VM and SC camera calibration module introduction -Basic

Hugh

2023-5-30

Course schedule

1 Introduction to VM Calibration Module

2 Introduction to VM board calibration

3 Introduction to VM distortion calibration

4 Introduction to VM N-point calibration (9-12 points)

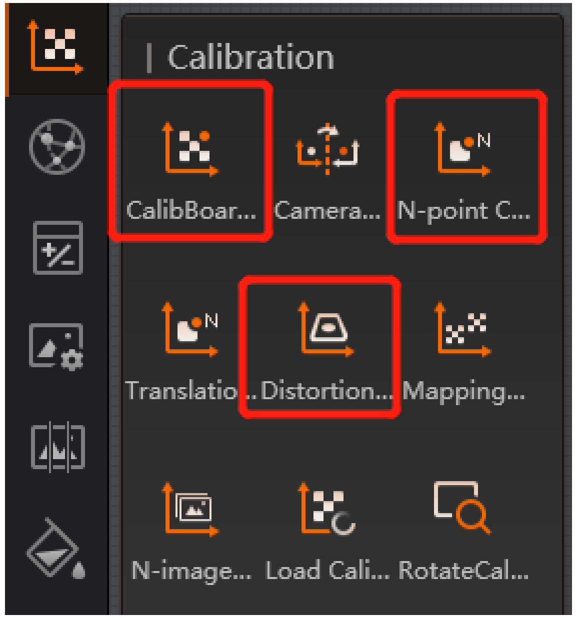
5 Introduction to SC N-point calibration (9-12 points)

1. Introduction to VM Calibration Module

• 1.1 Introduction

Feature:

The commonly used calibration tools include calibration board calibration tools, distortion calibration tools, N-point calibration tools, etc..



CaliBoard Calibration： By inputting the calibration board image and outputting the conversion relationship from the image coordinate system to the physical coordinate system

Distortion calibration： A tool for calibrating distorted calibration board images and generating distortion correction files

N-point calibration: Calculate the transformation relationship from the coordinate system of image points to the coordinate system of physical points by inputting point set pairs.

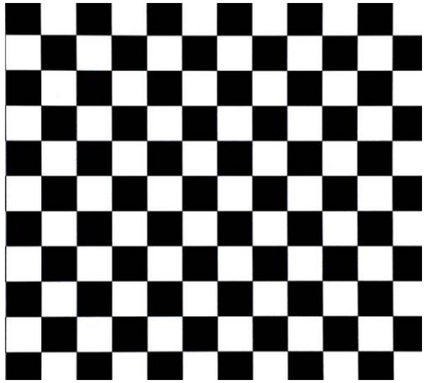
1. Introduction to VM Calibration Module

• 1.2 Calibration board type

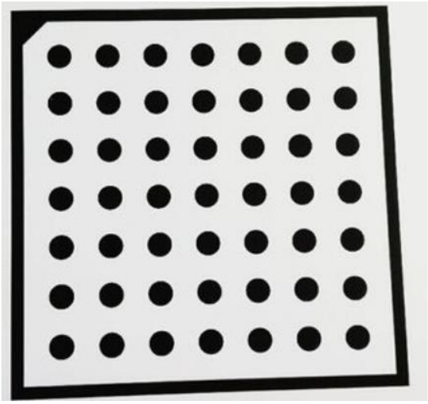
It mainly includes a checkerboard calibration board, a dot matrix calibration board, HIK Type I calibration board and HIK Type II calibration board.

- ✓ Type I calibration board consists of one self-developed code occupying four checkerboard positions;
- ✓ Type II calibration board is a self-developed code placed in the white space of the calibration board;

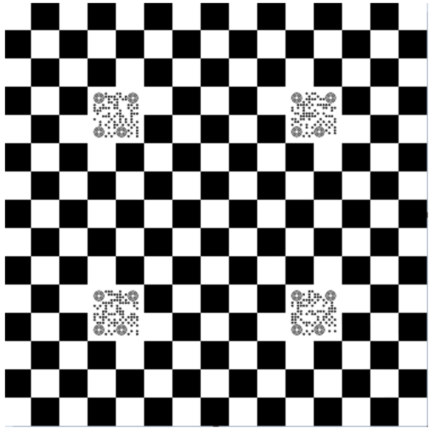
Calibration module	Supported calibration board types
CaliBoard calibration	All can work.
Distortion calibration	Checkerboard calibration board or circle calibration board
N-point calibration	All cannot, not use calibration board



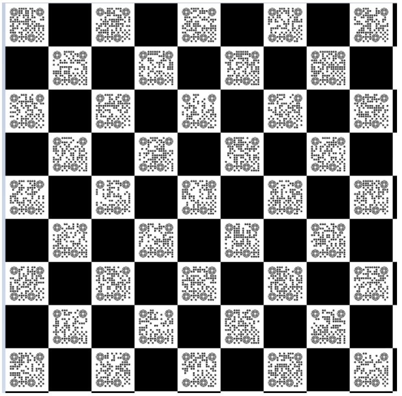
Checkerboard



Dot matrix



HIK Type I calibration board



HIK Type II calibration board

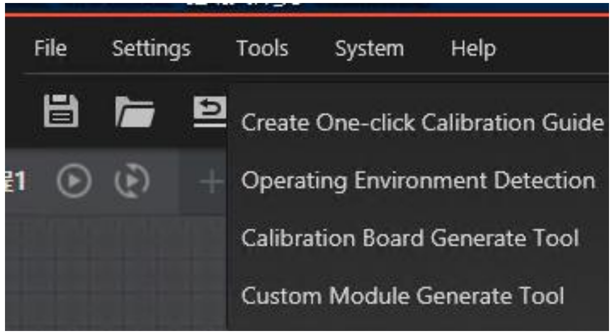
1. Introduction to VM Calibration Module

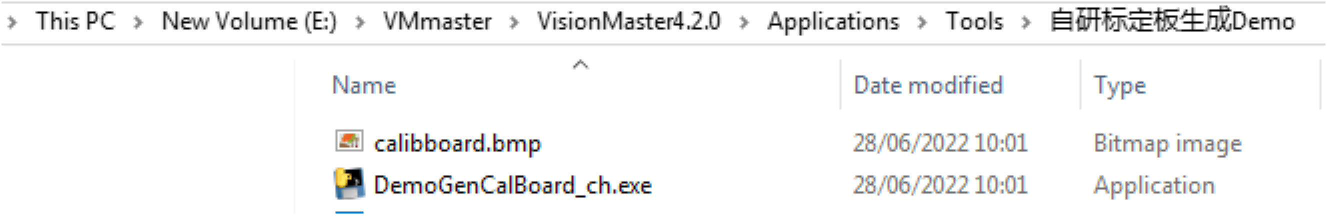
• 1.3 Calibration board generation tool

Calibration tool position:

HIK type I/II calibration board can be generated through the built-in calibration board generation tool.

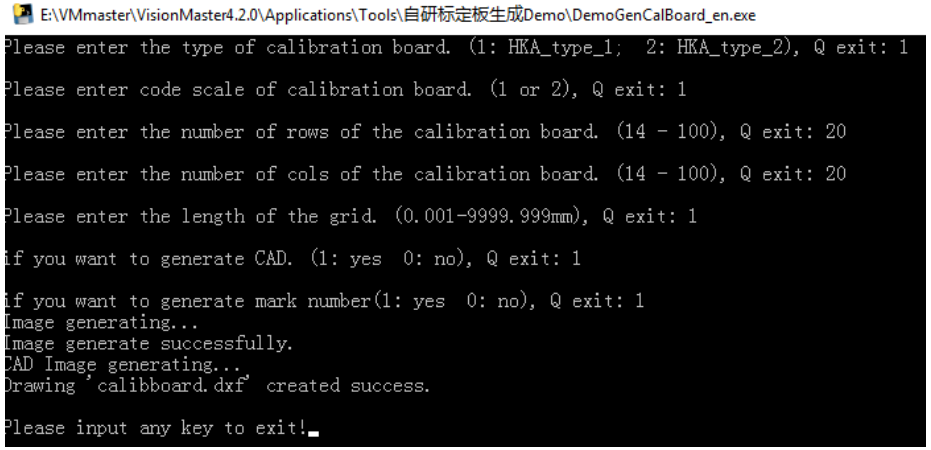
For VM400 and later versions, the calibration board generation tool can be directly found on the Tools tab.





Steps for using calibration tools:

1. Select HIK Type I/II calibration board according to requirements
2. Set the number of calibration board rows/columns;
3. Set the spacing between checkerboards, where it represents the width of a single checkerboard on the printed calibration board, in millimeters;
4. Choose whether to generate CAD drawings;
5. Choose whether to generate checkerboard markers;
6. After generation, bmp and dxf filecan be found in \VisionMaster4.1.0\Applications\Tools\自研标定板生成Demo



Course schedule

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1 Introduction to VM Calibration Module

2 Introduction to VM Caliboard calibration

3 Introduction to VM distortion calibration

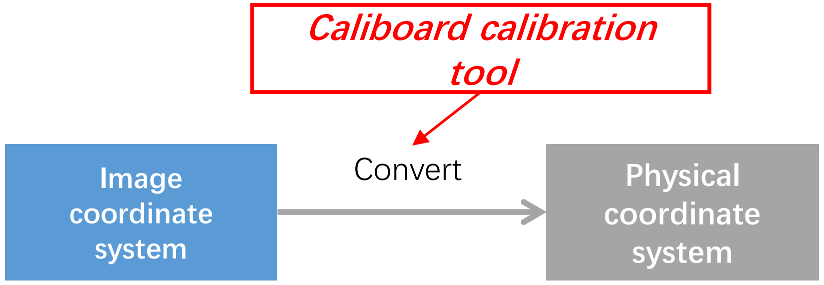
4 Introduction to VM N-point calibration (9-12 points)

5 Introduction to SC N-point calibration (9-12 points)

2. Introduction to VM Caliboard calibration

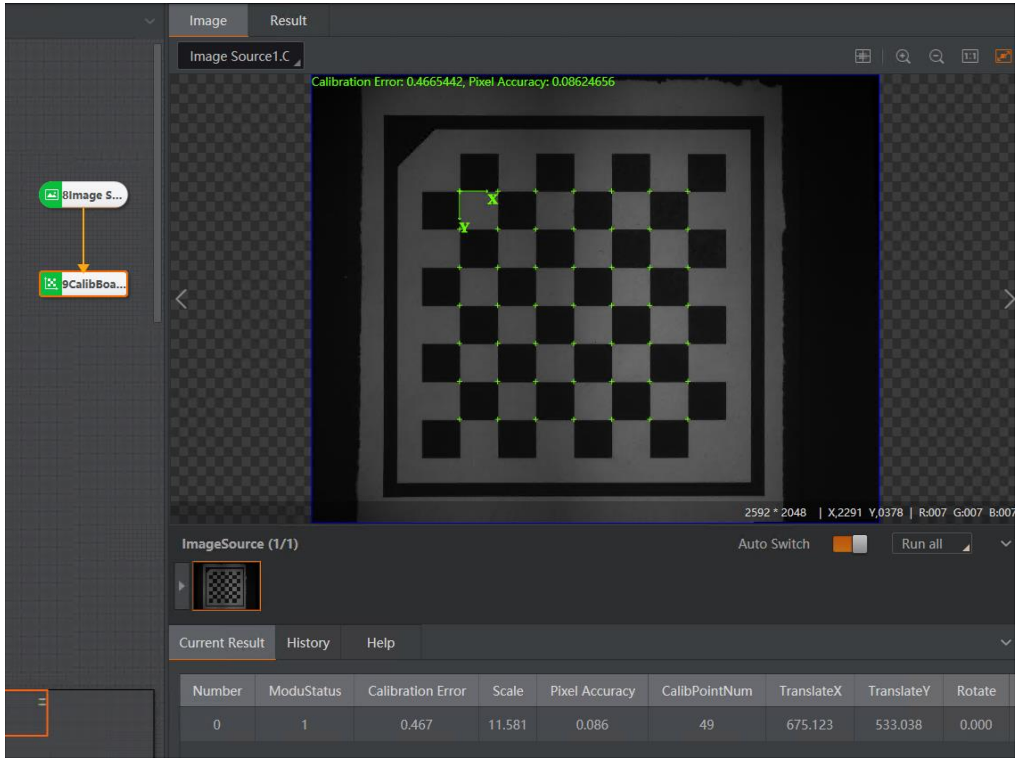
- **2.1 Function Introduction and VM Process Example**

By inputting the calibration board image and outputting the conversion relationship from the image coordinate system to the physical coordinate system (calibration file)



Step 1: Use the calibration board to obtain the calibration file.

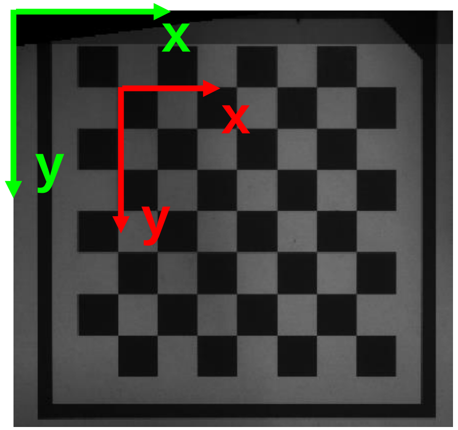
Step 2: Convert the coordinates of points in the image to corresponding coordinates in the physical coordinate system by using calibration file.

