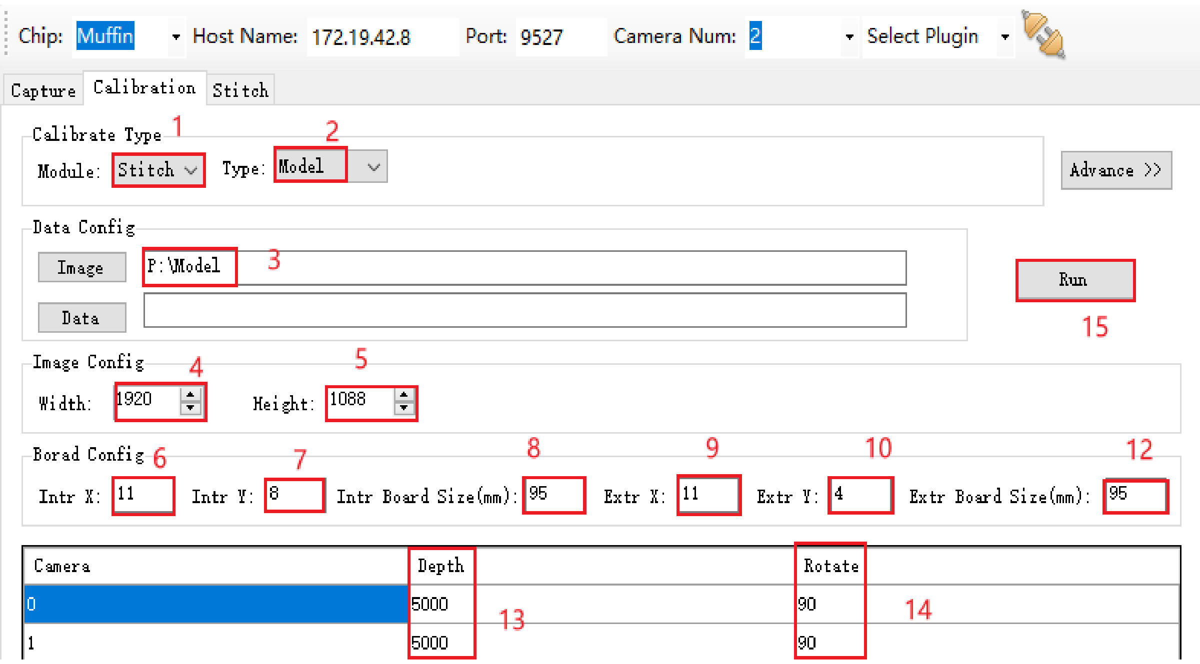


Figure 10: Using CV Tool to Perform Model Calibration

Table 6: CVTool Calibration Configuration

Setting	Description	Note
Module	Select calibration module.	Stitch: Stitch; NIR: Near-infrared Fusion; DPU: Deep learning Processing Unit; Single: Single Camera Calibration LenSpec: Correction using lens distortion coefficient OneDimeSingle: One-dimensional Correction
Type	Select calibration type.	Model: Model Calibration; Plc: Production Line Calibration; FineTune: Fine-tuning; Ptgui: Panoramic stitching tool.
Lens Type	Select lens type.	Standard: standard lens; Wideangle: wide-angle lens;

Setting	**Description**	**Note**
		FishEye: fish-eye lens; WideangleEx: wide-angle lens (expanded).
Image	The main directory for calibration.	Three subdirectories — intr, extr, stitch — should be included in the main directory.
Data	The path of intrinsic and extrinsic parameter directories output by model calibration.	The path should be set for production line calibration, while there is no need to set the path for model calibration.
Image Format	The format of calibration image.	RGB and YUV420 are supported.
Image Width	The component of width in the resolution of calibration image.	
Image Height	The component of height in the resolution of calibration image.	
File Prefix	The prefix used when naming calibration images.	
Rotate	The rotating degree of each lens.	Only 0, 90, and 270 degrees are supported.
Intr X	The number of internal corners on the horizontal axis in the checkerboard for monocular camera calibration.	
Intr Y	The number of internal corners on the vertical axis in the checkerboard for monocular camera calibration.	
Intr Board Size	The physical side length of black and white squares on the checkerboard for monocular camera calibration. The unit is mm.	
Extr X	The number of internal corners on the horizontal axis in the checkerboard for binocular camera calibration.	
Extr Y	The number of internal corners on the vertical axis in the checkerboard for binocular camera calibration.	
Extr Board Size	The physical side length of black and white squares on the	

Setting	**Description**	**Note**
	checkerboard for monocular camera calibration. The unit is mm.	
Blend	Blending mode.	alpha: alpha blending; multi: multi-band blending.
Depth	The optimal stitching distance. The unit is mm.	
Input/Output Sequence Mode	The order of calibration cameras.	Normal: normal order; Negative: reverse order.
Separate Bin Mode	LDC Bin format.	Overlap: LDC output image includes overlapping area; No Overlap: LDC output image does not include overlapping area.
ISP Mode	Input mode for ISP.	Horizontal: The images input to the ISP from each channel are placed in the horizontal direction; Vertical: The images input to the ISP from each channel are placed in the vertical direction.
Calibrate	Enable calibration.	
Cmodel	Enable offline modelling simulation.	If enabled, rendering of modelling simulation will be shown on PC.
Check Re-ProJection Error	Enable determination of re-projection error value being too large.	
Projection	Projection type.	Linear: linear projection; Cylindrical: cylindrical projection; Spherical: spherical projection; Fisheye: fisheye projection; Mercator: Mercator projection.
Crop	Cropping direction.	Options in Advance Mode: H: horizontal direction; V: vertical direction; H&V: Both horizontal and vertical directions.
Plc Mode	Production line calibration mode.	Intr&Extr: Both intrinsic and extrinsic parameters will be calibrated; Extr: Only extrinsic parameters will be calibrated.

Setting	**Description**	**Note**
Blend->Percentage	Percentage of overlapping area.	
Int Region Mode	The mode of region of interest.	Manual: manual mode; Auto: auto mode.
FovX	The FOV on the horizontal direction.	
FovY	The FOV on the vertical direction.	
PrjCenterX	The X-axis position in the output image of the center point of the projection.	
PrjCenterY	The Y-axis position in the output image of the center point of the projection.	
Yaw	The yaw angle, or the rotating angle around the Y axis.	Range: -18000 ~ 18000
Pitch	The pitch angle, or the rotating angle around the X axis.	Range: -18000 ~ 18000
Roll	The roll angle, or the rotating angle around the Z axis.	Range: -18000 ~ 18000
Crop	Whether black border will be removed.	Applicable to the Single mode of Maruko and OneDimSingle mode of Iford
Out Width	Output image width after cropping.	Applicable to the Single mode of Maruko and OneDimSingle mode of Iford
Out Height	Output image height after cropping.	Applicable to the Single mode of Maruko and OneDimSingle mode of Iford
Correct Alpha	Strength 1 of horizontal straightening.	Applicable to the Single mode of Maruko and OneDimSingle mode of Iford
Correct Beta	Strength 2 of horizontal straightening.	Applicable to the Single mode of Maruko and OneDimSingle mode of Iford
Off X	The starting X coordinate of output image after cropping.	Applicable to the Single mode of Maruko and OneDimSingle mode of Iford
Off Y	The starting Y coordinate of output image after cropping.	Applicable to the Single mode of Maruko and OneDimSingle mode of Iford
Rotate	ISP rotation mode.	Applicable to the Single mode of

Setting	**Description**	**Note**
		Maruko and OneDimSingle mode of Iford
Region Mode	Region mode of LDC mode.	360_PANORAMA: 360-degree panoramic mode, suitable for fisheye lens ceiling-mounting and floor-mounting modes 180_PANORAMA: 180-degree panoramic mode, suitable for fisheye lens wall-mounting mode NORMAL: Normal calibration mode
Mount Mode	Sensor mounting mode.	DESKTOP: floor-mounting mode CEILING: ceiling-mounting mode WALL: wall mounting mode
Crop Mode	Regional cropping mode of LDC mode.	NONE: No cropping is performed. FILING: Process according to the principle of stretching, and then the effective area of the processed image will be cropped as much as possible for output. STRETCH: Process according to the principle of equal proportions, and the processed image will be cropped and enlarged according to the expected width and height ratio of the output image.
In Width	Input image width.	Applicable only to LenSpec and Single modes.
In Height	Input image height.	Applicable only to LenSpec and Single modes.
Out Width	Output image width.	Applicable only to LenSpec and Single modes.
Out Height	Output image height.	Applicable only to LenSpec and Single modes.
X Center Ofs	The horizontal offset of the image center point in relation to the physical center point.	Applicable only to LenSpec and Single modes.
Y Center Ofs	The vertical offset of the image center point in relation to the physical center point.	Applicable only to LenSpec and Single modes.
Radius	The radius of image.	Applicable only to LenSpec and

Setting	**Description**	**Note**
		Single modes.
In Radius	The inner radius of the original image corresponding to the calibration area.	Applicable only to 360-degree panoramic mode.
Out Radius	The outer radius of the original image corresponding to the calibration area.	Applicable only to 360-degree panoramic mode.
Pan	The horizontal rotation angle/starting angle of the expanded area.	Representing the starting angle of the expanded area in 360-degree panoramic mode.
Tilt	The vertical rotation angle/inner radius of the expanded area.	Representing the inner radius of the expanded area in 360-degree panoramic mode.
Zoom H	Image scaling/horizontal scaling ratio/end angle of the expanded area.	This value indicates scaling ratio in NORMAL mode, horizontal scaling ratio in 180-degree panoramic mode, and end angle of the expanded area in 360-degree panoramic mode.
Zoom V	Vertical scaling ratio/outer radius of expanded area.	This value is invalid in NORMAL mode, but it indicates vertical scaling ratio in 180-degree panoramic mode, and outer radius of the expanded area in 360-degree panoramic mode.
Rotate	Image rotation	Effective only in NORMAL mode.
Out Rotate	Rotation angle of output image.	3
Focal Ratio	Used to describe the distance to the projection surface. The larger the value, the smaller the curvature, and the smoother the picture. The smaller the value, the smaller the curvature, and the more curved the picture.	Effective in 180-degree and 360-degree panoramic modes.
Distortion Intensity	Distortion intensity	
Advance >>	Switch to advanced mode setting.	
<< Simple	Switch to simple mode setting.	
Run	Start calibration.	

