celepixel

Operation Instructions

DVS Calibration Tool

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Contents

1. Introduction

1.1. Function

Seven functions are included in this tool. Open “calibration_tool.exe”, then the functions are listed in the console window as the following figure shown.

The details are listed in the following table:

No	Class	Name of tool	Description
1	Calibration tool	Online intrinsic parameters calibration	Calculate the intrinsic parameters of DVS, including focus length, principal point, distorted parameters.
2		Offline intrinsic parameters calibration	
3		Online extrinsic parameters calibration	Calculate the inverse perspective transform matrix of the DVS after a DVS is mounted on a vehicle.
4		Offline extrinsic parameters calibration	
5	Self-checking tool	IMU data recording	Record IMU raw data right after extrinsic parameters calibration
6		IMU data verification	Verify whether the DVS is fixed (without movement) based on two methods. Method 1: comparing IMU raw data directly. This method is suitable for quick checking. Method 2: Using bird's eye image. This method is more intuitive. Using both two methods are recommended.
7		Bird's eye image online transform	

1.2. Related devices

No	Name of tool	Related devices
1	Online intrinsic parameters calibration	Chessboard, ruler
2	Offline intrinsic parameters calibration	Images of a chessboard (the number should be the value of “image_count” in “config/camera_calib_config.ini”), parameters of the chessboard are known

3	Online extrinsic parameters calibration	tape measure or laser range finder, horizon road with two strength and parallel lines, five markers
4	Offline extrinsic parameters calibration	An image with five markers, vehicle width and the distance of markers are known
5	IMU data recording	(the firmware of the sensor has been updated)
6	IMU data verification	
7	Bird's eye image online transform	horizon road with two strength and parallel lines

1.3. Input Variable

"config/camera_calib_config.ini" includes the parameters for calibration. [camera_config] records the resolution of the camera. [config_intrinsic_calib] records the parameters of the chessboard which are listed in the following table and Fig 2-1. [config_extrinsic_calib] is general configure parameters of extrinsic calibration, moreover, [Offline_Ext_Calib_Info] input some position for offline extrinsic calibration, as shown in the following table and Fig 4-1.

No	Class	Parameters	Description
1	[camera_config]	ROWS_CELEX5	Row resolution of the DVS
2		COLS_CELEX5	Col resolution of the DVS
3	[config_intrinsic_calib]	corner_col	Column number of corners on the chessboard
4		corner_row	Row number of corners on the chessboard
5		board_length	Length of the lattice edge on the chessboard (mm, ±0.1mm)
6		image_count	Number of images for intrinsic calibration
7	[config_extrinsic_calib]	posi_num	Number of calibration position for extrinsic calibration, the default is 4.
8		width_vehicle	vehicle width (mm, ±0.1mm)
9		lon_dist_near	The distance from center of front wheel to the nearest calibration marker (mm, ±0.1mm)
10		lon_dist_far	The distance from center of front wheel to the farthest calibration marker (mm, ±0.1mm)
11	[Offline_Ext_Calib_Info]	img_point_1_x, img_point_1_y	The col/row position of 1st calibration marker on the image
12		img_point_2_x, img_point_2_y	The col/row position of 2nd calibration

			marker on the image
13		img_point_3_x, img_point_3_y	The col/row position of 3rd calibration marker on the image
14		img_point_4_x, img_point_4_y	The col/row position of 4th calibration marker on the image
15		test_posi_u, test_posi_v	The col/row position of test marker on the image

The parameters which are not listed have no influence on the calibration.

1.4. Output Variable

"config/CameraCalib.ini" records all calibration results. [Intrinsic_Parameters] records intrinsic parameters. [Matrix_Image2Vehicle] records inverse perspective transform matrix which herein is equal to extrinsic parameters. [IMU_Information] records IMU raw data.