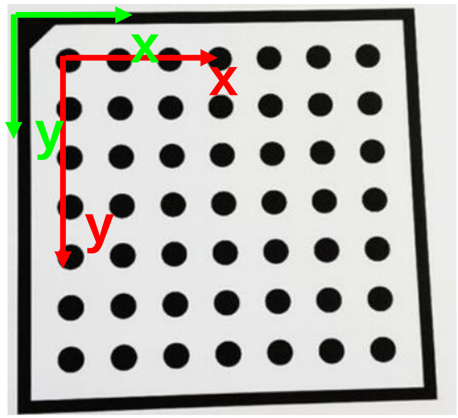


VM Process Example

2. Introduction to VM Caliboard calibration

- **2.2 Calibration board calibration tool: image coordinate system and physical coordinate system**



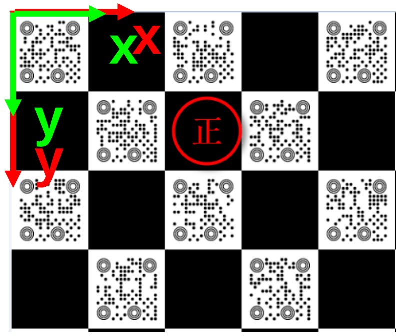


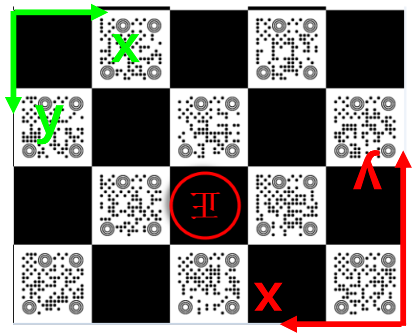
Green represents the image coordinate system, and red represents the physical coordinate system

1. **Image coordinate system**： The image coordinate system takes the top left corner of the image as the origin, horizontally to the right as the X axis, vertically to the bottom as the Y axis, corresponding to the green sign in the image.

2. Physical coordinate system: The physical coordinate system defaults to the coordinate system where the calibration board feature point (or circle point) is located, with the top left corner feature point as the origin. Corresponding to the red coordinate system in the figure.

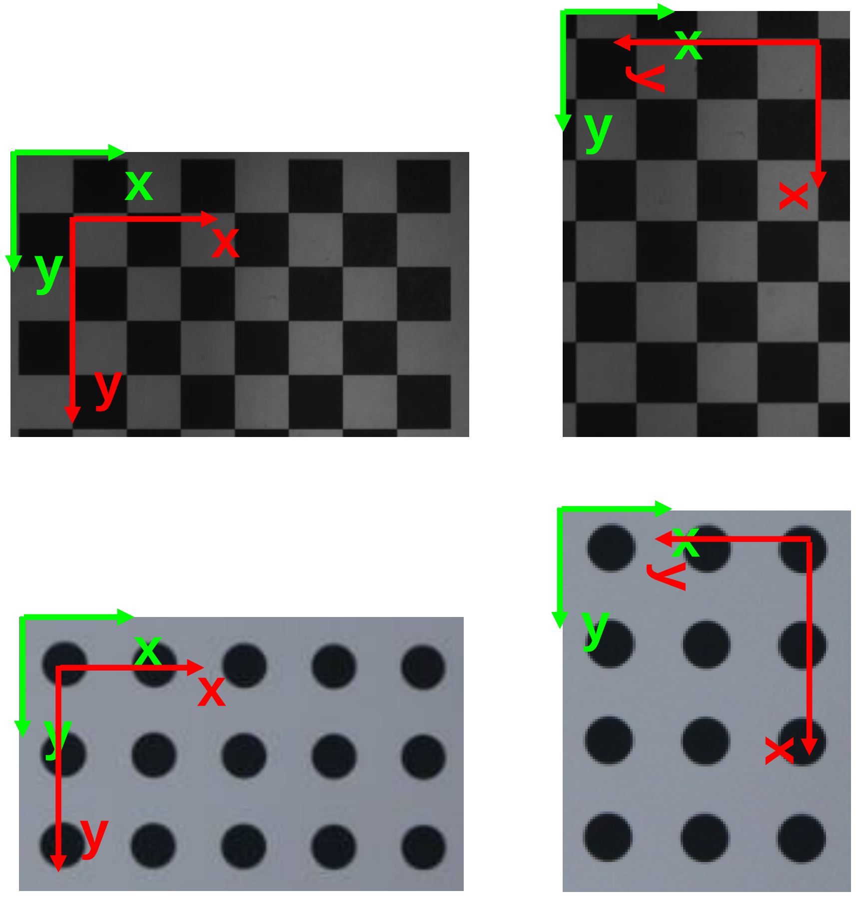
3. For self-developed calibration boards: Due to the self-developed code recording the physical coordinate information and direction information of corner points, regardless of how the calibration board is placed, there is the same default physical coordinate system.





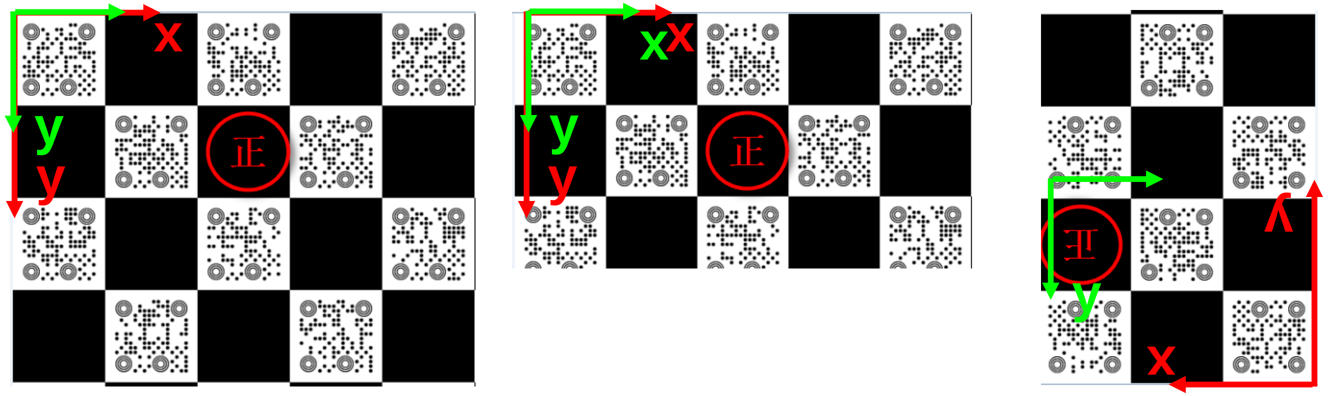
2. Introduction to VM Caliboard calibration

- **2.2 Calibration board calibration tool: image coordinate system and physical coordinate system**



Notice:

1. When the number of rows of extracted corner points exceeds the number of columns, the position and direction of the coordinate system will change, and the direction with more feature points is the X-axis direction;
2. For self-developed calibration boards, there is a self-developed code to record the physical and directional information of corner points, so regardless of how the calibration board prevents it, there is the same default physical coordinate system.

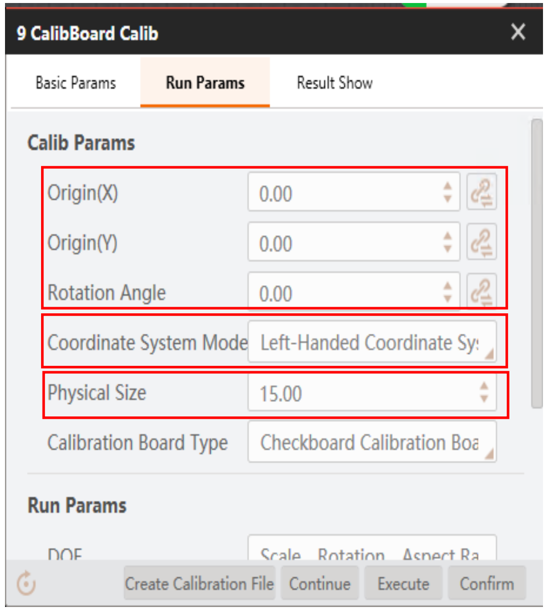


Green represents the image coordinate system, and red represents the physical coordinate system

2. Introduction to VM Caliboard calibration

- **2.2 Parameter setting**

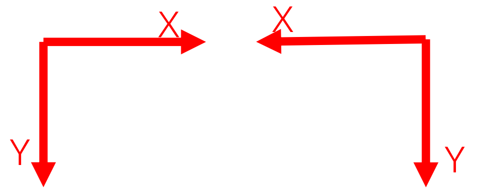
Caliboard calibration module:



The origin X and Y are the physical coordinates of the origin, and the coordinates of the origin can be set;The rotation angle can set the direction of the physical coordinate system

Select Left/Right Hand Coordinate System

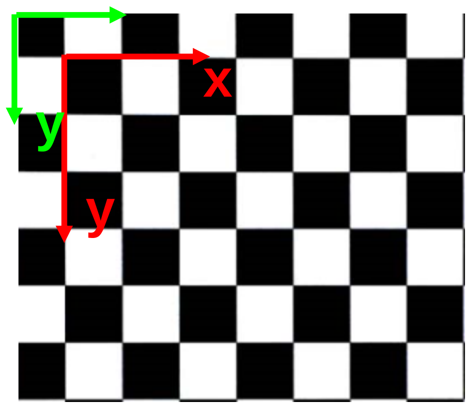
The edge length of a single checkerboard grid or the distance between the centers of two adjacent circles in a dot matrix, **in millimeters**



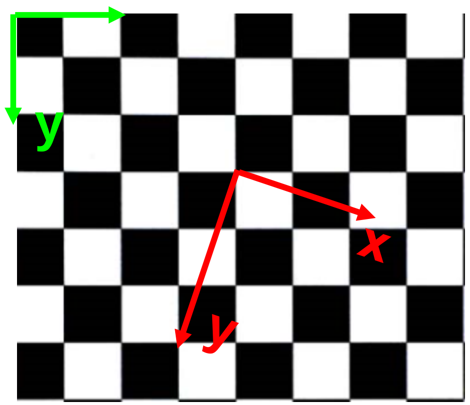
Left hand

Right hand

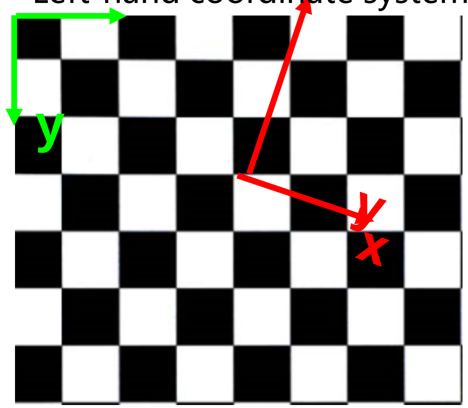
This coordinate system only supports planar inspection in both XY and XY directions, and cannot provide 3D detection of the Z-axis



Origin X and Y : (0, 0)
The rotation angle: 0
Physical size:1
Left-hand coordinate system



Origin X and Y : (3,2)
The rotation angle: 25
Physical size:1
Left-hand coordinate system



Origin X and Y : (3,2)
The rotation angle: 25
Physical size:1
Right-hand coordinate system

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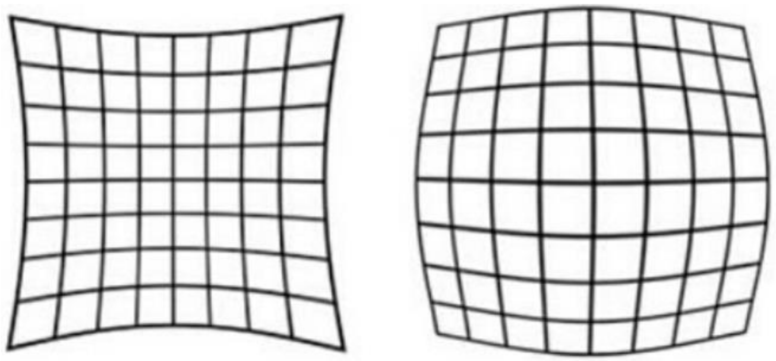
3. Introduction to VM distortion calibration

• 3.2 Introduction to Distortion Types

Radial distortion: refers to the distortion generated along the radial direction with the center of the distortion (usually the center of the image) as the center point. The farther away from the center point, the greater the distortion.

Perspective distortion: refers to the distortion of near large far small. When there is perspective distortion, the width of the checkerboard grid is near large far small. After correction, the grid size of the checkerboard grid is exactly the same. All grid widths are corrected based on the grid width near the set correction point.



Radial distortion

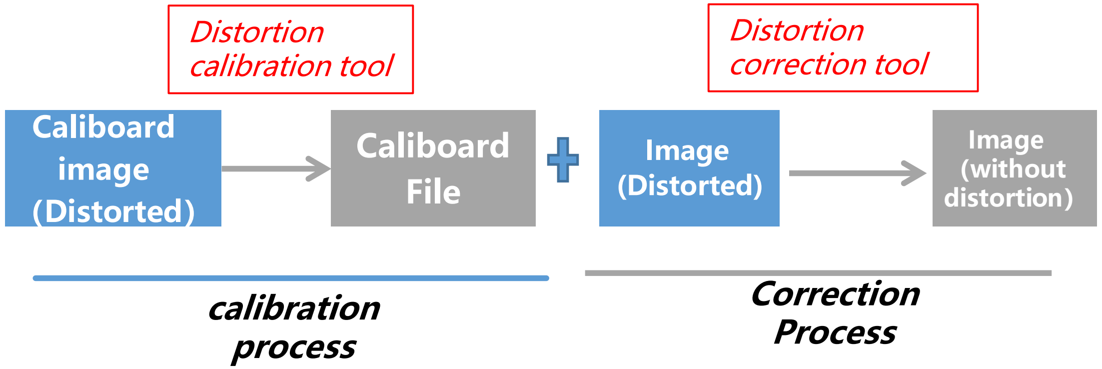
Perspective distortion

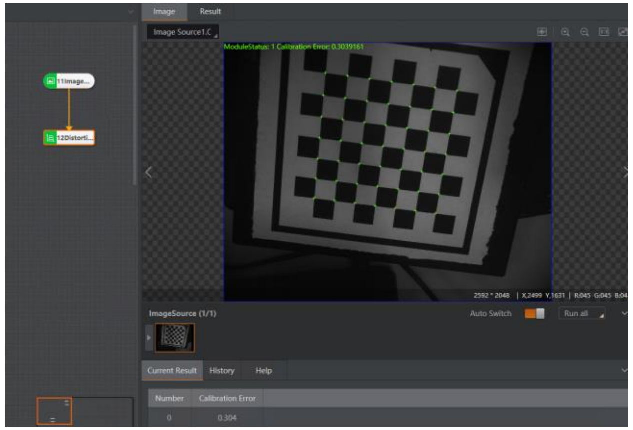
3. Introduction to VM distortion calibration

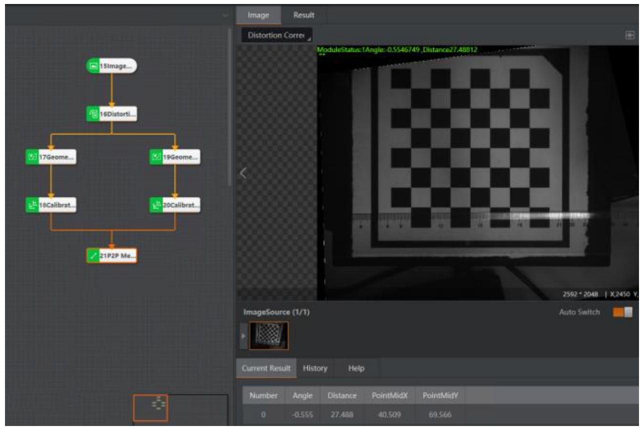
• 3.1 Function Introduction and VM Process Example

Distortion calibration: Calibrate the distorted calibration board image and generate the corresponding distortion correction file.