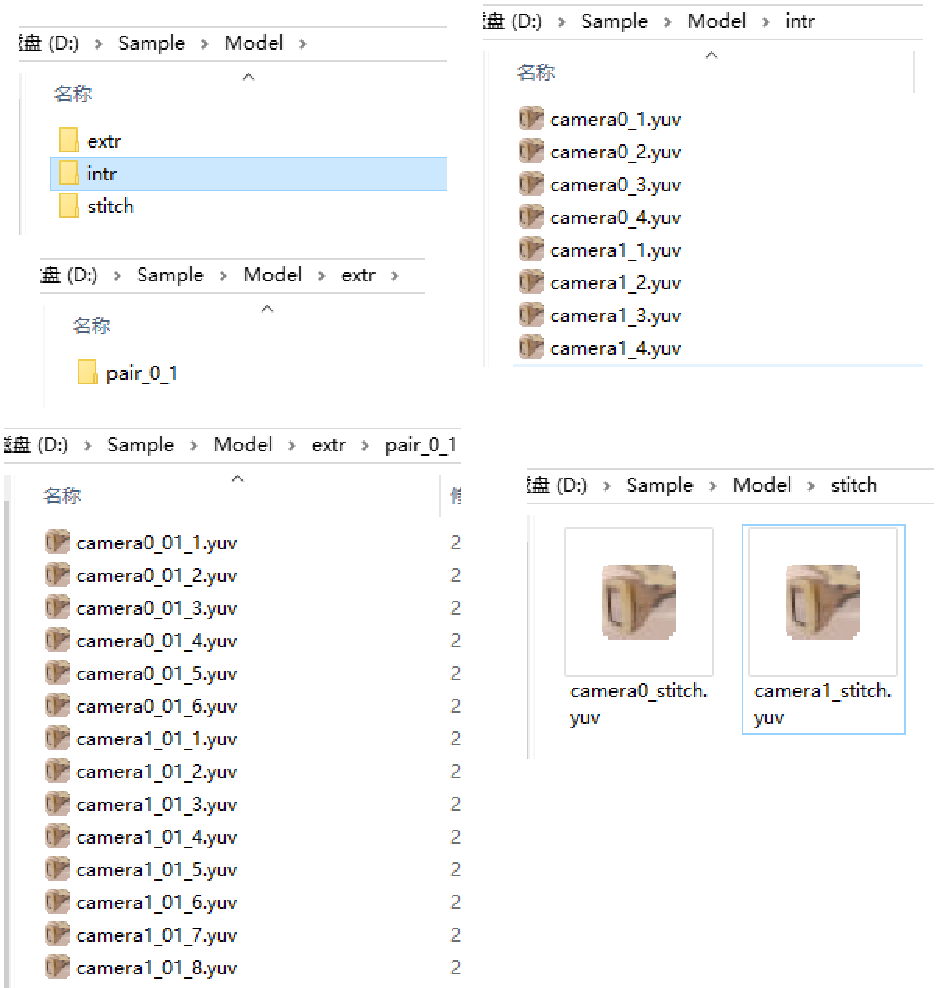


Figure 11: Directory Structure of Binocular Camera Model Calibration

Figure 12: Before Stitching

Figure 13: Stitching Rendering after Model Calibration

3.2.2 Production Line Calibration

Even though the same group of mechanism and sensor will have gone through model calibration in the lab, applying the calibration result directly to stitching will affect the final stitching result due to production assembly errors. Therefore, it is necessary to conduct production line calibration and make self-adaptive adjustment to both intrinsic and extrinsic parameters of cameras. To conduct production line calibration, a single camera will be picked up from each group of cameras and used to shoot a photograph, while a pair of cameras will be used to shoot a pair of photographs of the overlapping area. By doing so, a new bin file can be generated.

- Specifications of Calibration Checkerboard

  In order to improve the calibration precision, it is recommended to use a custom checkerboard calibration board. The side length of black and white checkerboard square should be 60 mm (physical unit), and the number of columns of internal corners in each overlapping area must be greater than or equal to 3 columns, while the edge of the checkerboard calibration board should retain at least 8 cm of white edge. These requirements are beneficial to the precision of internal corner detection. It should be noted that backlight and glare greatly affect the imaging effect of checkerboard, so you must pay attention to the lighting of production line environment during shooting, and try to avoid backlight projection as well as strong lights around the checkerboard.

- To Fix Calibration Checkerboard

  The shelf for fixing the checkerboard calibration board is shown in the figure below, and the specific parameters are also shown in the figure. Each shelf can hold two calibration boards. When fixing the upper and lower calibration boards, try to keep different angles.

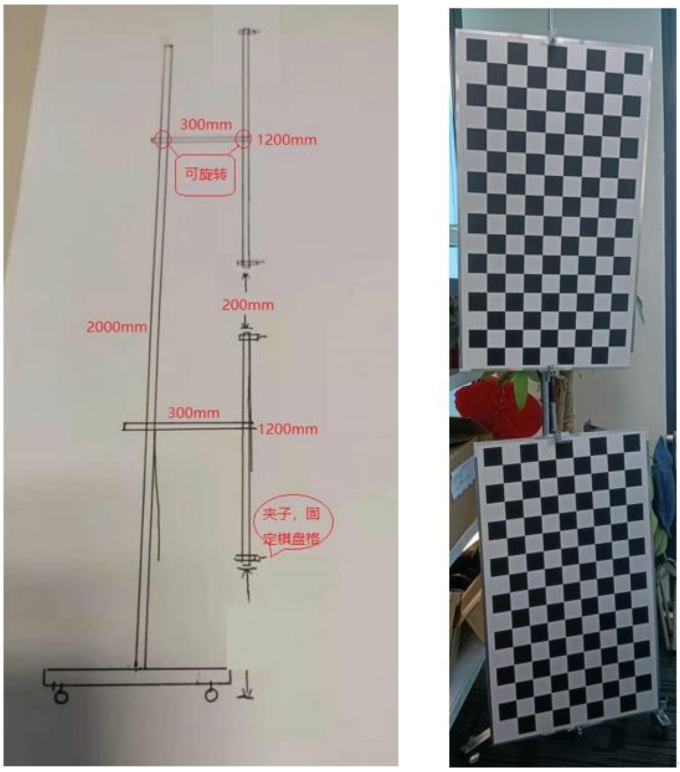


Figure 14: Fixing Calibration Checkerboard

- Camera Placement

  The schematic diagram of the shelf placement position of the fixed calibration board (four eyes) is shown in the figure below. The four rectangles in the middle of the figure represent four cameras, and the red solid line in the outermost circle represents the overlapping area of two adjacent cameras. It is used to calibrate the extrinsic parameters; the blue line represents the position of each camera, which is used to calibrate the intrinsic parameters. If you do not need to calibrate the intrinsic parameters, you can omit it. Taking the four eyes as an example, there are a total of 7 positions (7 solid lines in the outermost circle in the figure), and each position has 2 checkerboard grids, a total of 14 checkerboard grids.