No	Class	Parameters	Description
1	[Intrinsic_Parameters]	kFocal_length	Average focus length =(kFocal_length_x+kFocal_length_y) / 2
2		kFocal_length_x	Focus length along column direction
3		kFocal_length_y	Focus length along row direction
4		kPrincipal_x	Column pixel of the principal point
5		kPrincipal_y	Row pixel of the principal point
6		dist_coeff_k1	2 order radial distortion parameters
7		dist_coeff_k2	4 order radial distortion parameters
8		dist_coeff_p1	Tangential distortion parameters (p1)
9		dist_coeff_p2	Tangential distortion parameters (p2)
10		dist_coeff_k3	6 order radial distortion parameters
11		date	The specific time of the calibration (year-month-day-hour-minute-second)
12		sensor_id	Id of the sensor which is defined by user
13	[Matrix_Image2Vehicle]	proj_mat_00-proj_mat_22	9 elements of 3×3 inverse perspective transform matrix (Default proj_mat_22 = 1)
14		date	The specific time of the calibration (year-month-day-hour-minute-second)
15	[IMU_Information]	acc_x_mean_raw	Raw X-axis data of accelerometer(m/s^2)
16		acc_y_mean_raw	Raw Y-axis data of accelerometer (m/s^2)
17		acc_z_mean_raw	Raw Z-axis data of accelerometer (m/s^2)
18		date	The specific time of the operation (year-month-day-hour-minute-second)

Note: In "config/CameraCalib.ini", latest calibration results will add behind the previous results, in other word, Latest calibration results will not cover old results. Based on data, different

calibration results can be recognized. However, redundant should be removed when CameraCalib.ini is used.

2. Online Intrinsic Parameters Calibration

2.1. Chessboard for Calibration

The size of chessboard for calibration should be adapted to focus length. Adjust focus length according to target application before calibration. The proportion of chessboard in a picture should be larger than 0.5, and corners should be clear.

As an example, "Calibration checkerboard3.pdf" file can be printed on a non-deformable board (such as glass board) at 300dpi resolution to build a calibration board. "Calibration checkerboard3.pdf" file also can be printed on a paper to paste on a wall.

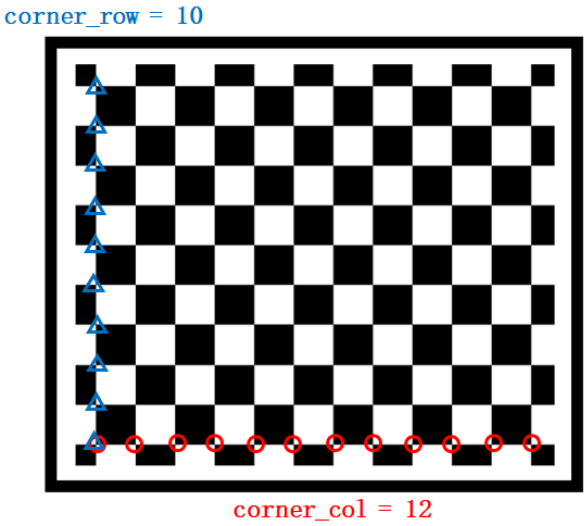

Fig 2-1 Chessboard

User can customize other chessboard to calibration. *Note: The pattern should be the same as Fig 2-1.*

The geometry parameters should be set in "config/camera_calib_config.ini", including corner_col, corner_row and board_length.

2.2. Calibration Process

1) Create FPN.txt, and copy to "config/". For more information, CeleX5_MP should refer to https://github.com/CelePixel/CeleX5-MIPI, and CeleX5_Z should refer to https://github.com/CelePixel/CeleX5-Zynq.

2) (CeleX5_Z only) If you use CeleX5_Z, please set the IP and Port at "config/zynq_conf.ini". To get other connection instructions for CeleX5_Z, please also refer to https://github.com/CelePixel/CeleX5-Zynq.

3) Connect sensor, open calibration_tool.exe, chose 1 and press “Enter”. A window of CeleX5 image is create. If the window is in black or gray unfortunately, connect the sensor again.

4) Press “l” or “d” to lighten or darken an image to the brightness as shown in Fig 2-2-1. Press arrow keys to flip image, the left and right arrow keys can horizontally flip the image and the up and down arrow keys can vertically flip the image. Then adjust the focus.