Distortion correction: Based on the distortion correction file, the input image with distortion is corrected to obtain a distorted image.

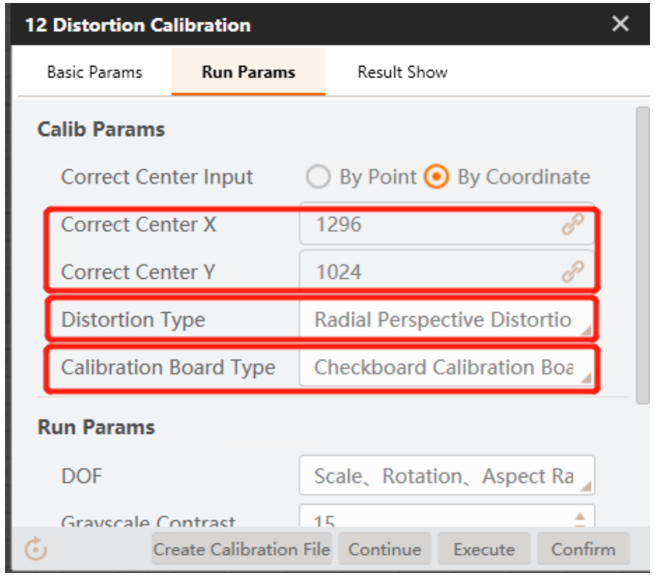






3. Introduction to VM distortion calibration

- **3.3 Parameters setting: distortion calibration**



Set correction center

Set distortion type

Set calibration board type

Set calibration parameters to obtain image points

Step1: Clink create calibration file

Step2：The correction center can be set to the center of the entire image, especially when there is radial distortion in the distortion

Step3：Set distortion type；

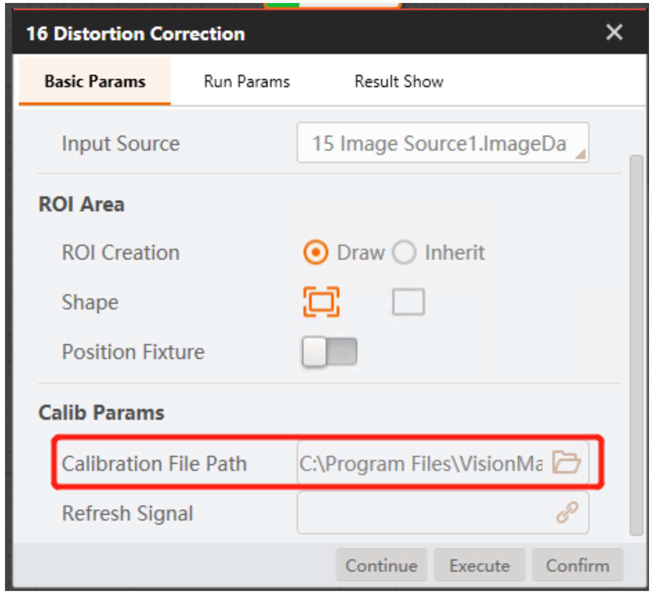
Step4：Set calibration board type；

Step5：Set parameters such as grayscale contrast, and refer to the calibration principle of the calibration board for parameter adjustment principles.

Step6：click execute to write info into the calibration file.

3. Introduction to VM distortion calibration

- **3.4 Parameters setting: distortion correction**



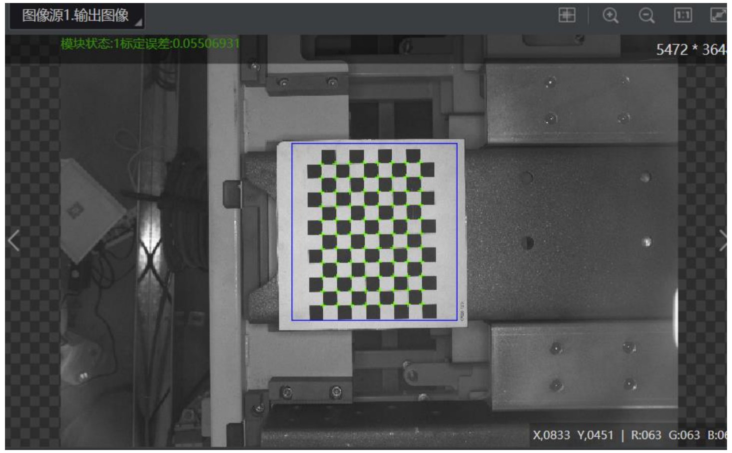
Set calibration parameters to obtain image points

Step1： Load the calibration file

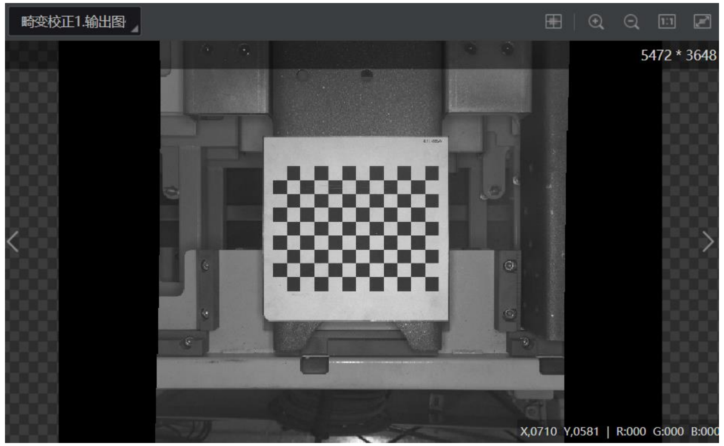
Step2： Subscribe the output image of the distortion correction.

3. Introduction to VM distortion calibration

- **3.4 Notice**



Example of non-standard use - before correction



Example of non-standard use - after correction

Distortion calibration

- ✓ When performing distortion calibration, it is recommended to fill the calibration board with the full field of view.
- ✓ When radial distortion is included in the distortion type, it is necessary to set the correction center point to the center of the image.
- ✓ When perspective distortion is included in the distortion type, when the number of extracted feature points in the rows exceeds the number of columns, the image will be rotated

Distortion correction

- ✓ The surface of the object being photographed needs to be ensured to be in the same plane as the calibration board plane placed during calibration.

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4 Introduction to VM N-point calibration (9-12 points)

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4. Introduction to VM N-point calibration (9-12 points)

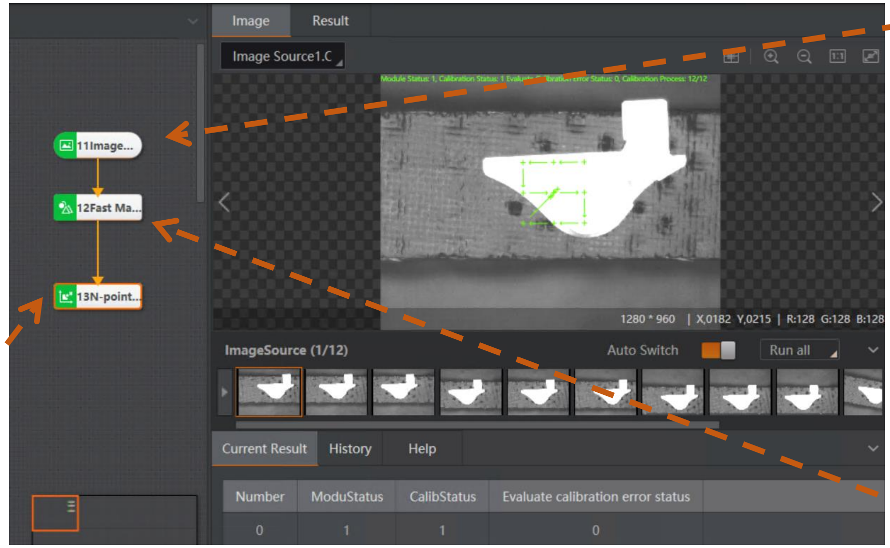
• 4.1 Function Introduction and VM Process Example

A tool for calculating the conversion relationship (calibration file) from image point coordinate system to physical point coordinate system by inputting point set pairs.

N point calibration tool

Image coordinate system → Convert → Physical coordinate system

1.Image source
Multiple (9 or 12) images obtained through mechanism motion. Mechanism motion includes either mechanism driven object motion or mechanism driven camera motion.



2. **Fast match tool (or other position tool)**
Used to obtain the position of image points for the same target object in each image .

3. **N-point**
By obtaining point set pairs - image points and physical points - the conversion relationship is obtained to generate a calibration file.

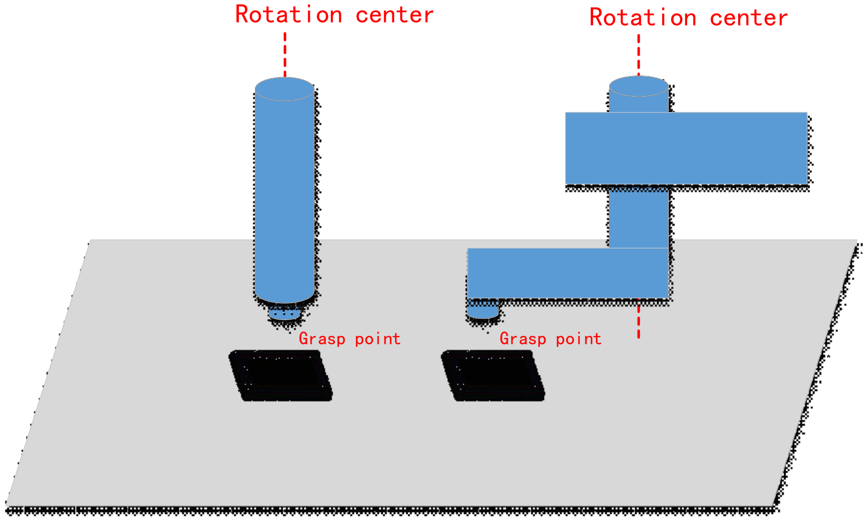
VM Example

4. Introduction to VM N-point calibration (9-12 points)

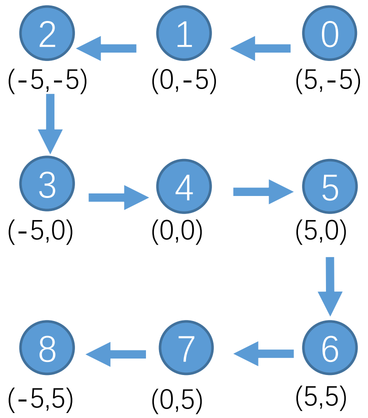
- **4.2 Using 9 point calibration/12 point calibration**

(1) If the motion of the robotic arm is coaxial, it can be calibrated at 9 points through 9 translations;

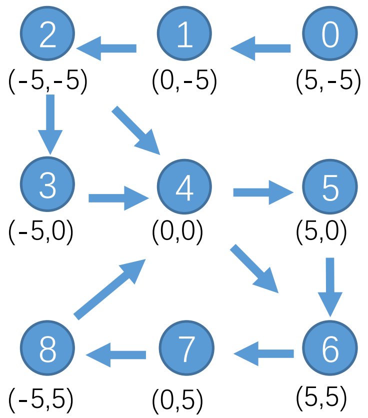
(2) If the robotic arm performs non coaxial motion, it needs to be rotated three more times and calibrated at 12 points.