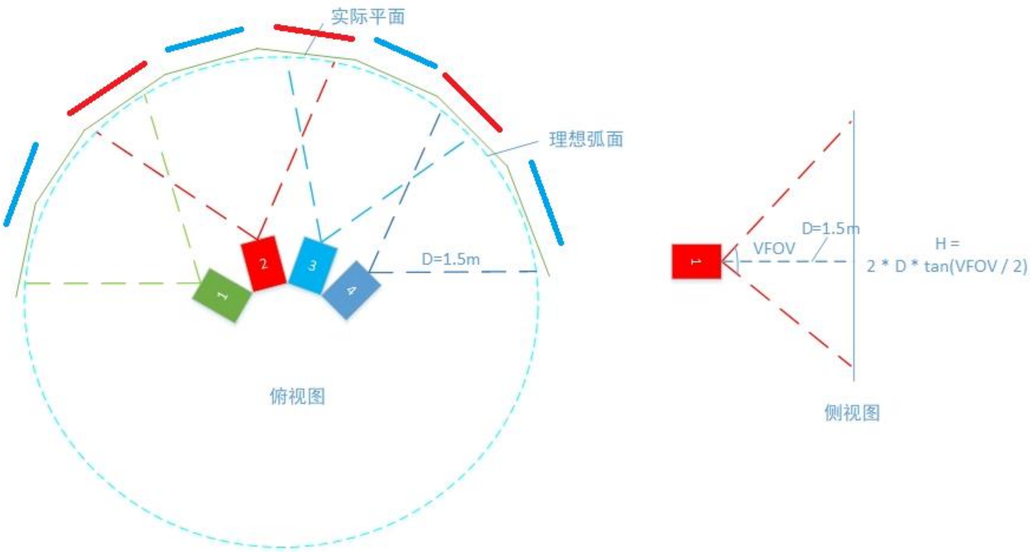


Figure 15: Checkerboard Placement for Production Line Calibration

- The distance between the shelf and the lens is related to the focal length of the camera, FOV and the ratio of the overlapping area. It is necessary to ensure that the captured internal corner points are clear, and that the number of internal corner points is sufficient (>= 3). To ensure the coverage of the checkerboard in the vertical direction will not be limited by the vertical height of the panel, we suggest that you set the distance within the range between 1 to 1.5 m. The distance is set to 1.5 m in the example.
- The angle in the horizontal direction is determined by the horizontal field of view of the multi-eye camera. For example, the horizontal FOV of the four-eye camera is about 180°, and the number of required shelves and checkerboards will also increase. In the example, 7 shelves and 14 checkerboards were used.
- The height of the panel in the vertical direction is determined by the vertical field of view (VFOV) and the distance of the panel, and the coverage should be as complete as possible. The formula is as follows:

$$H = 2 * \mathrm{D} * \tan\left(\frac{\mathrm{VFOV}}{2}\right)$$

In the formula above, H represents the height of the panel, D represents the distance from the panel to the camera, and VFOV represents the vertical field of view.

- Production Line Calibration Picture Shooting Requirements

  The images obtained by each camera need to meet the following requirements:

  a) The number of internal corner point columns should be greater than or equal to 3.
  b) the two checkerboards in the vertical direction should cover at least 75% and less than 90% of the entire overlapping area;
  c) For multi-camera calibration pictures, that is, paired calibration pictures with the same overlapping area, the two checkerboard in the horizontal direction should cover the entire overlapping area as much as possible; the wider the coverage, the better;
  d) The corners of the checkerboard are clear, without any obvious reflections/shadows that cause uneven brightness and darkness;

e) The clip for holding the checkerboards should be farther away from the black and white checkerboard squares;

- Shooting Pictures for Production Line Calibration
  a) See Figure 15 for the placement of checkerboards
  b) Use VLC, Potplayer or SigmaStar CV Tool to capture pictures, and name the pictures according to single camera calibration.

Figure 16: Example of Production Line Calibration Pictures

- Production Line Calibration Flow
  a) Create an empty main directory for the input and output of production line calibration. After that, create three empty directories "intr", "extr", "stitch" in the main directory, and then create empty directory "pair_i_i+1" in the extr directory, where "I" represents the number of the camera. Copy the model calibration output result — "calib_para folder" — to the main directory;
  b) Put single camera calibration pictures for the production line calibration into the intr directory, one from each camera;
  c) Copy the four pictures from production line calibration and place them in the corresponding pair_i_i+1 directory in the extr directory, where "i" represents the number of the camera. Taking four-eye camera as an example, there are camera0_0.yuv, camera1_0.yuv, camera2_0.yuv, camera3_0.yuv in the intr directory. There are three subdirectories — pair_0_1, pair_1_2, and pair_2_3 — in the extr directory, where camera0_0.yuv and camera1_0.yuv are stored in the pair_0_1 directory; camera1_0.yuv and camera2_0.yuv are stored in the pair_1_2 directory; camera2_0.yuv and camera3_0.yu are stored in the pair_2_3 directory;
  d) Place the offline stitching rendering testing picture in the stitch directory;
  e) Configure the parameters according to the steps in Figure 17. The meaning of the parameters is shown in Table 4: CV Tool Setting. If the parameters fail to meet the requirements, you may enter advanced mode;

f) Click Run to start production line calibration. After the calibration succeeds, the offline stitching rendering will be displayed, and the stitching parameter file **calib_out.json** and calib_parameter.txt(used for mi ldc) for the chip will be generated.