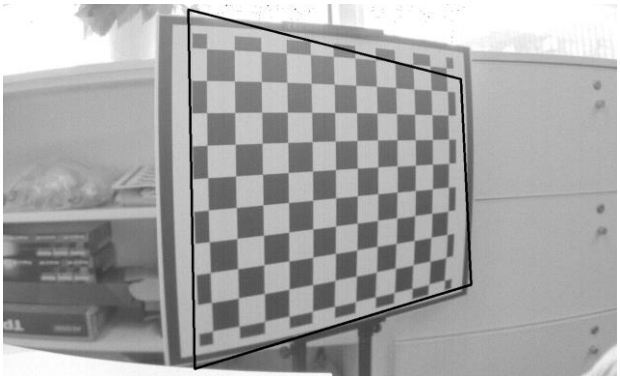

Fig 2-2-1

5) Adjust position and orientation, the outline of the chessboard is inside the black frame (little deviation is acceptable, but all squares must appear in an image as shown in Fig 2-2-1). The black frames in the image can assist adjusting. Totally 20 pictures are needed, in which the directions and positions of the chessboard are different as shown in Fig 2-2-2. The number in left-top of an image indicates the appearance order. The sensor and chessboard of left view and right view are shown in Fig 2-2-3.

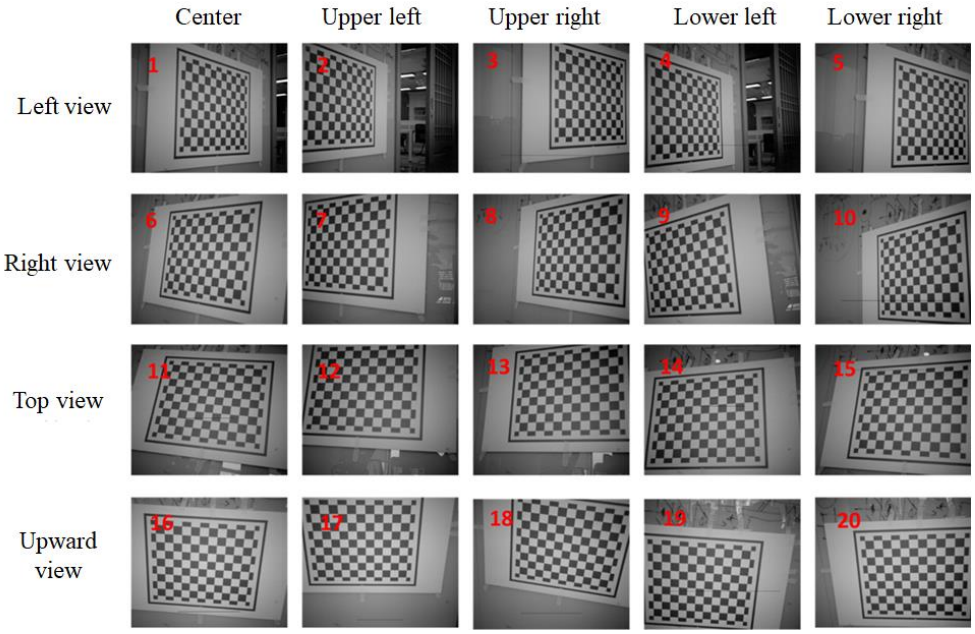

Fig 2-2-2 Totally 20 pictures are needed.

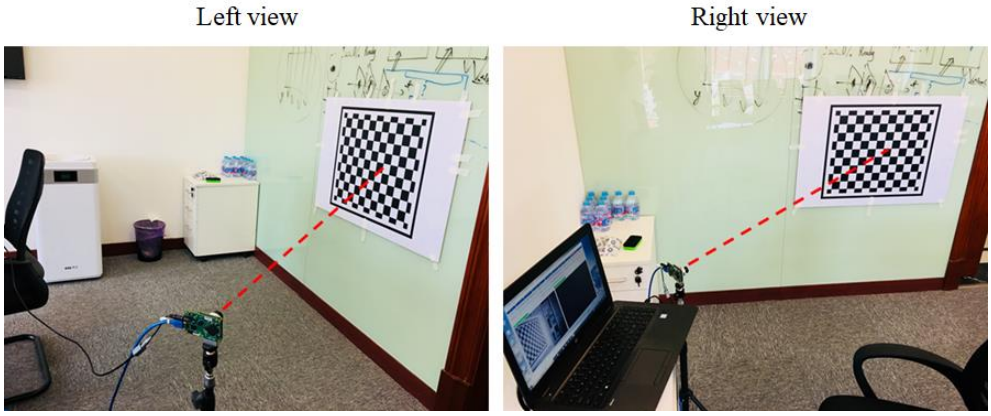

Fig 2-2-3

6) If the position and orientation has been fixed according to step-5), press “s”, the tool will automatically find corners. If corners are found, “Find No. ? corner data!” is printed, and picture will be saved with named “img_online/img?.jpg”. Then, change to a new position (return to step-5)). If corners are not found, Console prints a warning of “Can not find corners! Please use another picture or you can tune the FPN, focus or brightness.”. Then, repeat this calibration step at the same position.