Schematic diagram of the rotating axis of the robotic arm



9-point calibration track



12-point calibration track

4. Introduction to VM N-point calibration (9-12 points)

- **4.2 Why it need to be 9 points?**

Ans: Actually 3 points can allow to calibrate the whole image plane. Using 9 points for calibration is partly due to the need to solve the optimal solution of matrix M so that the matrix satisfies this equation.

x	y
1974.378,	861.757
1806.283,	862.286
1626.983,	862.503
1627.381,	1040.624
1796.191,	1041.077
1974.199,	1041.594
1973.741,	1221.094
1805.784,	1220.898
1626.610,	1221.074

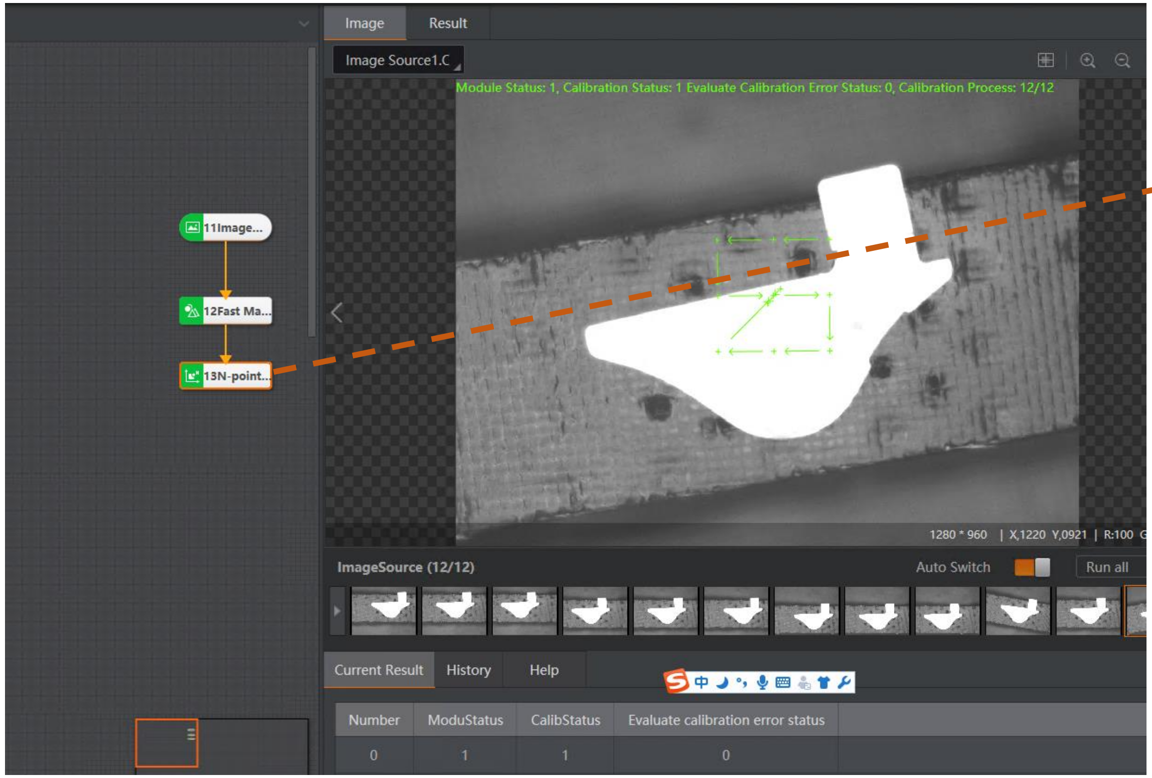
$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = M * \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

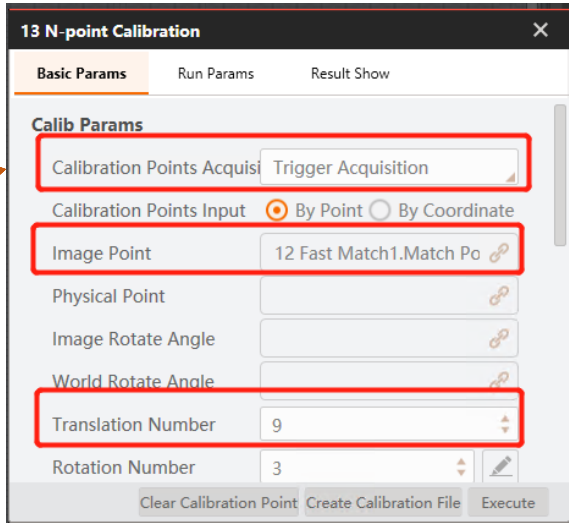
u	v
-1.010,	-1.020
0.005,	-1.060
1.020,	-1.010
1.050,	0.006
0.002,	0.041
-1.001,	0.002
-1.002,	1.021
0.003,	1.001
1.004,	1.012

4. Introduction to VM N-point calibration (9-12 points)

• 4.3 9-point calibration - trigger acquisition

Basic parameters - Calibration parameters: Set calibration parameters to obtain image points





Acquisition of calibration points

Matching points of image point subscription positioning module

Determine the number of input points for translational motion

1. Set calibration parameters to obtain image points

Step1: Select trigger acquisition

Image points Obtain the matching points for feature matching based on the image processing results of the subscription front-end module;

physical points Automatically generated based on physical coordinate system parameters;

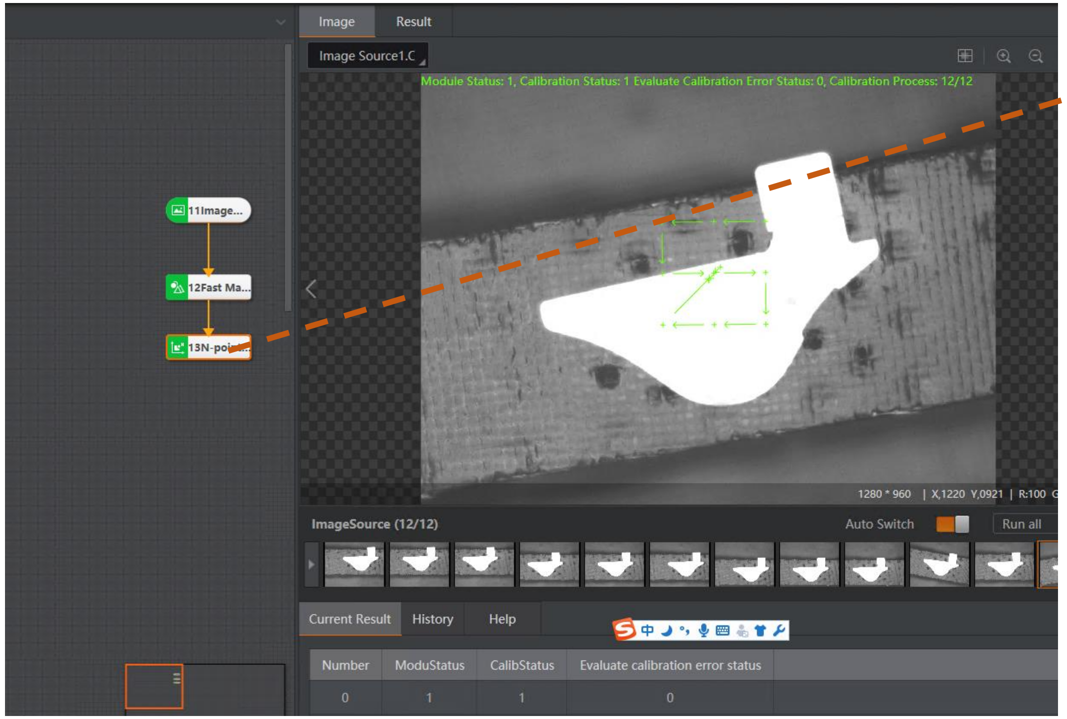
Step2: Image point subscription - locating matching points of the module;

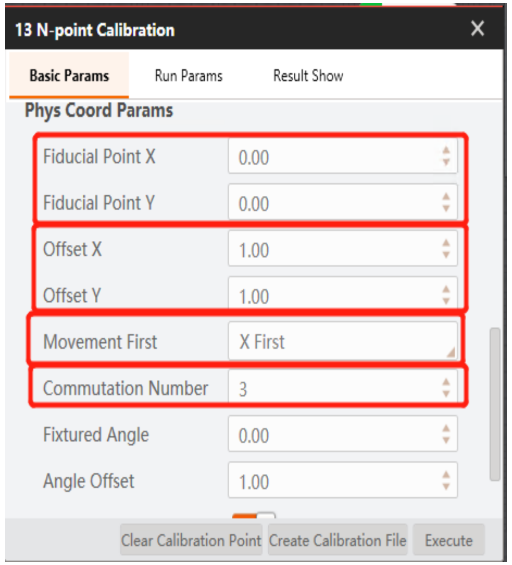
Step3: Input points of translational motion;

4. Introduction to VM N-point calibration (9-12 points)

• 4.3 9-point calibration - trigger acquisition

Basic parameters - Physical coordinate system parameters: can be generated by setting physical coordinate system parameters





Coordinates of point 4. When using relative coordinates, it is generally set to (0, 0)

Step size of point 4 relative to point 0

The direction of priority offset for the robotic arm

The robotic arm undergoes directional movement every few point

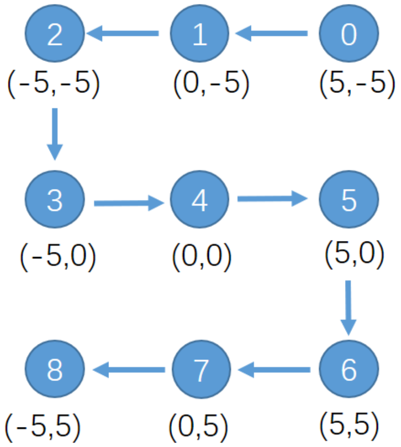
2. Set physical coordinate system parameter obtain physical points

Step1: Set reference point XY ; (0 , 0)

Step2: Set the offset XY; 5.00

Step3: Set X first;

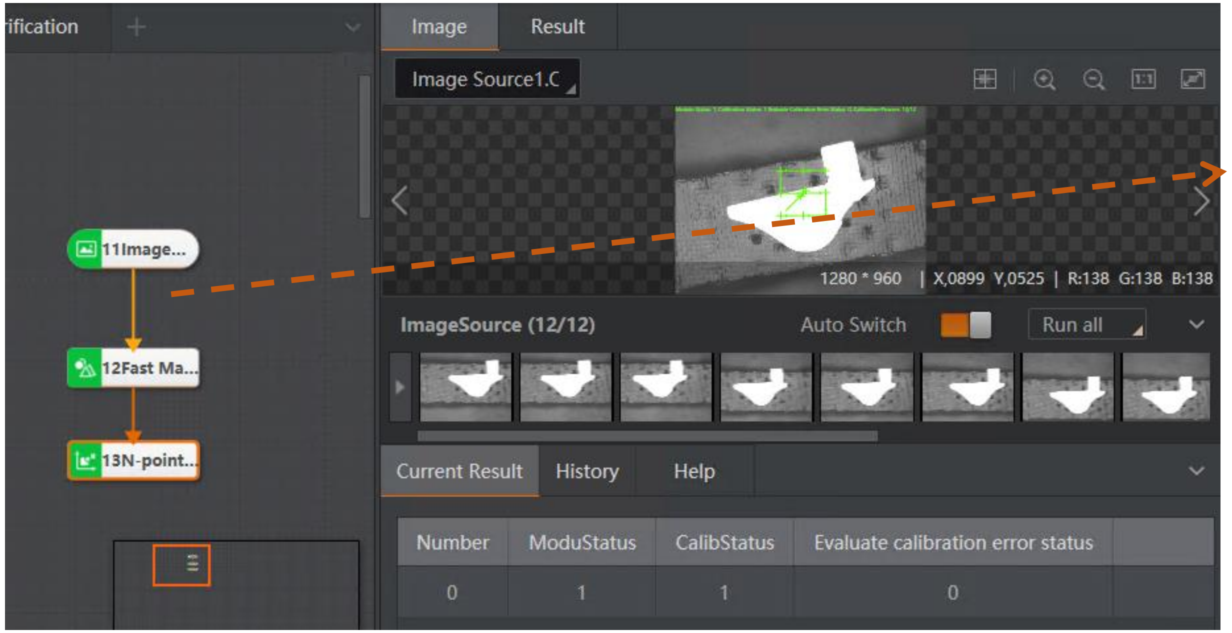
Step4: Set the number of directional moveme

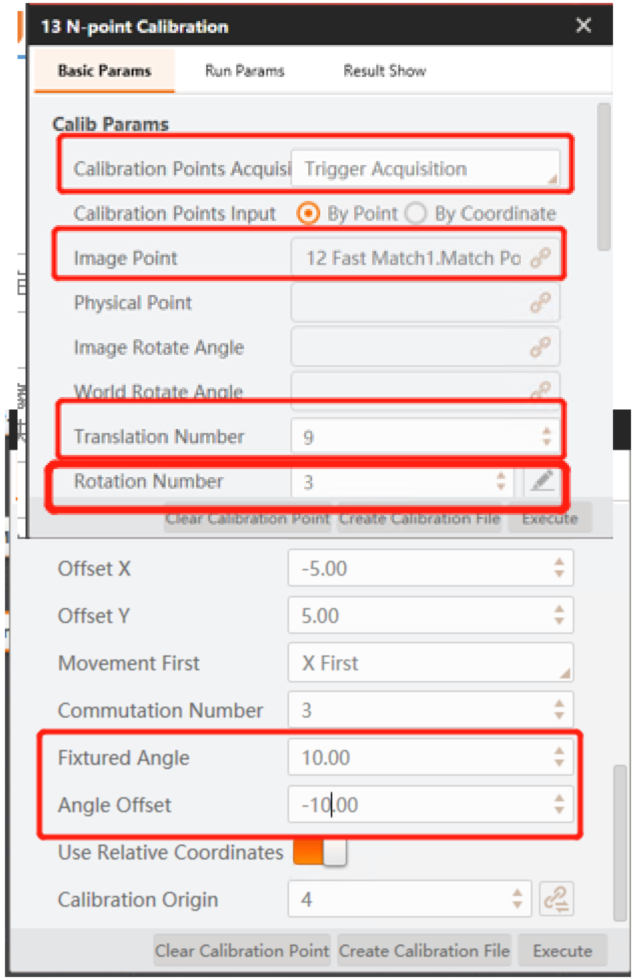


4. Introduction to VM N-point calibration (9-12 points)

- **4.4 12-point calibration - trigger acquisition**

Basic parameters - Calibration parameters: Set calibration parameters to obtain image points





Acquisition of calibration points

Matching points of image point subscription positioning module

Determine the number of input points for translational motion

Number of rotation.