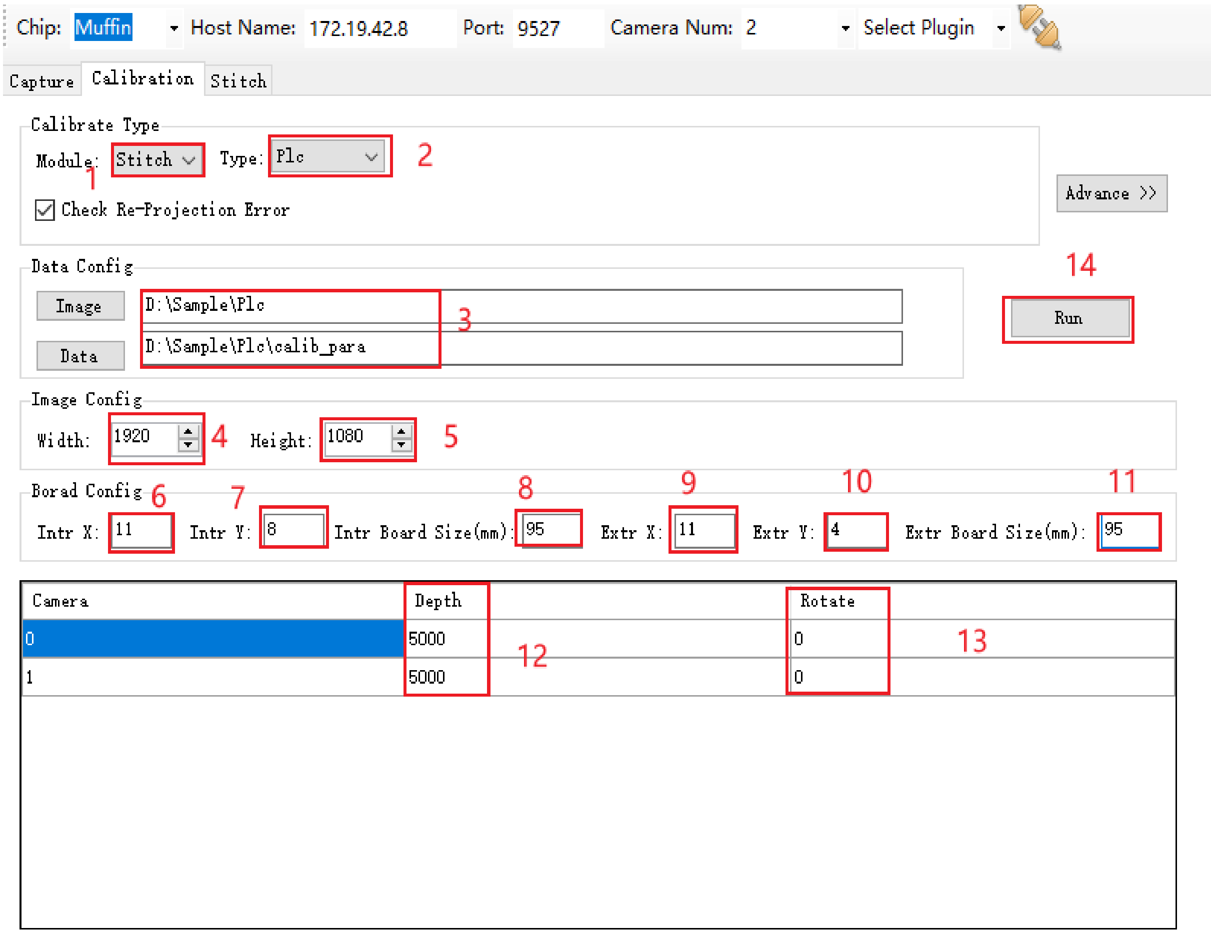


Figure 17: Using CVTool to Perform Production Line Calibration

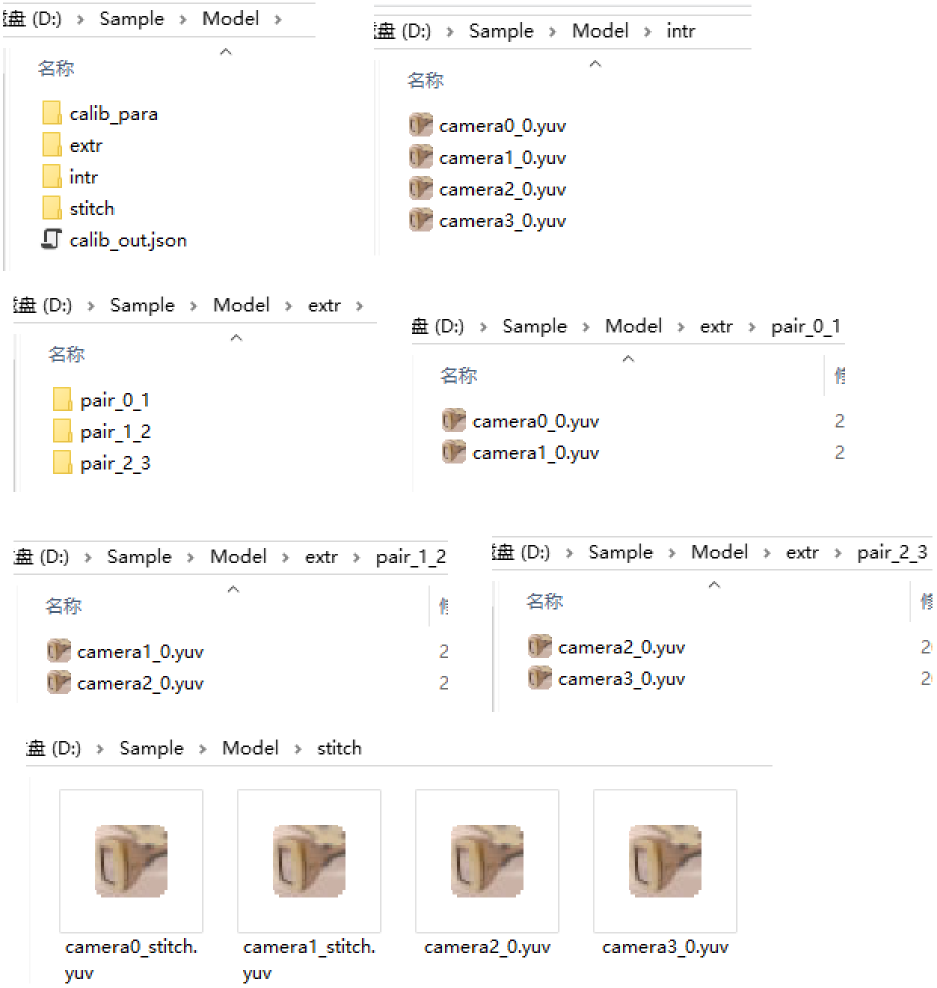


Figure 18: Directory Structure of Four-Eye Camera Production Line Calibration Pictures

Figure 19: Four-Eye Camera Production Line Calibration Rendering

- Precautions
  1. When shooting the checkerboard, make sure that there is sufficient light so that the contrast in photographs can be stronger;
  2. Make sure that checkerboard surface is clean, and there should be no reflective areas on the surface;
  3. Make sure that there is a certain distance between two checkerboards to prevent them from being detected as one checkerboard;
  4. The software calibration failure may be caused by the background process of the software. It is necessary to clear the background process and then re-enter the software;
  5. Pay attention to the clip that fixes the checkerboard. The clip should be fixed on the edge of the calibration board as much as possible, away from the black and white squares.

3.2.3 Auto Fine-Tune

After the camera is calibrated, the camera mechanism may shift due to environmental changes, transportation, etc. In other words, the results of model or production line calibration may no longer be applicable. In this case, you can use the function of Auto Fine-Tuning for fine-tuning to correct the offset that happens after calibration is done. Auto Fine-Tuning uses one of the cameras as a reference, and calculates the relative positional relationship between other cameras and the reference camera, so that the stitching misalignment can be optimized. It should be noted, however, that Auto Fine-Tuning can only be used as a supplementary measure after calibration, and it has certain limitations for on-site optimization based on calibration results.

- Auto Fine-Tuning Shooting Requirements
  a) Multi-camera simultaneous shooting (each camera only takes one picture);
  b) Auto Fine-Tune can only optimize small calibration misalignment, although larger dislocations can be corrected, the effect is limited;
  c) There must be complex features in the overlapping area, because Auto Fine-Tune relies on feature point detection. If the detected feature points are not obvious or there are many repeated features in the overlapping area, the calibration result may be deteriorated.
  d) Detailed textures should be evenly distributed as much as possible, and excessive concentration of details in the same area should be avoided.
  e) It is required that the image parallax is uniform and the depth of field is more than 6 meters. If the parallax is uneven, Auto Fine-Tuning will cause partial misalignment.
- Shooting Pictures for Auto Fine-Tuning

  Use VLC, PotPlayer, or SigmaStar CV Tool to shoot pictures with all lenses simultaneously, with each camera shooting only one photograph. Please refer to the section in Single Camera Calibration for the naming rule.

Figure 20: Example of Auto Fine-Tuning

- Calibration Flow
  1. Create an empty main directory to store the input and output of Auto Fine-Tuning, and create two empty directories — "in" and "stitch" — in the main directory;
  2. Put the calib_out.json output by the production line calibration or model calibration into the "in" directory of the main directory;
  3. Put the offline stitching pictures into the stitch directory;
  4. Put the individual pictures taken by each camera during the Auto Fine-Tune calibration process into the main directory, and the naming rules are the same as the naming rules for single-camera pictures taken in the model calibration;
  5. Configure the parameters according to the steps in Figure 21. For the parameters, please refer to the Table 6: CV Tool Setting. If the parameters cannot meet the requirements, you can enter the advanced mode;
  6. Click Run. After calibration succeeds, the offline stitching rendering will be displayed and the stitching parameter file calib_out.json for the chip will be generated.

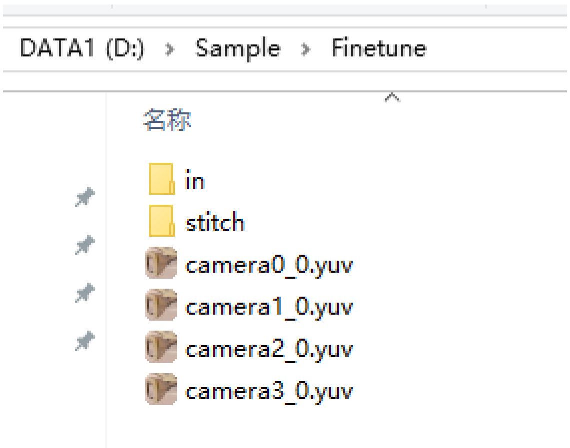


Figure 21: Directory Structure of Auto Fine-Tuning

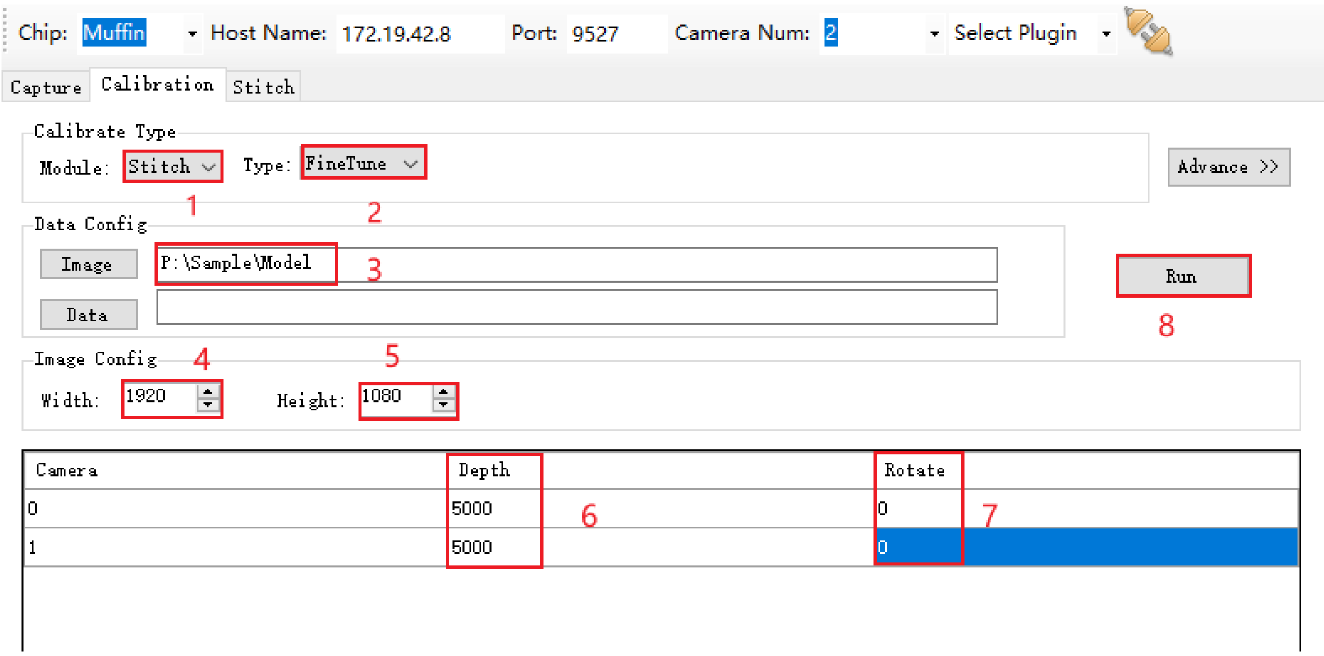


Figure 22: Parameters in CV Tool for Auto Fine-Tuning

- Precautions for Auto Fine-Tuning
  a) The pictures taken must include a rich variety of features, and large areas of white walls in the image should be avoided. If the number of feature points is too small (at least 4 pairs of matching points should be included), an error will be reported and re-shooting is required;
  b) The distance to the subject should be more than 6 meter, and the image depth should not change drastically, that is, the scene in the picture should be kept at a similar distance;
  c) There is a separate setting of object distance in the Auto Fine-Tuning configuration file at the place labeled 6 in Figure 22, and the object distance captured by the camera can be set during Auto Fine-Tuning calibration. Be careful not to confuse it with the object distance in the object distance used for stitching.