   Note: For 6th, 11th and 16th position, visual angle should be changed a lot.

7) After recording 20 pictures, the console will print the calculated parameters which are also recorded in “config/CameraCalib.ini” (in [Intrinsic_Parameters] block). All the 20 20 pictures are automatically saved in “img_online/” folder.

3. Offline Intrinsic Parameters Calibration

3.1. Process

1) Based on the method of chapter 2, acquire 20 pictures first. Copy those pictures to “img_offline” folder. Name those pictures as “Pic (no.).jpg”, such as “Pic (1).jpg” is the name of the first picture.
2) Configure the parameters in “camera_calib_config.ini”, such as the parameters of chessboard.
3) Open calibration_tool.exe, press “2” and press “Enter”, calibration automatically runs. If find corners on the No.* picture, the console prints “Find No.* corner data!”. If corners are not found, “Cannot find corners! Please use another picture or you can tune the FPN, focus or brightness.” is printed.
   Note: On majority situation, the parameters are acceptable if corners are found on more than 10 pictures. The reasons that corners cannot found are losing some corner on the

picture or low quality of the picture (wrong PFN, brightness or focus). If higher accuracy is preferred, replace the invalid picture with new picture and repeat step-3).

4) All calibration parameters are recorded in "config/CameraCalib.ini".

4. Online Extrinsic Parameters Calibration

4.1. Preparation

1) If distortion rectification is preferred for extrinsic calibration, intrinsic parameters should be acquired first in [Intrinsic_Parameters] of "config/CameraCalib.ini", moreover, undistort_enable_flag should set as 1 in "config/camera_calib_config.ini". Otherwise, undistort_enable_flag = 0, and the picture during extrinsic calibration is distorted.
2) Find a horizontal field with two straight and parallel lines as shown in Fig 4-1.
3) Drive vehicle carefully until the vehicle is parallel to the two lines. In other words, the distances from the front and rear edge of vehicle to the line are the same.
4) Install a sensor. Location at the center of vehicle and keeping the lens horizontal is preferred.
5) The vehicle coordinate is defined in Fig 4-1. The origin of the coordinate system is at the center of front wheel axle, X-axis is along forward direction and Y-axis is along left direction.
6) Measure the width of the vehicle, and revise the width_vehicle in "camera_calib_config.ini".
7) Put 4 calibration markers. For nearer two markers, x = lon_dist_near, y = ±width_vehicle / 2. For farer other two, x = lon_dist_far, y = ± width_vehicle / 2. Thus, the 4 markers are not only parallel, but coincided with the two edges of the vehicle. lon_dist_near and lon_dist_far can be set in "camera_calib_config.ini".
   Note: All markers should appear on the picture. Recommended value of the two parameters are 8.0 m and 30.0 m, respectively.
8) Put another test marker at a certain positon, such as x=40m, y= width_vehicle / 2 for testing the calibration accuracy.