Fixtured angle: The reference angle during rotational motion Angle offset: The amount of angle rotation per motion during rotational motion;

4. Introduction to VM N-point calibration (9-12 points)

- ## 4.5 Debugging suggestions and precautions

Debugging suggestions :

When using the N-point calibration tool for calibration fails or has a high error, it is usually necessary to check whether the input point data is correct:

1. When the translation error is large, you need to observe the translational motion track in the image to see if the track is normal. Are the X/Y displacement trajectories of image points parallel to each other? If they are not parallel, it will increase the calibration error

2. When the rotation error is large, observe whether the position of the rotation center is reasonable. If the position of the rotation center is incorrect, check whether the input angle is incorrect;

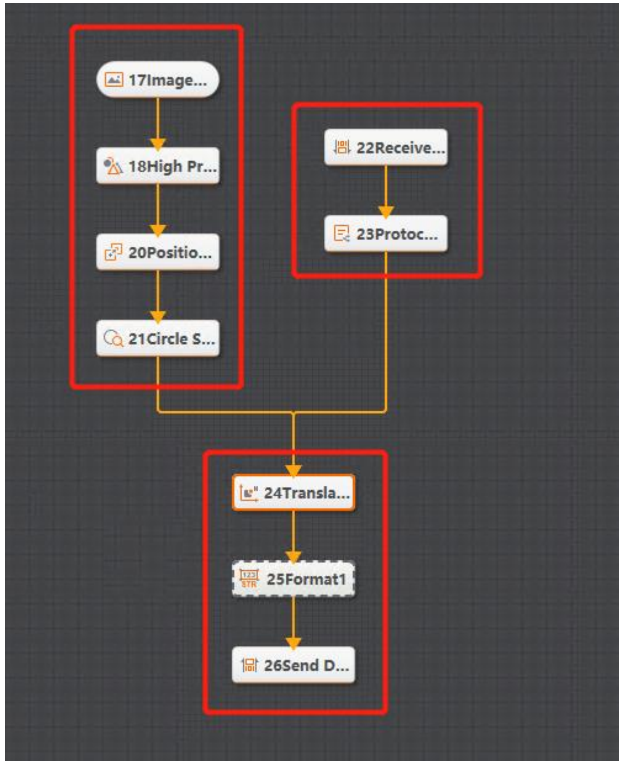
Large radius scenes: In some scenes, due to the limitation of the mechanism, a large radius of rotation is required. At this time, the accuracy of the rotation center needs to be improved. It is recommended to rotate several times and increase the rotation data input to improve the accuracy of the calibration results;

Small angle scenes: In order to obtain the center of rotation more accurately, the rotation angle should not be too small, and the points used to calculate the center of rotation should not be too close. If the rotation angle is small, consider moving multiple times to calculate the rotation center more accurately for multiple points.

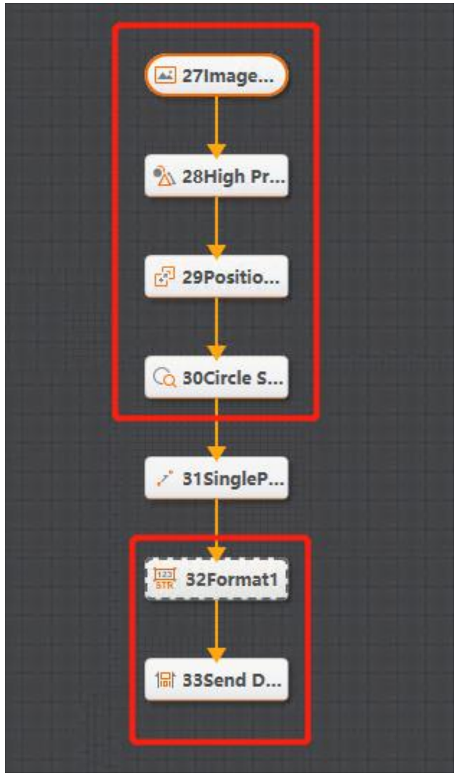
4. Introduction to VM N-point calibration (9-12 points)

- **4.6 VM4.2.0 New Features**

Translation Calibration module



Single point grab module



Note: the same function as N-point calibration, but simplify the parameters filling

Note: used for teaching and producing without manually calculating offset

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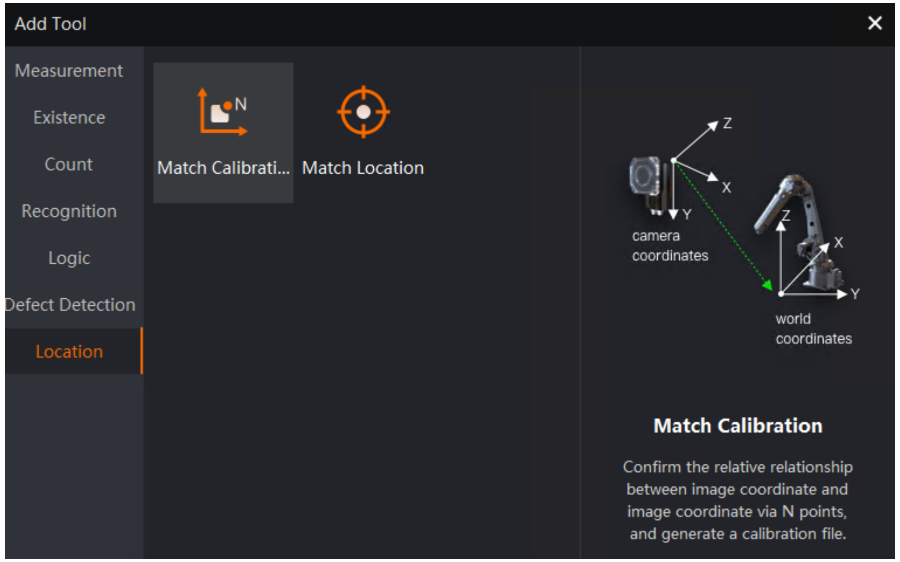
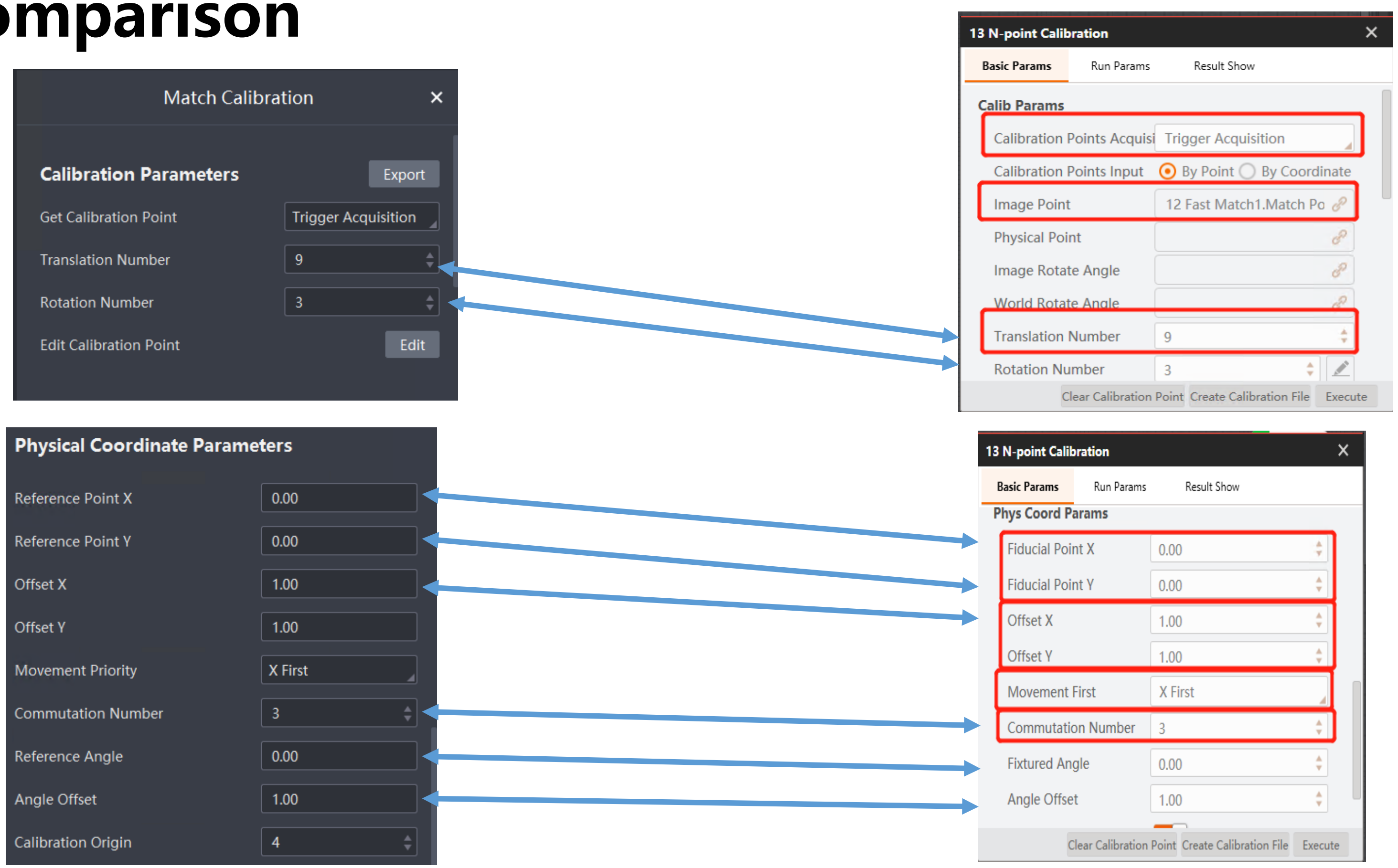
- 5. Introduction to SC N-point calibration (9-12 points)

- **5.1 N points parameters comparison**

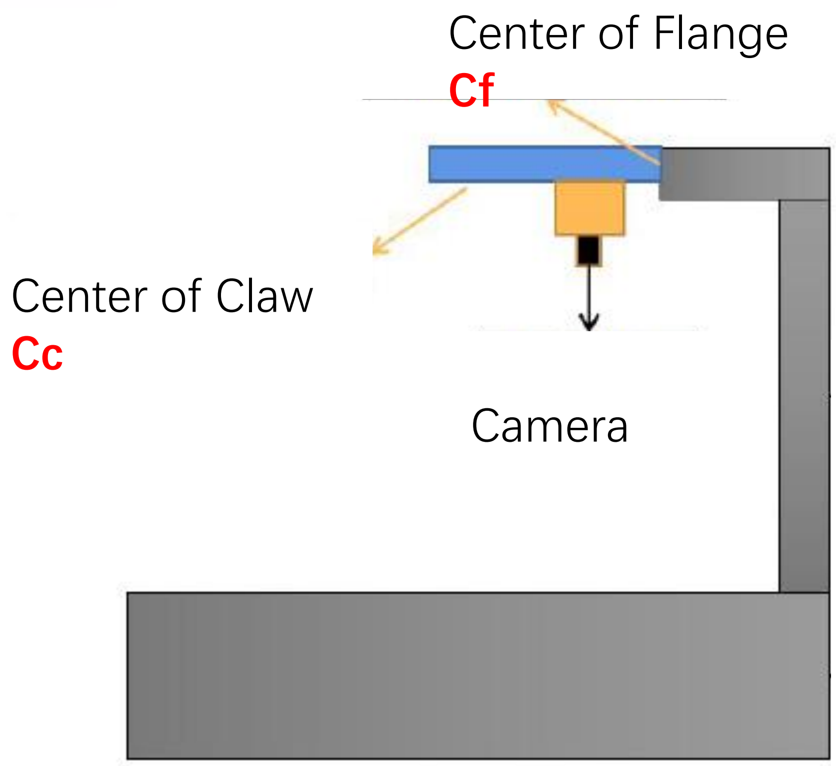




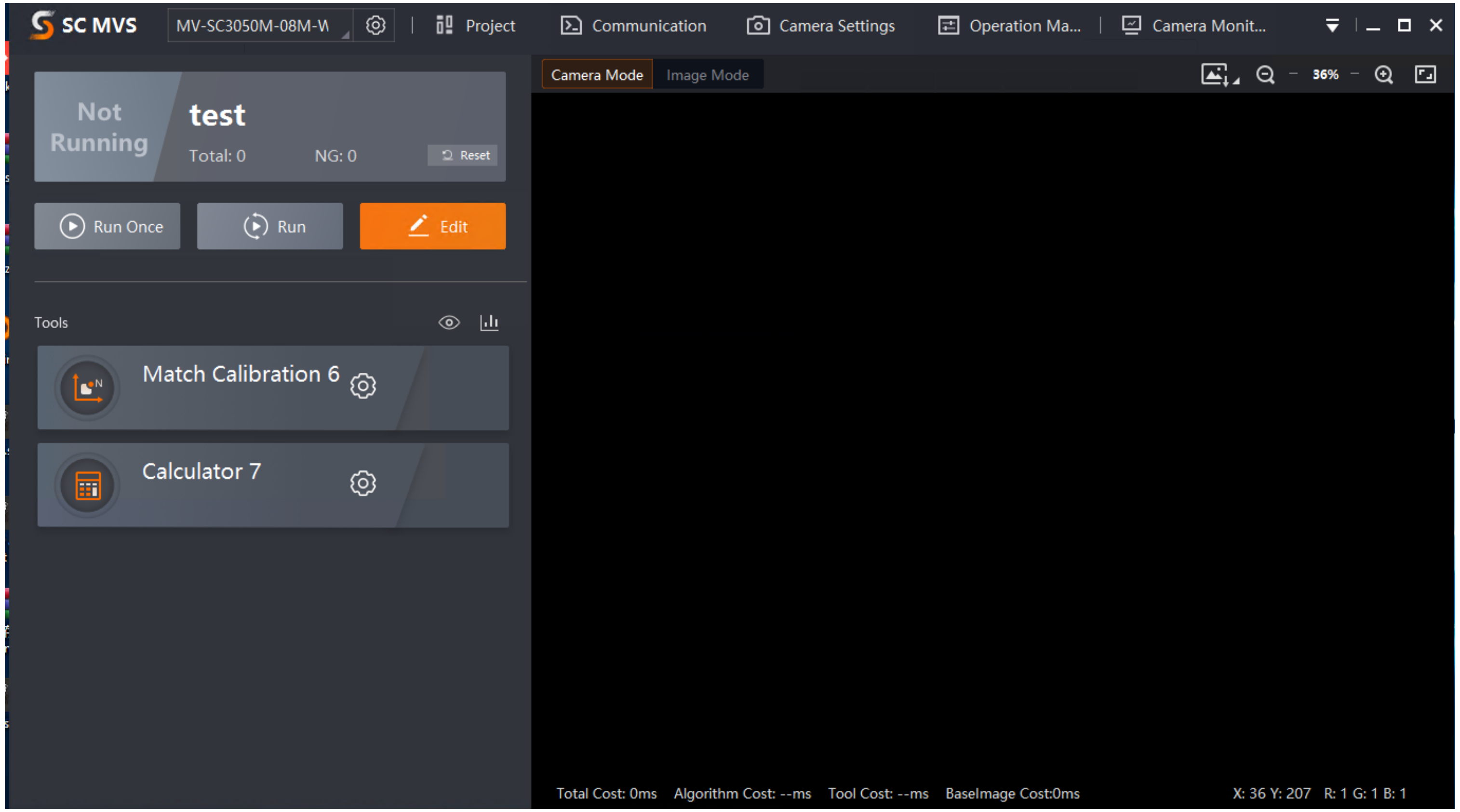
- 5. Introduction to SC N-point calibration (9-12 points)