3.2.4 Single Camera Calibration

3.2.4.1. Calibration Based on Checkerboard Calibration Board

Single-camera calibration aims to obtain the intrinsic parameters of the camera and to correct the lens distortion of the camera based on the intrinsic parameters.

- Single Camera Calibration Picture Shooting

  Single-camera calibration is used to obtain the intrinsic parameters of the camera. For picture shooting, please refer to the section Photographing for Monocular Camera Calibration.

- Offline Rendering Picture Shooting

  The rendering pictures are used to display the rendering effect after single camera has undergone lens distortion correction. You can directly select or retake a picture from the single camera calibration pictures, and put it in the ldc directory. The images should be named as camera_ldc.jpg/yuv.

  Note: For fisheye lens, take a single overexposed picture, name it camera_AE.jpg/.yuv, and put it in the main directory.

- Single Camera Calibration Flow

  a) Create an empty main directory to store the input and output of the single camera calibration, and create two empty directories "intr" and "ldc" in the main directory;

  b) Put the pictures taken by single camera calibration into the "intr" directory;

  c) Put the offline rendering picture into the "ldc" directory, and the directory structure of the single camera calibration is shown in Figure 23;

  d) Configure the parameters according to the steps in Figure 24. The meaning of the parameters is shown in Table 6. If the parameters cannot meet the requirements, you can enter the advanced mode;

  e) Click Run to start the model calibration. After the calibration succeeds, offline stitching rendering will be displayed and the stitching parameter file calib_out.json for the chip will be generated.

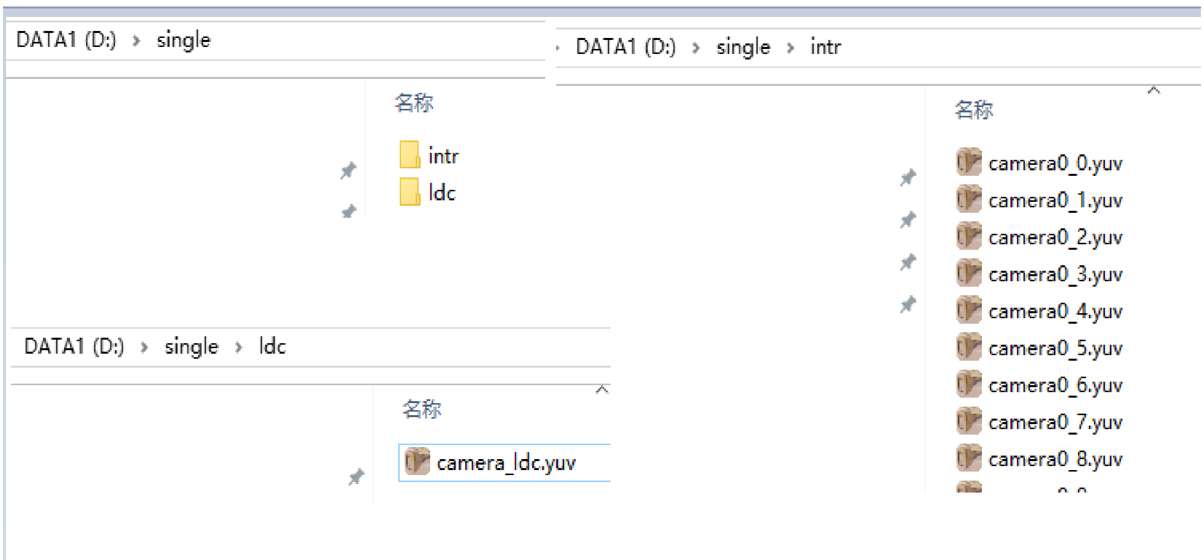


Figure 23: Directory Structure of Single Camera Calibration

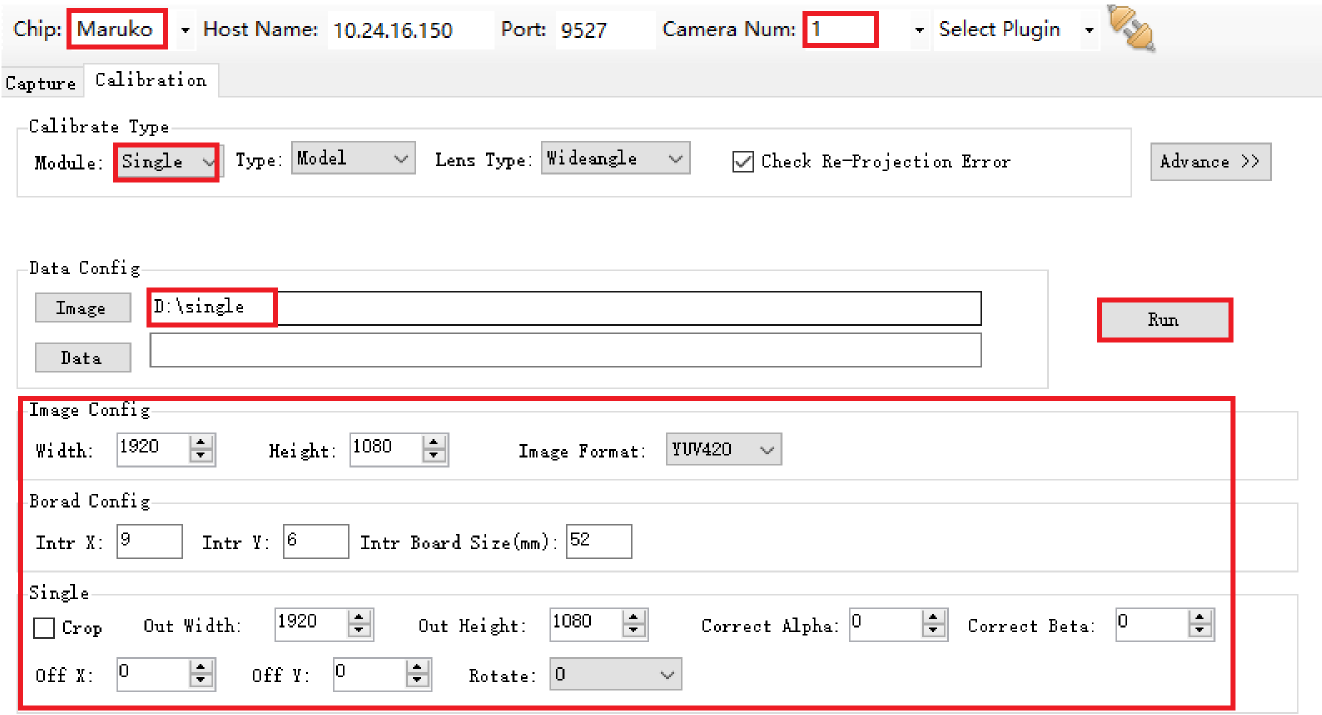


Figure 24: Workflow of Single Camera Calibration for MARUKO series

Note: Iford OneDimSingle mode is similar to Souffle, just change Chip to Iford and Module to OneDimSingle

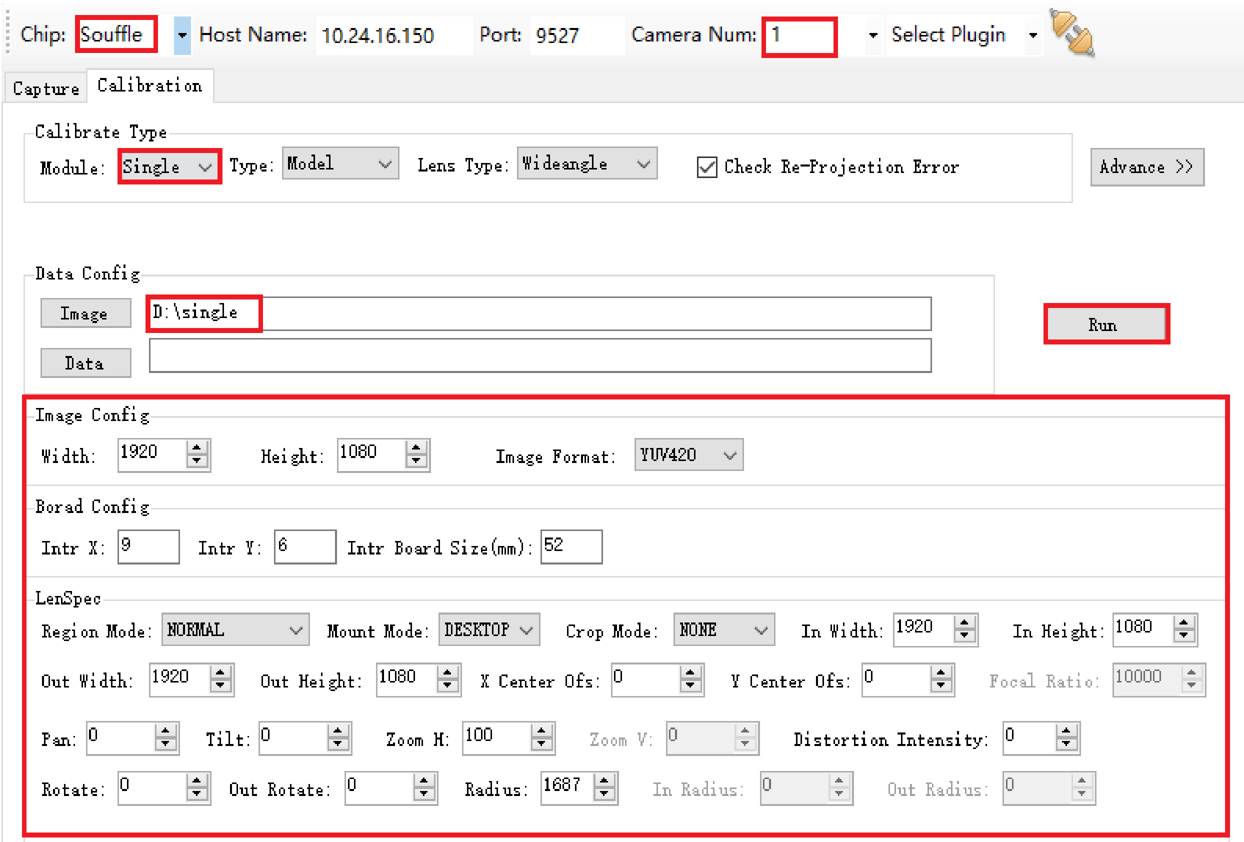


Figure 25: Workflow of Single Camera Calibration for Souffle series

Note:

(1). Maruko series generates calib_out.json in the main directory.