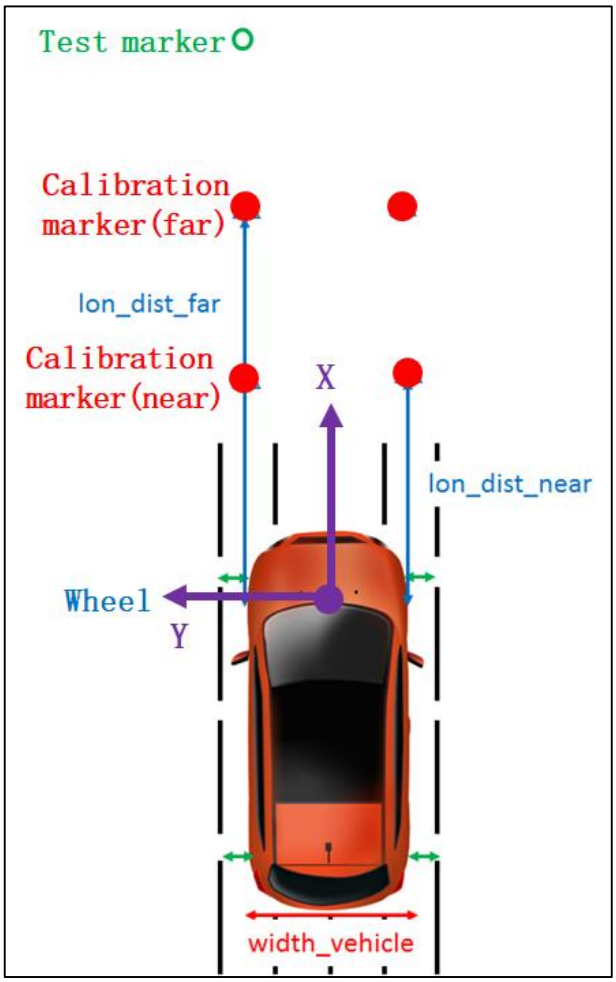

Fig 4-1

4.2. Calibration Process

1) According to step-2.2-1), adjust FPN.
2) (CeleX5_Z only) If you use CeleX5_Z, please set the IP and Port at "config/zynq_conf.ini".
3) Connect sensor, open calibration_tool.exe, chose 3 and press "Enter". A window of CeleX5 image is create. If the window is in black or gray unfortunately, connect the sensor again.
4) According to step-2.2-4), adjust the picture.
5) If five markers all appear in the picture, click "s" to save the picture as shown in Fig 4-2.

Fig 4-2

6) Click at bottom of the four calibration markers first, as shown in Fig 4-2 (the four red arrows). There is not a requirement for click sequencing of this four markers.
7) Then click the bottom of the last test marker, as the shown in Fig 4-2 (the green arrow).
8) Console displays the position in pixel of the four calibration markers in Fig 4-3. Fig 4-4 shows the final picture after step-7). Check all click points are at the bottom of the marker, and all the position in pixel are not repeated.

```
No. 0 position, x: 159 y: 687
No. 1 position, x: 372 y: 447
No. 2 position, x: 915 y: 417
No. 3 position, x: 915 y: 436
```

Fig 4-3

Fig 4-4

9) Calibration results are printed on console.
10) In addition, the position of the test marker is also calculated as shown in Fig 4-5.
Note: The accuracy can be estimated based on the calculated position and the ground truth distance. The accuracy should be less than 3% within 50m. Such as, the deviation of Fig 4-5 is quite larger.

```
Success write ProjectionMatrixImage2Vehicle in ini file.
test position at pixel, u: 503 v: 581
test position in vehicle coordinate, x = 105.63, y = 1.60406
```

Fig 4-5

11) The calibration results are recorded at [Matrix_Image2Vehicle] of "config/CameraCalib.ini". Calibration raw picture (raw_img.jpg) and marked picture (marked_img.jpg) as shown in Fig 4-4 are saved in "img_online/" folder.

5. Offline Extrinsic Parameters Calibration

5.1. Calibration Process

1) Refer to chapter 4 to obtain a calibration raw picture as shown in Fig 4-2.
2) In [config_extrinsic_calib] (i.e., from img_point_1_x to img_point_4_y) of "camera_calib_config.ini", input the position of the four calibration markers in left-to-right order. Then, input the position of the test maker, i.e., test_posi_u and test_posi_v.
3) Open calibration_tool.exe, chose 4 and press "Enter".
4) The calibration results are recorded at [Matrix_Image2Vehicle] of "config/CameraCalib.ini".

6. Camera Orientation Recording

After extrinsic calibration, the camera orientation should be recorded. Thus, the camera orientation can be checked before each use.

Note: Raw IMU data are used herein.

6.1. Process

1) (CeleX5_Z only) If you use CeleX5_Z, please set the IP and Port at "config/zynq_conf.ini".
2) Open calibration_tool.exe, chose 5 and press "Enter". The tool will acquire IMU data. Now, a window named "EventBinaryPic" is created.
3) If "EventBinaryPic" window displays event data, the console window will print "[Calibration] IMU information:" soon. The IMU accelerometer data is recorded in [IMU_Information] of "config/CameraCalib.ini".
4) Otherwise, if "EventBinaryPic" window is black and the console window prints "No IMU data", no IMU data is acquired. Please restart the sensor.