- **5.2 Schematic diagram of camera calibration**

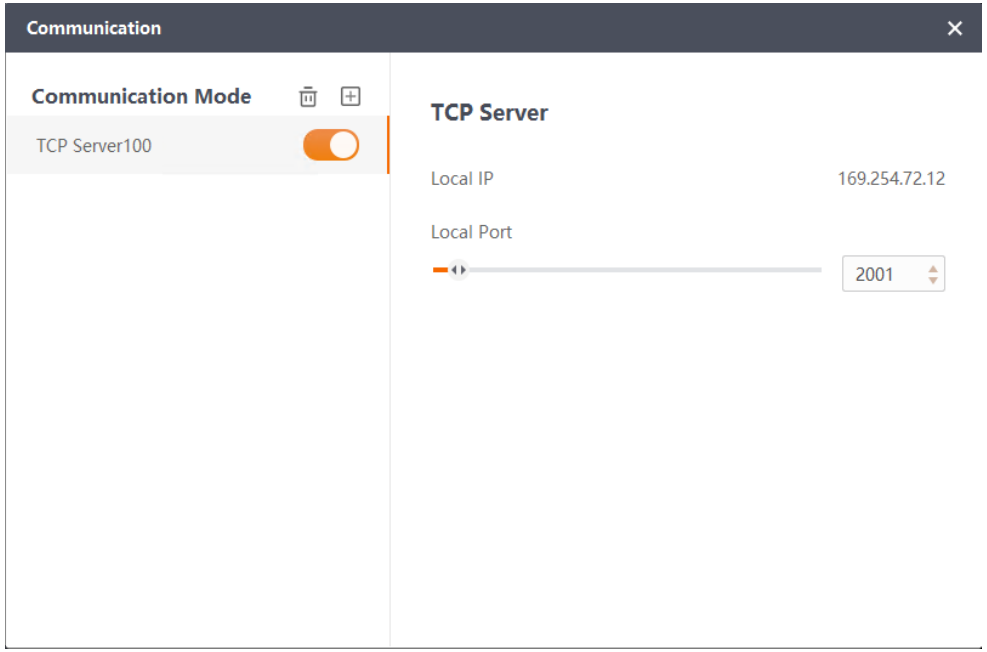
1. The coordinate system used for the robotic arm is Cc, wobj0.
2. The original center point (0 ,0) is the center of the claw.
3. The offset is -50, and the angle offset is -10. This data is defined by the robotic arm

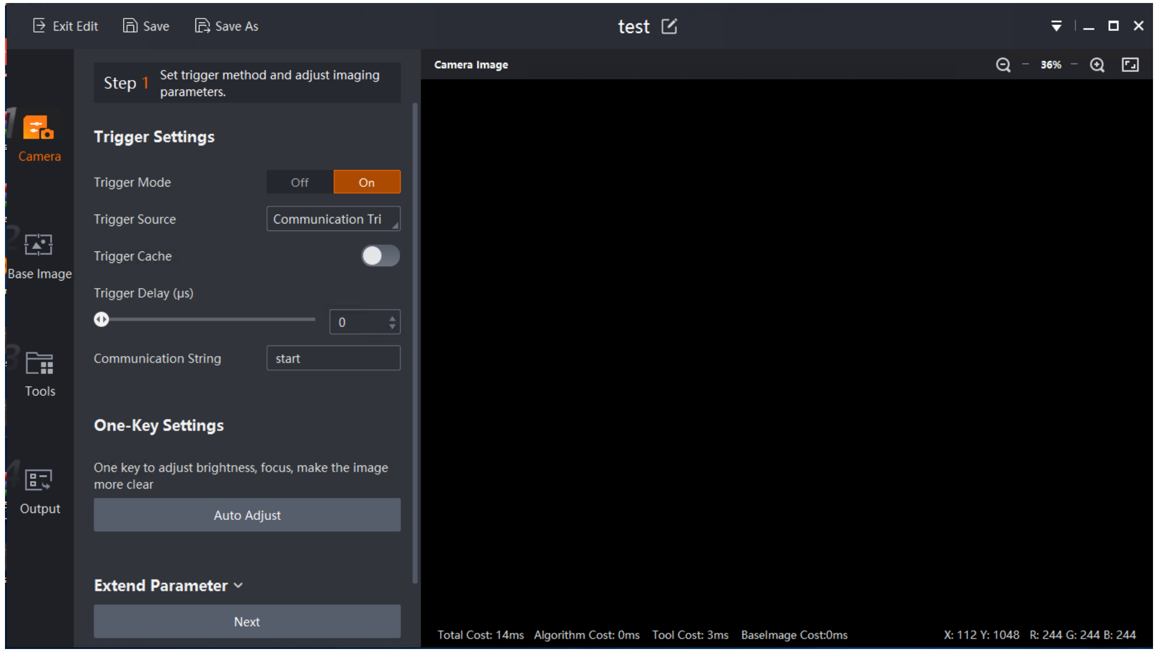


- 5. Introduction to SC N-point calibration (9-12 points)
- **5.3 Calibration tools building**



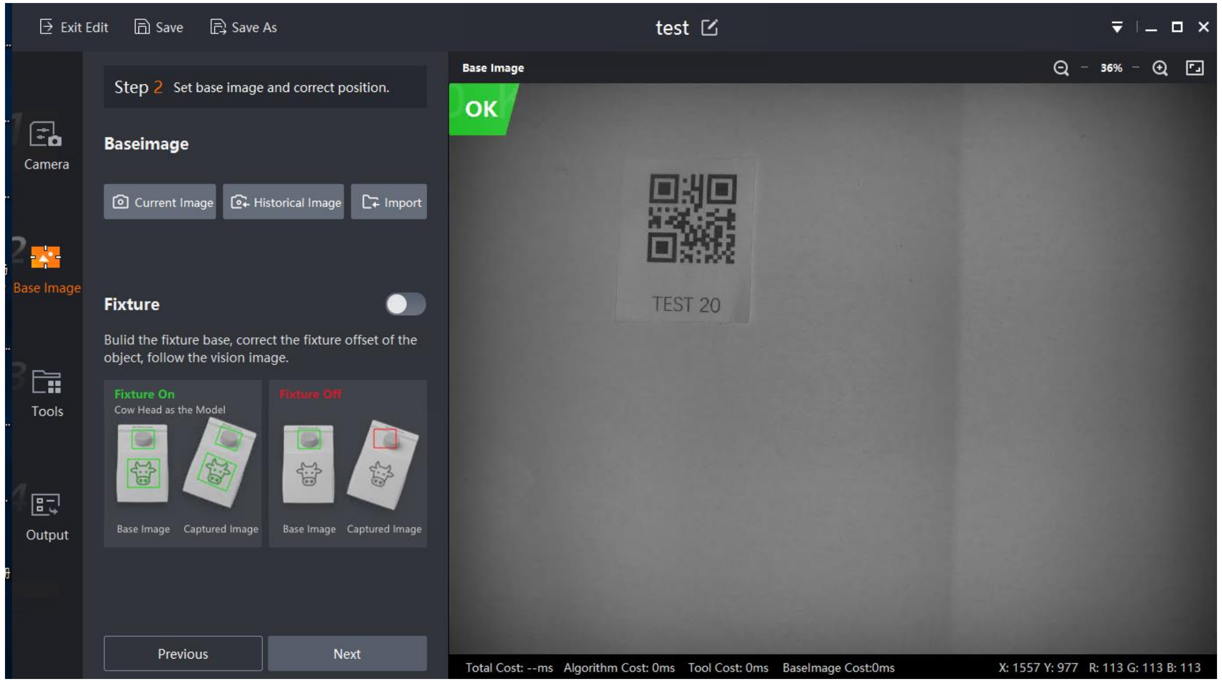
- 5. Introduction to SC N-point calibration (9-12 points)
- **5.4 9-12 points Calibration- communication setup**





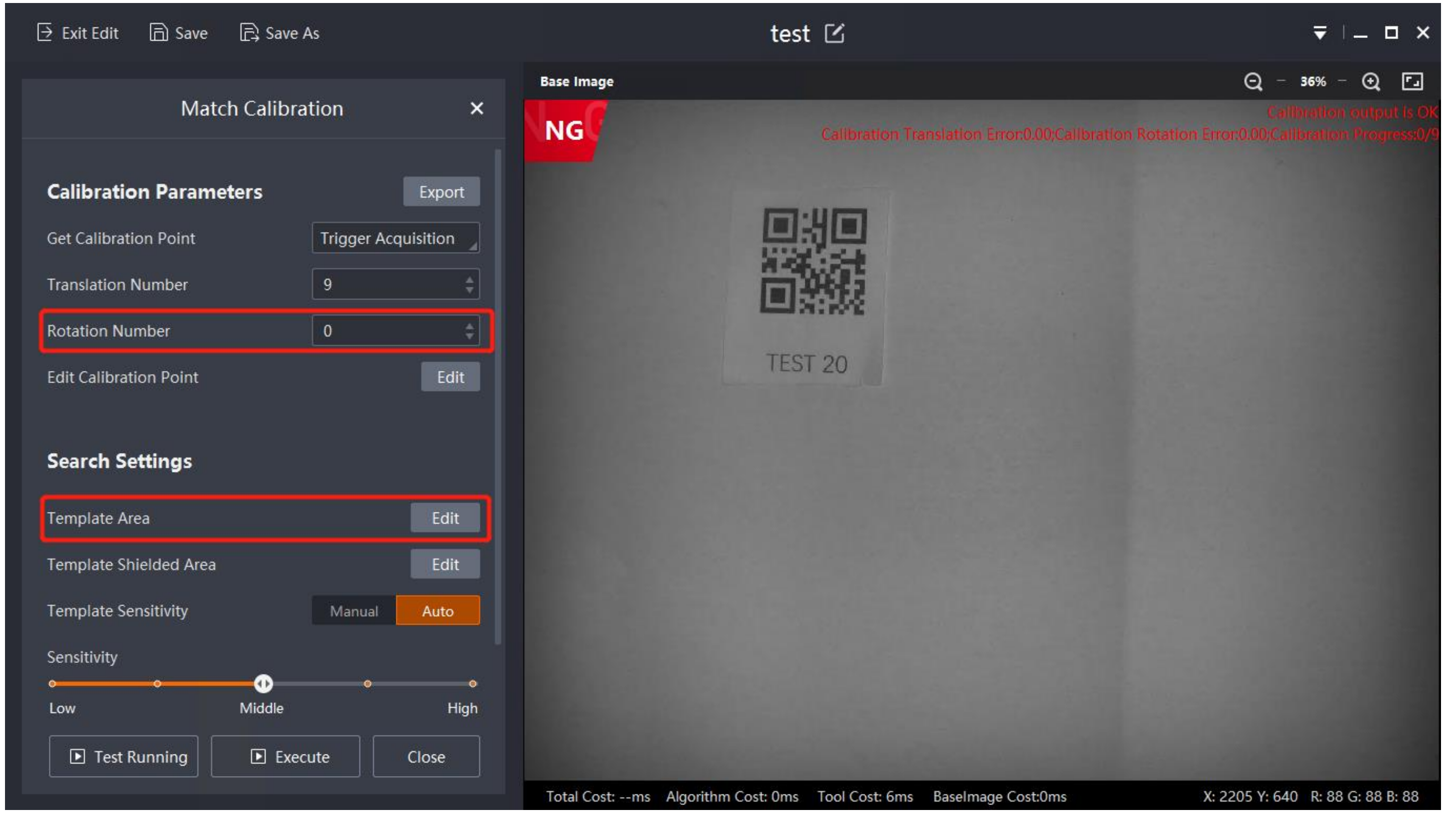
Step 1: building communication, TCP is the most simple way
Step 2: Auto focus and set the trigger string, which would be sent from robot arm

- 5. Introduction to SC N-point calibration (9-12 points)
- **5.4 9-12 points Calibration- base image setup**



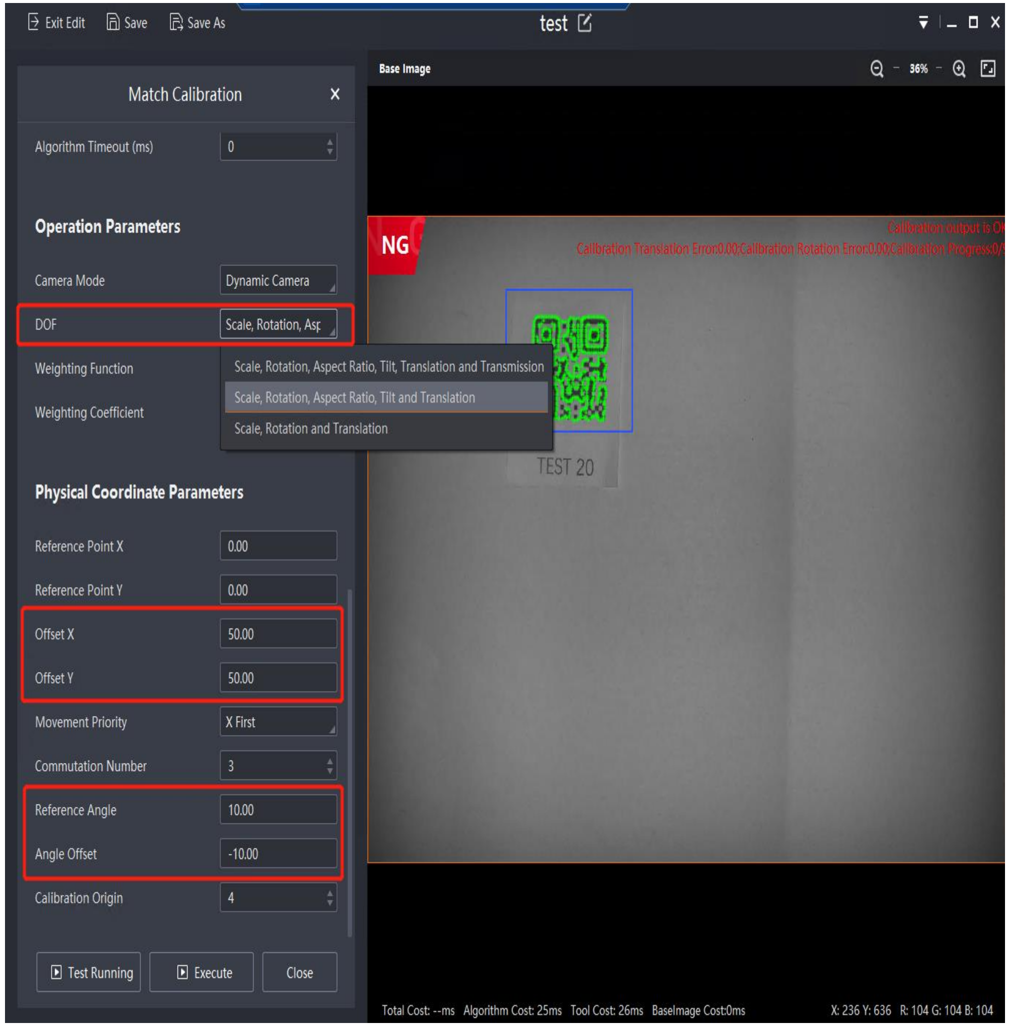
Step 3: Setting the base image. Subsequent benchmark data reading and template establishment will automatically use this image.