(2). Opera series generates mapX.bin and mapY.bin in the main directory.

(3). Souffle series generates CalibPoly_new.bin under poly/out.

(4). To obtain normal offline correction effects for Souffle series chips, it is necessary to backfill xc, yc, and radius in poly/out/LenSpec.dat generated by calibration to X Center Ofs, Y Center Ofs, and Radius respectively. The calculation method is as follows:

X Center Ofs = xc – In_Width / 2

Y Center Ofs = yc – In_Height / 2

Radius = radius

(5). Iford single mode is similar to Souffle, just change Chip to Iford

3.2.4.2. Lenspec Calibration

LenSpec calibration generates x, y map, or CalibPoly_new.bin based on lens parameter for the purpose of distortion calibration.

- LenSpec.data preparation.
- Shooting offline rendering images.

  The rendering is used to show the rendering after distortion correction. You can use the lens to take a normal picture and put it in the ldc directory. Pictures are named as follows: camera_ldc.jpg/yuv.
- Calibration Flow:
  - a) Create an empty main directory and create the ldc directory in the main directory;
  - b) Place LenSpec.data in the main directory;
  - c) Put the offline effect pictures in the ldc directory;
  - d) Configure parameters according to the steps in Figure 27 or Figure 28. See Table 6 for parameter description;
  - e) Click Run. After success, corresponding files will be generated in the directory.

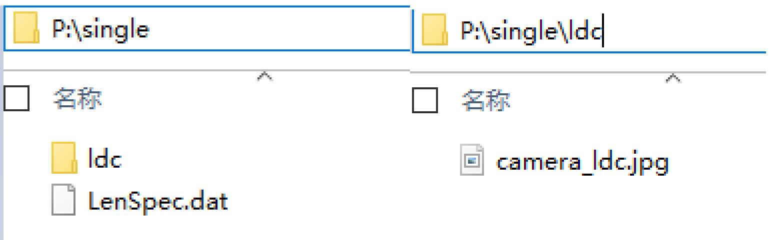


图 26 Directory Structure of LenSpec

Note:

1. SOC from Opera series generates mapX.bin, mapY.bin, and map_info.txt.
2. In non-Opera series, SOC generates CalibPoly_new.bin under poly/out/ directory.

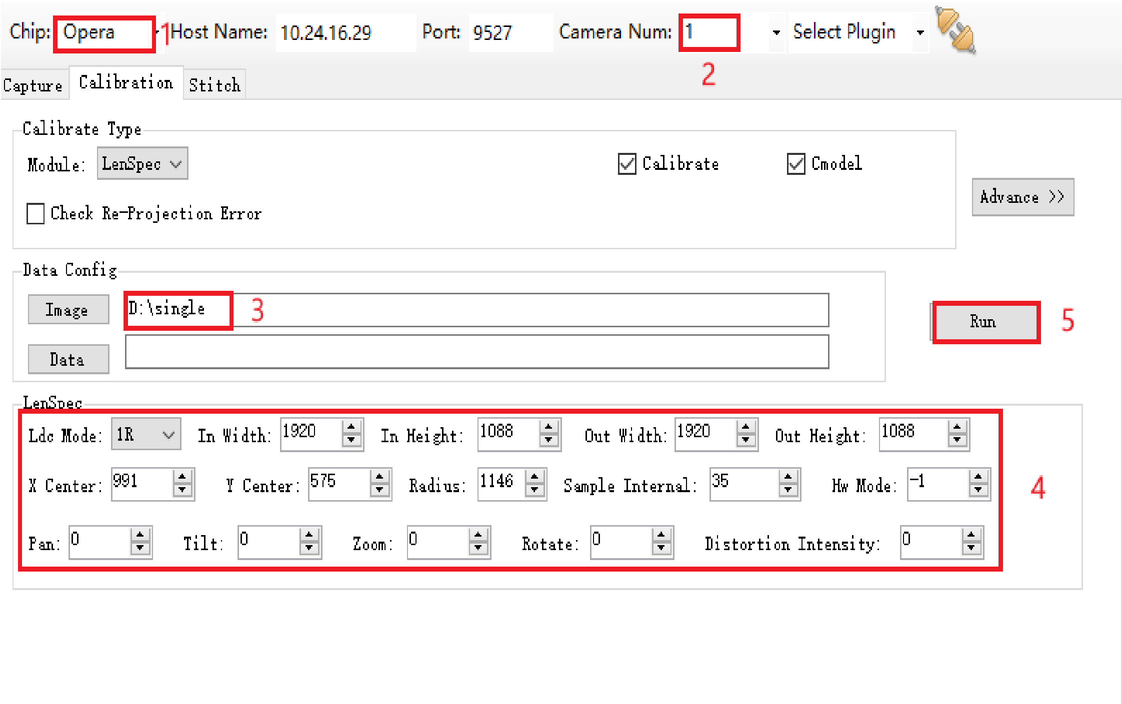


Figure 27: Opera Series LenSpec Calibration

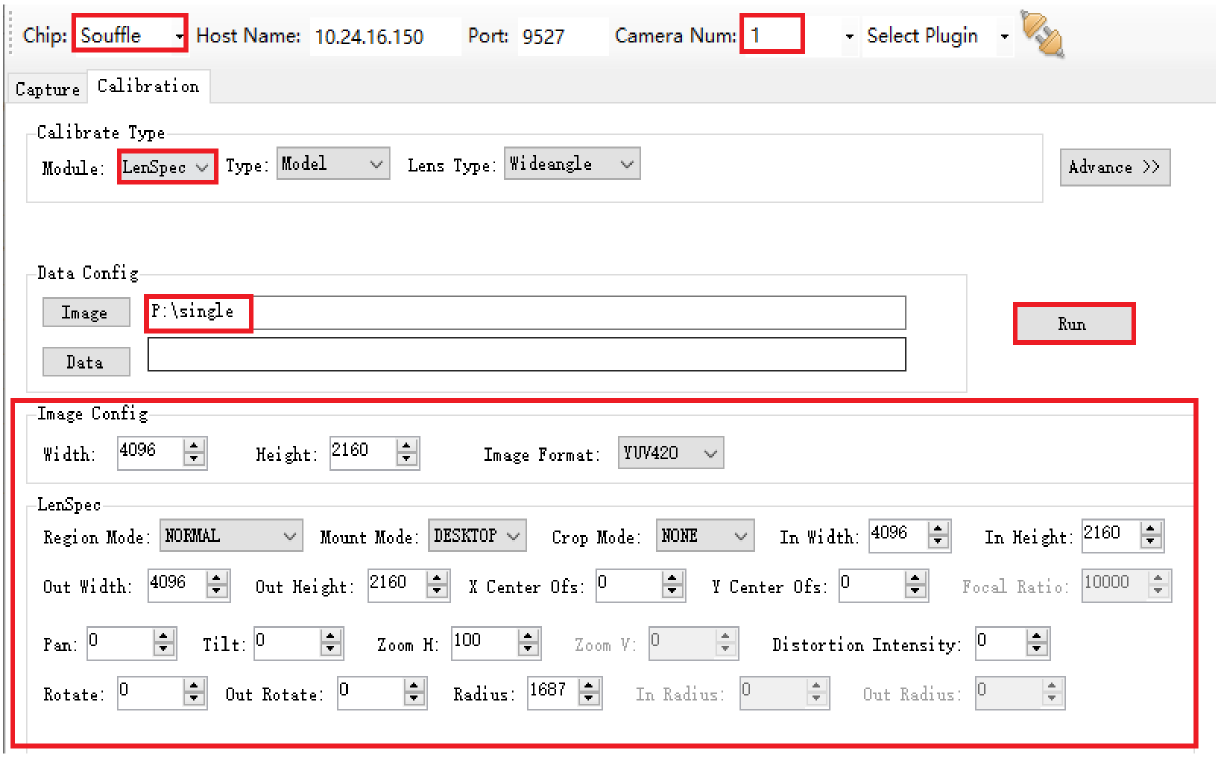


Figure 28: Souffle Series LenSpec Calibration

Note: Iford is similar to Souffle, just change Chip to Iford

3.2.5 NIR Calibration

NIR calibration calculates intrinsic and extrinsic parameters by taking checkerboard pictures, and fuses the same image collected by VIS and NIR into a new image.