7. Camera Orientation Checking (IMU)

7.1. Preparation

Accelerations have been recorded at [IMU_Information] of "config/CameraCalib.ini".

7.2. Process

1) (CeleX5_Z only) If you use CeleX5_Z, please set the IP and Port at "config/zynq_conf.ini".
2) Open calibration_tool.exe, and chose 6. The tool will acquire IMU data and a window named "EventBinaryPic" will be created.
3) If "EventBinaryPic" window displays event data, the console window will print IMU information includes current 3-axis accelerometer data (acc_current) and recorded 3-axis accelerometer data from **Camera Orientation Recording Tool** (acc_recorded). If all deviation of each 3-axis are less than 0.05, the console prints "The sensor is fixed.", i.e., the extrinsic parameters are right. If any deviation of each 3-axis is not less than 0.05, the console displays "The sensor has been moved. Please calibration again.".
4) Otherwise, if "EventBinaryPic" window is black and the console window prints "No IMU data", no IMU data is acquired. Please restart the sensor.

8. Camera Orientation Checking (Bird View)

8.1. Preparation

Besides **Camera Orientation Checking (IMU)**, bird view is a more intuitive way to check extrinsic parameters. Extrinsic parameters have been recorded at [Matrix_Image2Vehicle] of "config/CameraCalib.ini". Copy right FPN to the path "config/".

If distortion rectification should be applied, intrinsic parameters should be acquired first in [Intrinsic_Parameters] of "config/CameraCalib.ini", moreover, undistort_enable_flag should set as 1 in "config/camera_calib_config.ini". Otherwise, undistort_enable_flag = 0, and the picture during extrinsic calibration is distorted.

8.2. Process

1) (CeleX5_Z only) If you use CeleX5_Z, please set the IP and Port at "config/zynq_conf.ini".
2) Open calibration_tool.exe, and chose 7. Raw picture will be showed in "Image" window and related bird view image will be showed in "bird_view" window. Adjust the picture, according to step-2.2-4).
3) Drive vehicle along horizontal road where lane lines are obvious.
4) Check the parallelism of lane lines on "bird_view" window. If all lane lines are mutually parallel and lines are vertical in the image as shown in Fig. 8(a), the extrinsic parameters

are acceptable, though vibration is somewhat influent the bird view. If lane lines are obviously non-parallel or not vertical as shown in Fig. 8(b), the extrinsic parameters are wrong.

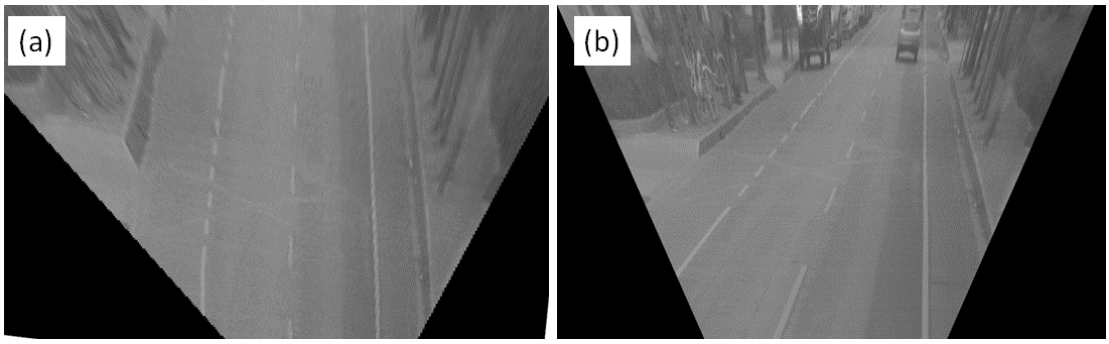

Fig. 8 (a) Right bird view and (b) wrong bird view

Appendix A: Q&A

1. No data or image when sensor is open.

Possible problem: Sensor fails in opening.

Solution: Check the power and cable, restart the sensor.

Appendix B: Change Control

Version	Description	Date	Author	Proof
v1.1	Add some description for CeleX5_Z	2019.07.19	Qisheng He	Yu Zhang