- 5. Introduction to SC N-point calibration (9-12 points)
- **5.4 9-12 points Calibration- calibration setup**



Step 4: If it is a 9-point calibration, the rotation number is filled with 0; 12 points calibration, rotation number fill in 3
Step 5: Selecting a QR code to establish a template can adjust the accuracy appropriately to make the positioning point more accurate

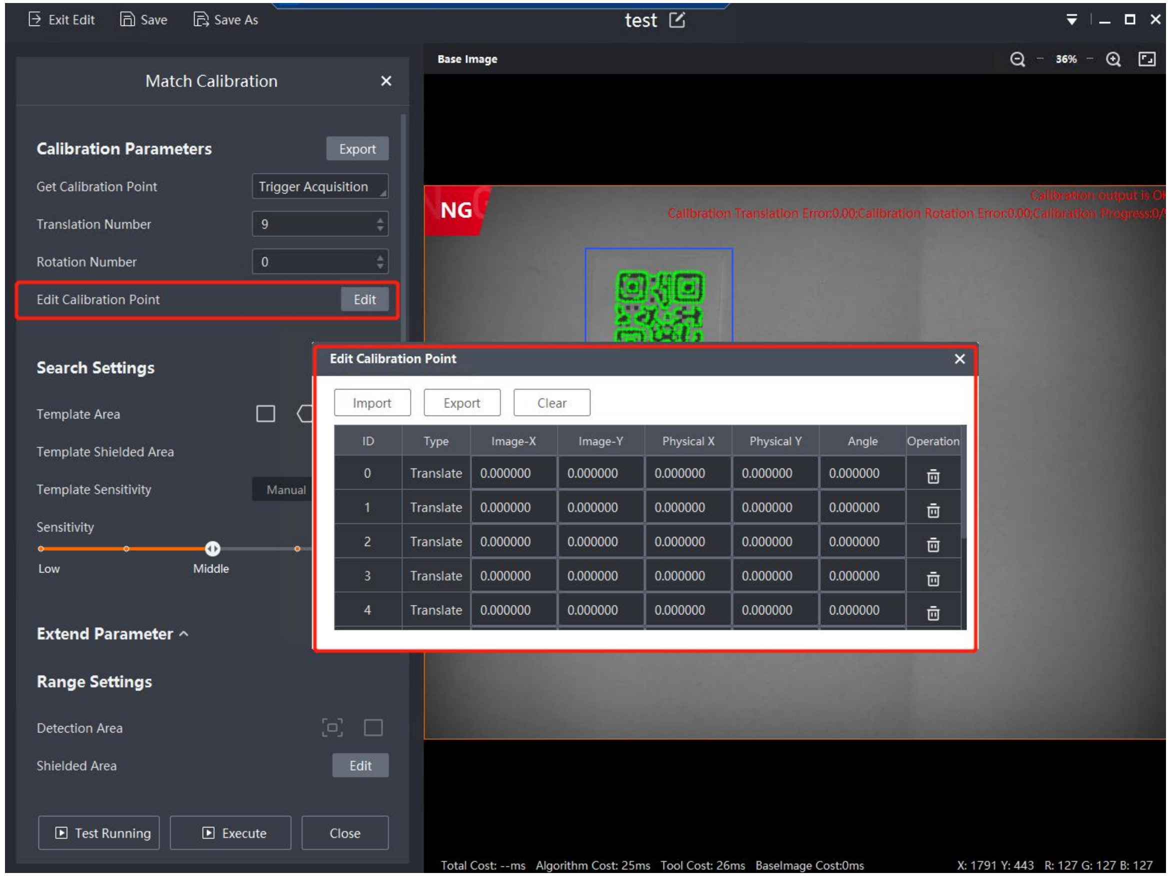
- 5. Introduction to SC N-point calibration (9-12 points)
- **5.4 9-12 points Calibration- calibration setup**



Step 6: DOF selects the second option, offset X/Y, reference angle and angle offset, to control according to the offset of the robotic arm For the convenience of calculation, when the coordinate system of the robotic arm is perpendicular or parallel to the image coordinate system, the offset value can be directly used in units such as physical distance, millimeters, etc.

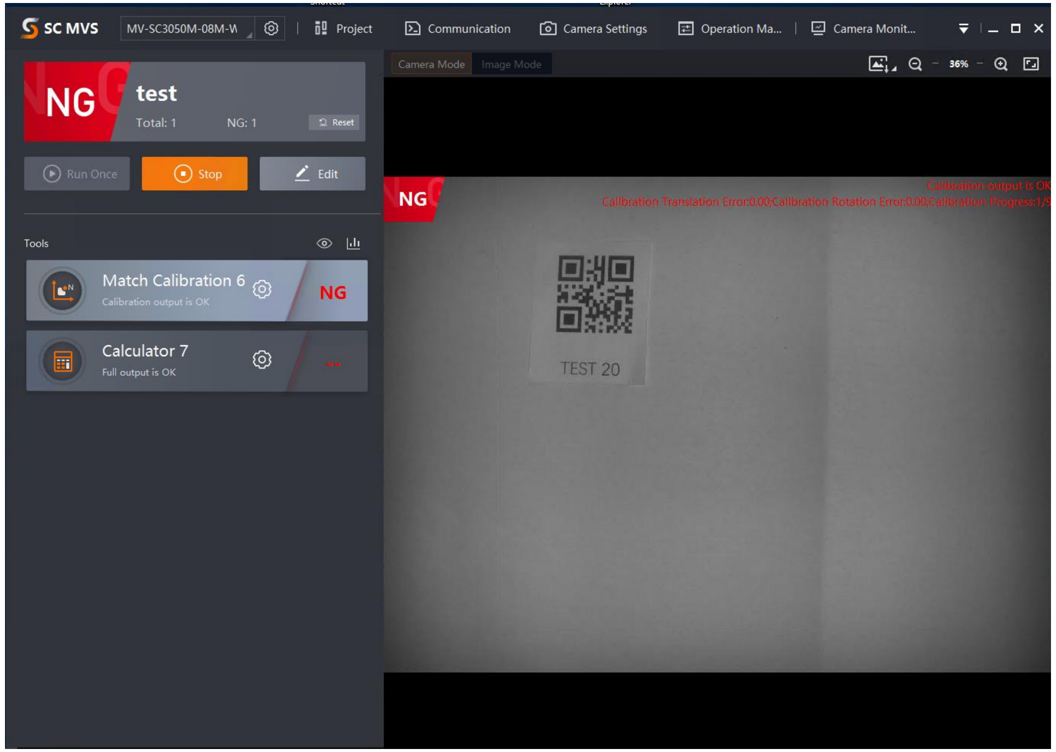
- 5. Introduction to SC N-point calibration (9-12 points)

- **5.4 9-12 points Calibration- calibration setup**

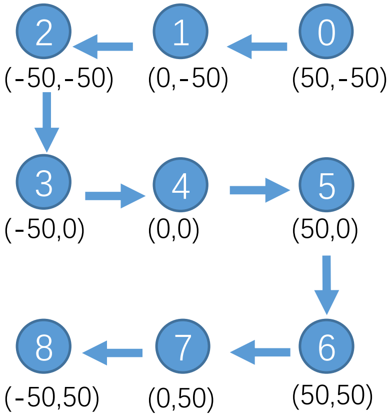


Step 7: Click close before clear all data in the calibration point

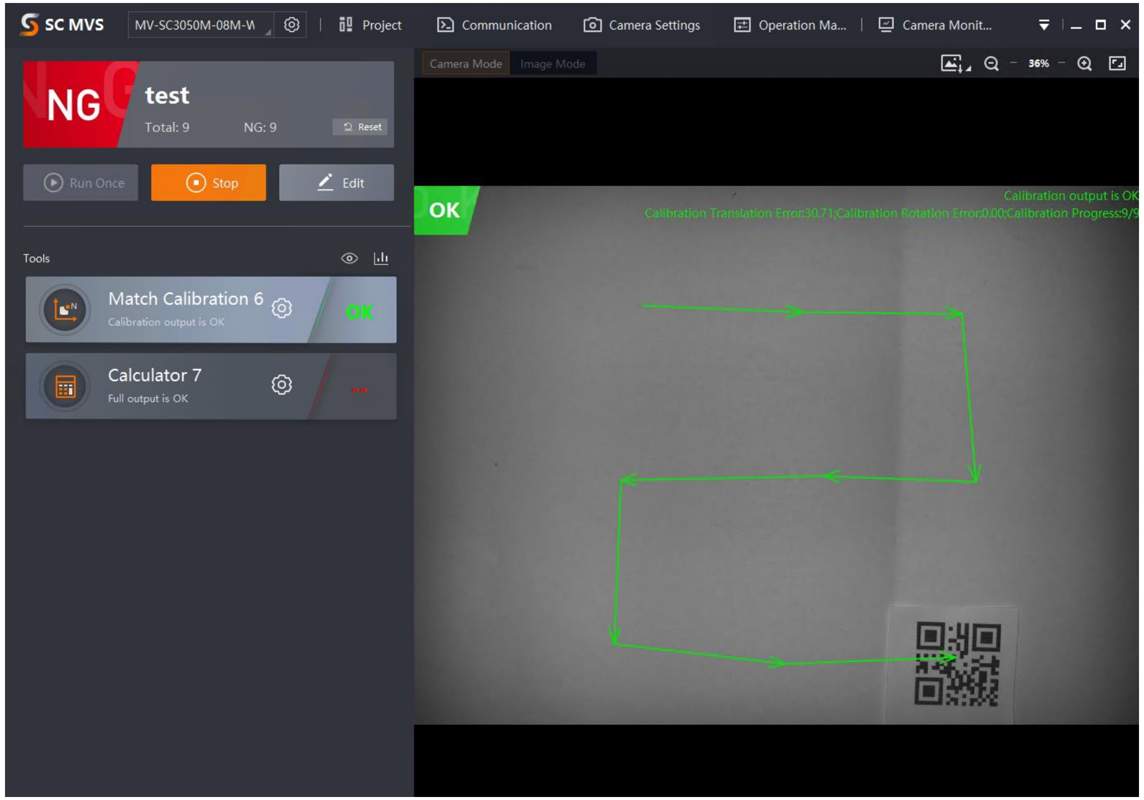
- 5. Introduction to SC N-point calibration (9-12 points)
- **5.5 9-12 points Calibration- calibration setup**



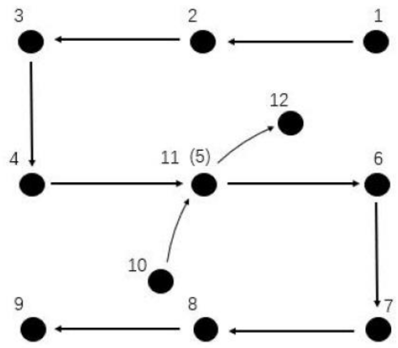
Step 8: Click saving the project and start run continuously.
Step 9: Start calibration step by step along the corresponding XY offset. Every time the robotic arm moves an offset, it sends a trigger signal to the camera end to calibrate it once



- 5. Introduction to SC N-point calibration (9-12 points)
- **5.5 9-12 points Calibration- calibration setup**