- Monocular Camera Calibration Picture Shooting

  Monocular camera calibration is used to obtain the intrinsic parameters of the camera. For picture shooting, please refer to the section of Photographing for Monocular Camera Calibration.
- Binocular Camera Calibration Picture Shooting

  Binocular camera calibration is used to obtain the extrinsic parameters of the camera. For picture shooting, please refer to the section of Photographing for Binocular Camera Calibration.
- Offline Effect Picture Shooting

  The effect picture is used to display the post-calibration rendering. It can be directly selected from the calibration pictures of binocular camera or retake two pictures at the same time with two lenses, and put them in the NIR directory. The picture is named cameraX_Y_nir.yuv, where X is the lens number, and Y is the serial number of picture. The NIR offline effect requires at least 2 pictures.
- Calibration Flow
  a) Put the pictures for monocular camera calibration into the intr directory.
  b) Put the pictures for binocular camera calibration into the pair_0_1 directory under the extr directory.
  c) Put the picture of NIR cmodel in the NIR directory, at least two for each sensor.
  d) Configure relevant parameters according to the corresponding steps in Figure 29. Description of the parameters can be found in Table 7.
  e) Click Run to start calibration
  f) After calibration succeeds, parameter "calib_out.json" used by NIR will be generated in the Image directory. Meanwhile, "NIR_out_stream.jpg" (rendering picture of cmodel) will also be generated in nir_cmodel directory.

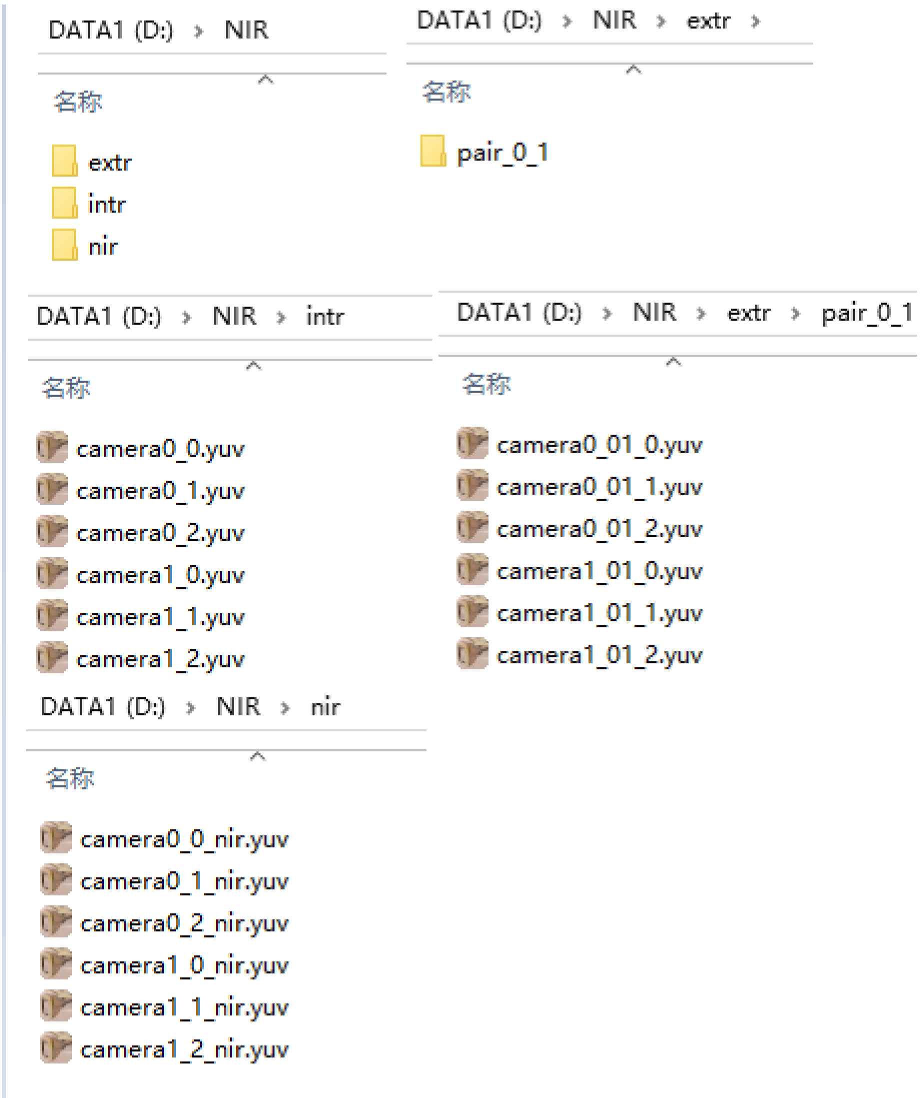


Figure 29: Directory Structure of NIR Calibration Picture

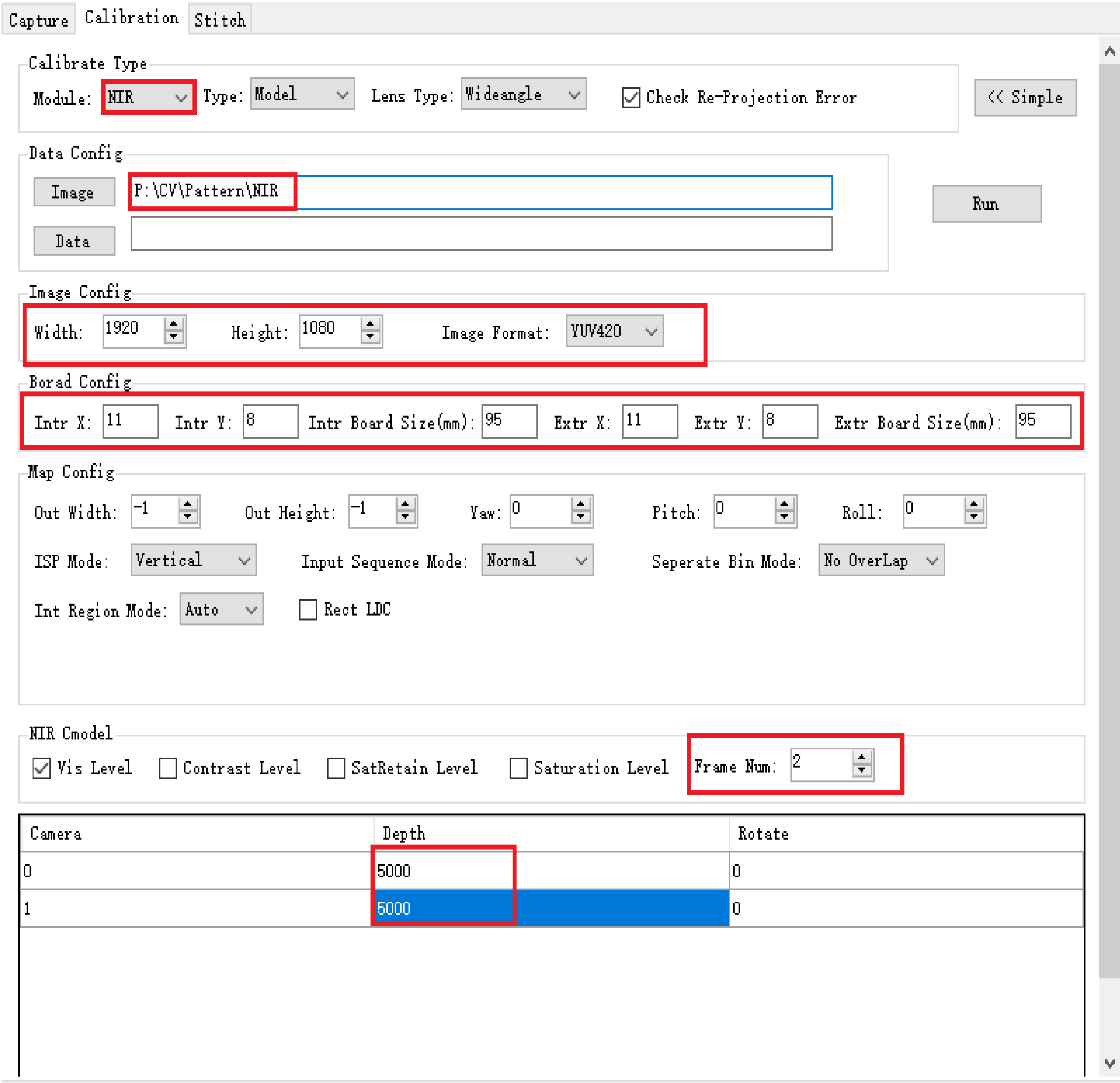


Figure 30: Workflow of NIR Calibration

3.2.6 Parameter Description of calib_out.json

After calibration by CV Tool is finisheds, a calib_out.json file will be output to the main directory. The calib_out.json file consists of two major sections — CalibInfo and mapgen, and the following two tables are set out for the description of their parameters.