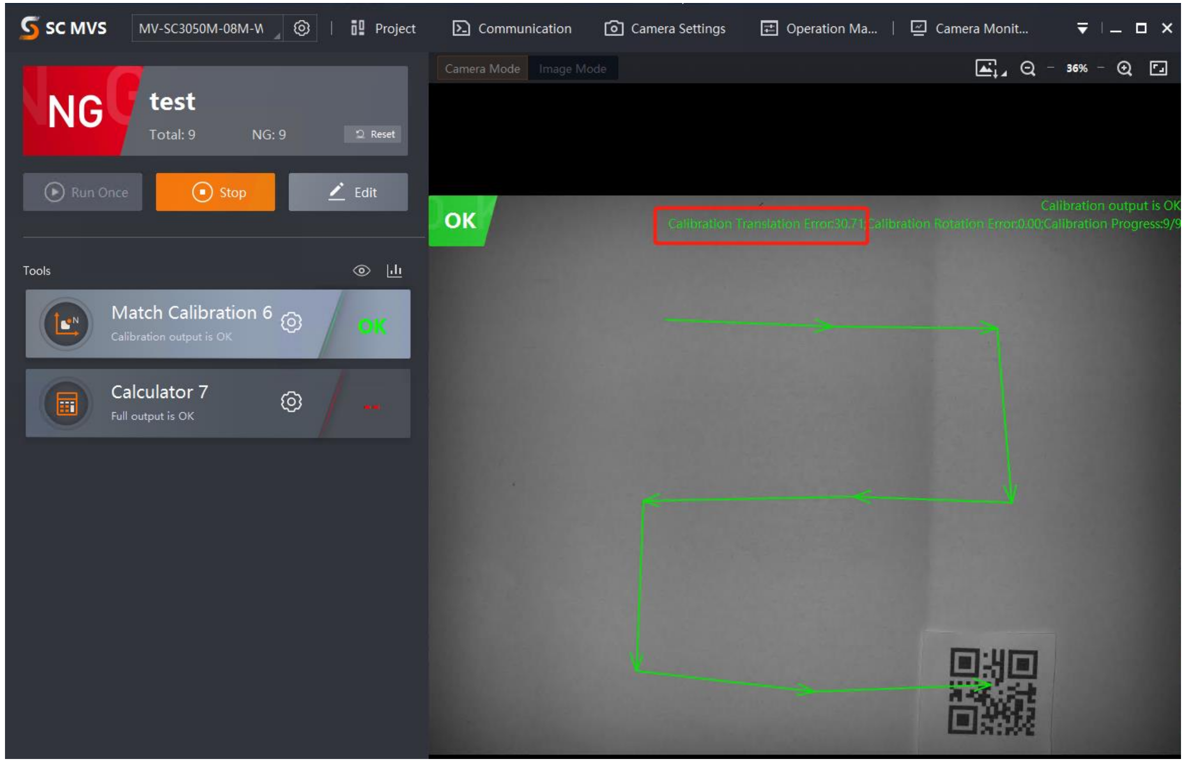
Step 10: If it is a 9 point calibration, the whole process is over. If it is a 12 point calibration, it is necessary to return the robotic arm to position 4 and trigger once.
Rotate to 0 degrees and trigger once.
Rotate to -10 degrees, trigger once



• 5. Introduction to SC N-point calibration (9-12 points)

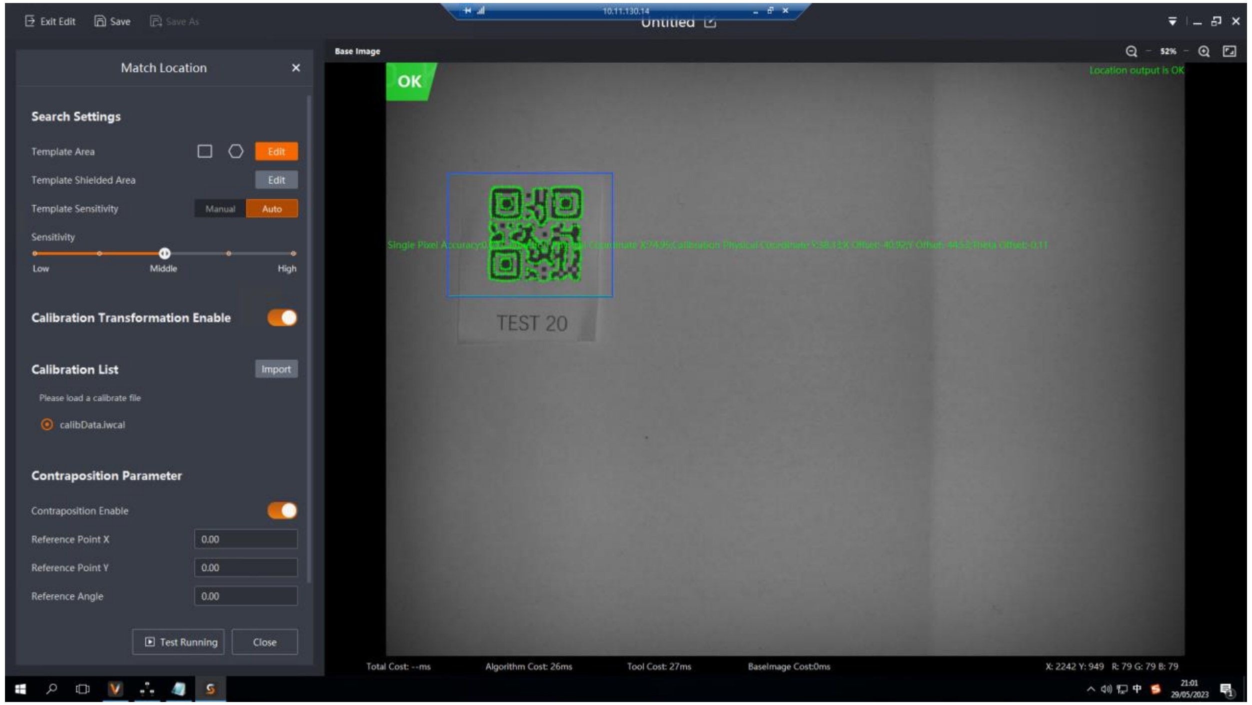
• 5.6 9-12 points Calibration error

1.Make sure whether you translation and rotation error here is below 2 pixels error. If it is too large, it is necessary to check if there are any issues with the robotic arm program or if the template is not accurate enough.



- 5. Introduction to SC N-point calibration (9-12 points)
- **5.6 9-points Calibration verification**

1. Create a new solution by importing the previous reference map and returning the original coordinate system position of the robotic arm. Use the match location module and place the target object in the field of view
2. Enable the calibration file and import the previously created calibration file. If the physical coordinate values of the object are consistent with those of the robotic arm after clicking on the test run, it indicates successful calibration

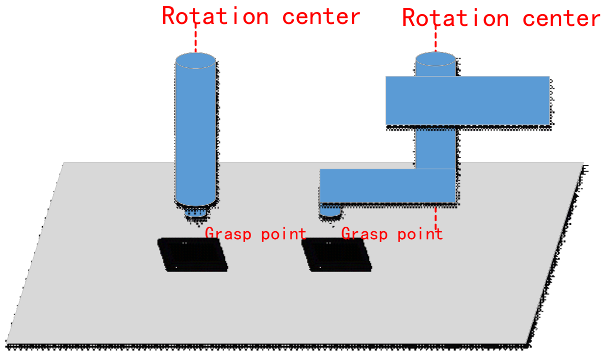


• 5. Introduction to SC N-point calibration (9-12 points)

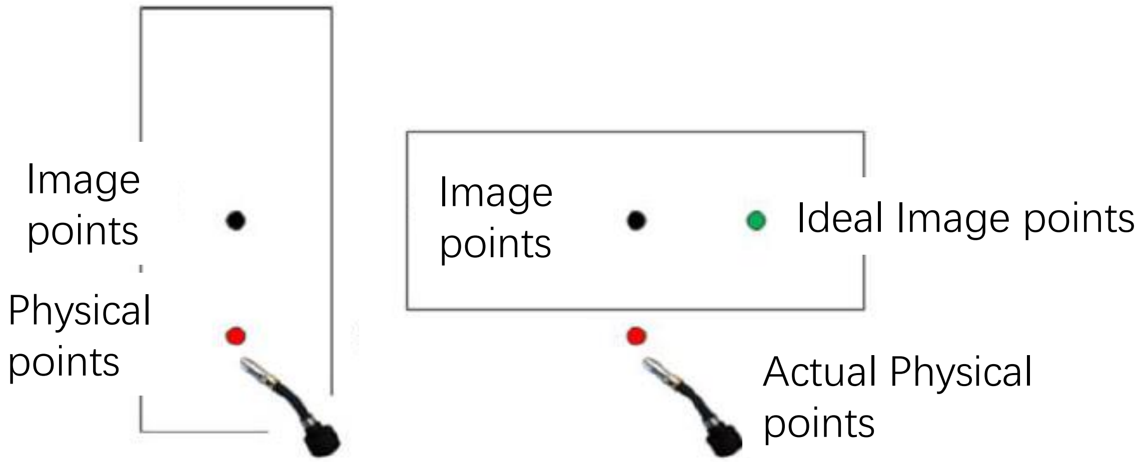
• 5.7 Rotation offset calculation

Only for 12 points calibration

Why it requires to calculate the rotation offset?
ANS: The 12 points calibration is the sum of 9-point calibration and the rotation calibration. Mainly used to handle non coaxial problems.
Non coaxial: refers to the phenomenon where the operating point and reference point do not coincide, and when the reference point rotates, the operating point will change.



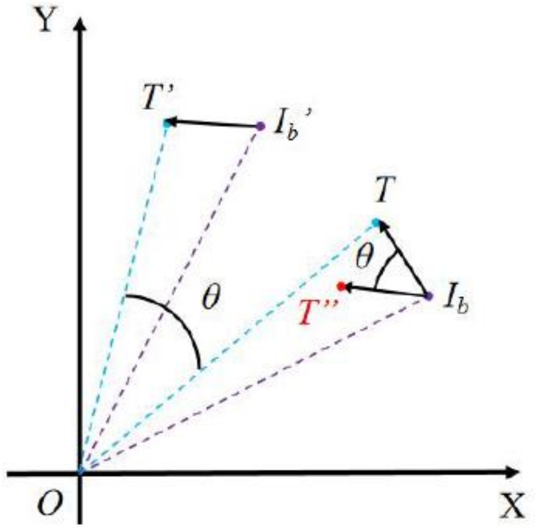
Schematic diagram of the rotating axis of the robotic arm



- 5. Introduction to SC N-point calibration (9-12 points)

- **5.7 Rotation offset algorithm calculation**

Only for 12 points calibration



O is the original physical point
I_b (I_{bx}, I_{by}) is the base image point corresponding to the physical point
T (T_x, T_y) is the teaching point
I_b' ($I_b'_x$, $I_b'_y$) is the physical point after rotation
T' (T'_x, T'_y) is the teaching point after rotation
T''(T''_x, T''_y) is the physical point after T' rotates around I_b

Rotation offset = $(T''_x - T_x, T''_y - T_y)$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} x-a \\ y-b \end{bmatrix} + \begin{bmatrix} a \\ b \end{bmatrix}$$

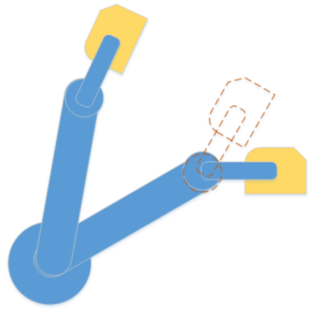
$$T''_x = cos\theta * (T_x - I_{bx}) - sin\theta * (T_y - I_{by}) + I_{bx}$$

$$\Delta X = T''_x - T_x$$

$$= (cos\theta * (T_x - I_{bx}) - sin\theta * (T_y - I_{by}) + I_{bx} - T_x$$

$$\Delta Y = T''_y - Ty$$

$$= (cos\theta * (T_y - I_{by}) + sin\theta * (T_x - I_{bx}) + I_{by} - T_y$$



Top view

- 5. Introduction to SC N-point calibration (9-12 points)
- **5.7 Rotation offset algorithm calculation**

Only for 12 points calibration

Total offset includes move offset and rotate offset:

Move offset X= RunX – MarkX (directly use the match location tools to obtain, the baseworld system, 4th point)
Move offset Y = RunY – MarkY(directly use the match location tools to obtain)

RotateOffset:

Rotate offset X = RotateX – TeachPosX
= (TeachPosX - BasicWorldX) * Cos((1)* TR) - (TeachPosY - BasicWorldY)*Sin((1)*TR) -TeachPosX

Rotate offset Y = RotateY – TeachPosY
= (TeachPosX - BasicWorldX) * Sin((1)*TR) + (TeachPosY - BasicWorldY)Cos((1)*TR)- TeachPosY

OffsetX = MoveOffsetX + RotateOffsetX;
OffsetY = MoveOffsetY + RotateOffsetY;
OffsetR = TR ;

- 5. Introduction to SC N-point calibration (9-12 points)
- **5.7 Rotation offset algorithm calculation**

Notes: The smart camera does not have a single point grab module or script function, and cannot provide rotation offset calculation. Therefore, all calculations require programming at the robotic arm end to provide.

Fast calculation				
Base	base image physcial positionX	base image physcial positionY	base image physcial positionR	It is the base image point (Cc, wobj0)
	287.42	-806.7	-179.88	this point is provided by the robot arm
Marker point	base image image positionX	base image image positionY	base image image positionR	It is the base image point. But it is the physical point after using match location tool
	119.77	98.22	-89.22	this point is provided by camera
Teach point	teach physical positionX	teach physical positionY	teach physical positionR	The true object place point
	260.592	-915.812	-178.057	this point is provided by the robot arm
IB(BASE+Marker)	Image physical point X	Image physical point Y		Current base point image reference physical coordinates
	407.19	-708.48		From calculation
Tech-IB	deltaX	deltaY		Distance between teach points and maker points
	-146.598	-207.332		From calculation

- 6. Introduction to comparison of both products

Vision master	Smart camera
Communication support	Communication support
Visionmaster can use single point grab module or script function to obtain offset values	If 12 point calibration is required, the robotic arm itself needs to be able to program offset values
Can receive and send data	Only can sent data
Support for data format splitting and assembly	Do not support for splitting and assembly
Support for multi camera alignment calibration	Alignment not supported
Supports higher precision calibration	The highest accuracy is in millimeters, with a degree deviation of around 1 degree

• 7. Common troubleshooting

Camera side common issues:

1. The camera is not parallel to the calibration plane
2. The features in the shape matching tool are not obvious, and it is necessary to avoid angle problems caused by symmetrical objects during calibration
3. To calibrate the thickness of an object, it is necessary to keep it as thin as possible and avoid problems caused by height differences when fitting the object

Robot arm side common issues:

1. The calculated rotation deviation of the robotic arm is incorrect, resulting in incorrect movement position of the robotic arm. Need to negotiate with the robotic arm provider to guide programming
2. The angle and pose of the robot arm when teaching or running should be consistent with the calibration.
3. The motion mechanism is unstable, such as instability caused by motor voltage issues. It is recommended to conduct static and dynamic tests to verify the stability of the motion mechanism.

Static test: Repeat taking 100 images and calculate if there is a significant change in the center point and angle.
Dynamic test: Move back and forth 100 times and trigger a photo to calculate if there is a significant change in the center point and angle

Thank you！

hikrobot@hikrobotics.com

www.hikrobotics.com