- CalibInfo (All parameters and their values in this section cannot be modified)

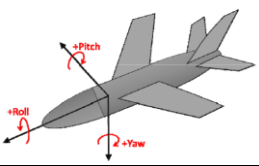
Table 7: Parameter Description of CalibInfo

Parameter	**Definition**	**Notes**
module	Select calibration module.	Stitch: Stitch; NIR: Near-infrared Fusion; DPU: Deep learning Processing Unit; Single: Single Camera Calibration.
inputType	Select calibration type.	0: Model Calibration; 1: Production Line Calibration; 3: Finetune.
imgWidth	The component of width in the resolution of calibration image.	
imgHeight	The component of height in the resolution of calibration image.	
imgDepthList	The best stitching distance, in the unit of mm.	The number of distances should correspond to the number of camera lens. Eg. If the best stitching distance is 2m, you should set "2000,2000" for binocular camera; "2000, 2000, 2000" for trinocular camera.
rotateAngleList	The rotating degree of each lens. Currently, 0, 90, and 270 degrees are supported. Set this parameter by looking at calibration images and see how many degrees are needed to rotate the image clockwise to the right position.	The number of rotation angles corresponds to the number of camera lens. Eg. If there are two lenses, and the calibration images captured by them should be rotated clockwise by 90 degrees, you should set this parameter to "90, 90".
camNum	The number of lens.	Eg. Set it to two if you are calibrating binocular cameras.
camIDList	The list of lens ID.	Eg. Set it to "0, 1," if you are calibrating binocular cameras; "0, 1, 2," for trinocular camera.
camPairNum	The number of pairs for multi-lens camera.	"1" pair if you are using binocular cameras; "2" pairs for trinocular camera.
camPairIDlist_0	The first list of paired lens.	Eg. Set it to "0, 1," if you are using trinocular camera.
camPairIDlist_1	The second list of paired lens.	Eg. Set it to "1, 2," if you are using trinocular camera.
camOffxList	Default is 0, and no modification is needed.	
camOffyList		
imgEdgeTopList		

Parameter	**Definition**	**Notes**
imgEdgeBottomList		
imgEdgeLeftList		
imgEdgeRightList		
mapProjType	Projection type.	0: Linear Projection; 1: Cylindrical Projection; 2: Spherical Projection; 3: Fish-eye Projection; 4: Mercator Projection.
mapCropType	Cropping type.	0: No cropping; 1: Horizontal cropping; 2: Vertical cropping; 3: Both horizontal and vertical cropping.
optimalFocal	The best focal length.	The value is estimated by calibration.

- mapgen

Table 8: Parameter Description of mapgen

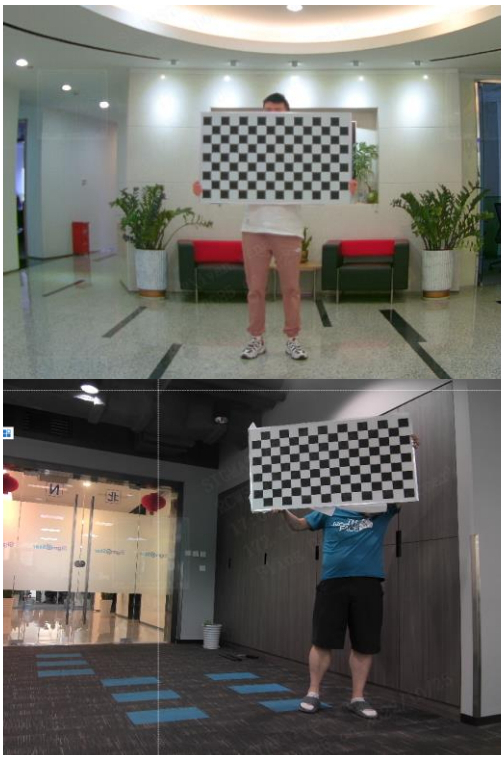
Parameter	**Definition**	**Notes**
scaleWidth	The width of output image.	● If only one of the two parameters is -1, the parameter value will be automatically adjusted with the other; ● If both parameter values are set to -1, the parameter value will be automatically calculated by the algorithm.
scaleHeight	The height of output image.	
in_seq_mode	The distribution sequence of input images in memory.	0: Negative; 1: Normal.
src_mode	The mode of distribution of input images in memory.	0: vertical; 1: horizontal.
yaw	Rotate along the X-axis in three-dimensional coordinates.	The adjustment of the attitude angle in three directions is used to adjust the position of the image on the projection plane.
pitch	Rotate along the Y-axis in three-dimensional coordinates.	
roll	Rotate along the Z-axis in three-dimensional coordinates.	
autoCalcMode	Whether the images of effective area should be auto-calculated.	1: Auto; 0: Manual.

Parameter	**Definition**	**Notes**
FOVX	The horizontal FOV of output image.	This parameter is enabled only when autoCalcMode is set to 0. This parameter should be set along with output image size, which are scaleWidth and scaleHeight.
FOVY	The vertical FOV of output image.	
prjCenterX	The X-axis coordinate of the center point of the projection.	
prjCentery	The Y-axis coordinate of the center point of the projection.	
camRotation	For internal algorithms only; no need to change.	
outputPath		
gridSize		
seprate_bin_mode		
preCropType		
ovp_capacity		
ovp_max_width		
updateBinMode		
hw_mode		
VerticalNum		
out_seq_mode		

4. APPENDIX

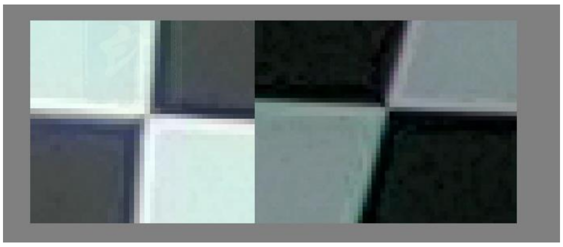
This chapter shows several pairs of bad IQ rendering versus perfect IQ rendering;

1. The quality of the checkerboard is blurred; (Top: blurry picture quality; Bottom: better picture quality)

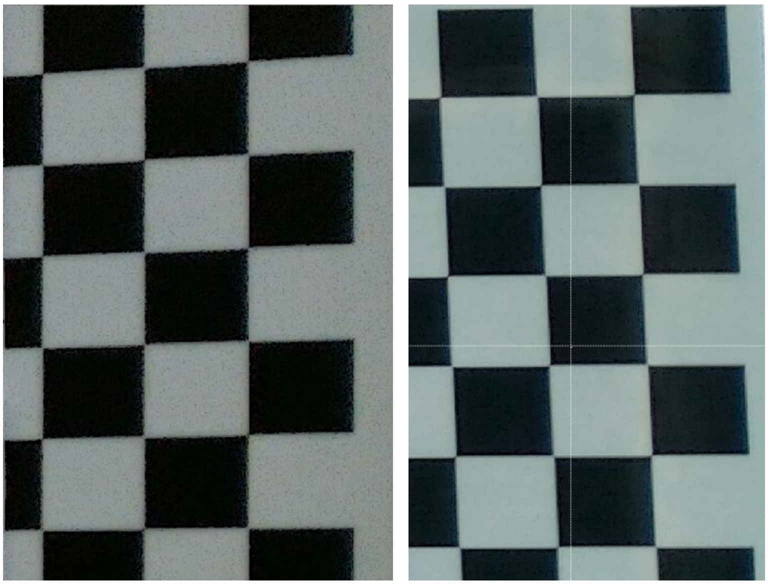


2. Transition area inside the diagonal black square of the checkerboard is too large, and the corner points cannot be accurately identified by the naked eye; (Left: the transition area is too large; Right: the transition area is small.)

3. The sharpened white edge of the checkerboard squares is too wide, resulting in imprecise corner detection; (Left: sharpened white edge is too wide; Right: sharpened white edge is narrower.)



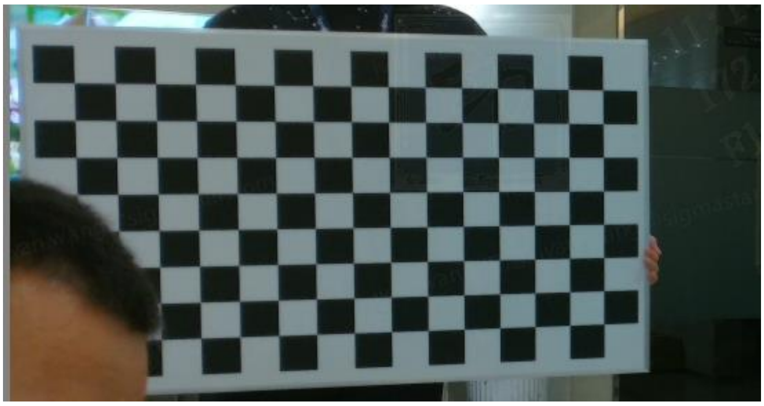
4. Too many noise points occur in the picture, and the noise intensity is high; (Left: before brightness adjustment; Right: increase picture brightness and exposure time.)



5. Glare/shadow that cause uneven brightness and darkness should not appear in the picture, otherwise the corner points will not be detected; (the following picture shows corners failing to be detected due to strong glare.)

6. The black and white squares of each checkerboard must be completely photographed, otherwise the corner points will not be detected; (the following picture shows the first row of black squares on the top being incomplete, resulting in corner points not being detected.)

7. During shooting, do not touch the black and white squares in the checkerboard with your hands, and do not block the view of squares, otherwise the corner points will not be detected;



- Relatively perfect IQ renderings (the corners are clearly visible to the naked eye).