Camera_Calibration

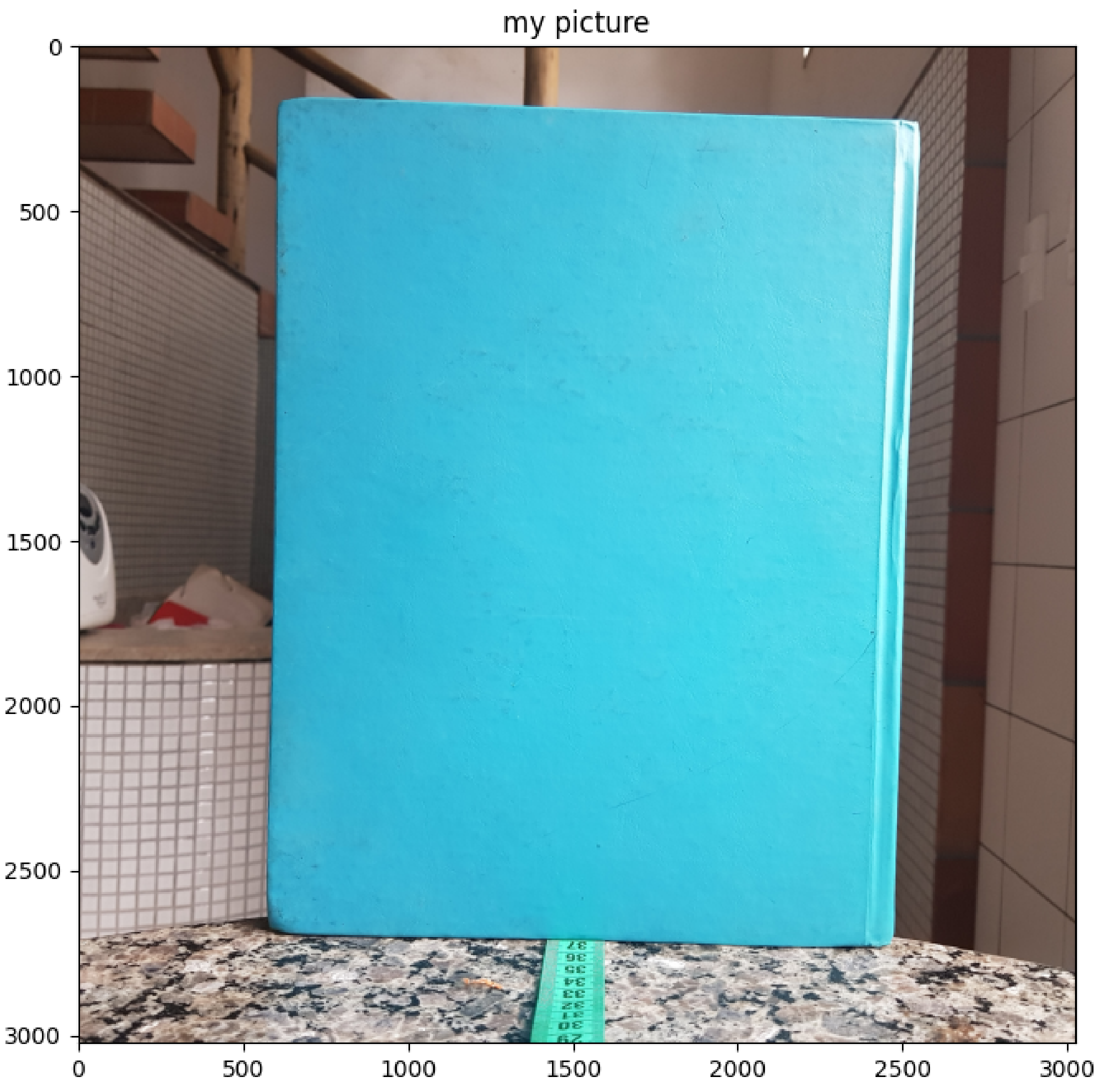
June 21, 2021

1 Camera Calibration Methods

[607]:
```
import numpy as np
import matplotlib.pyplot as plt
import cv2
import glob
import sys
import os

plt.rcParams['figure.figsize'] = [12, 8]
plt.rcParams['figure.dpi'] = 100 # 200 e.g. is really fine, but slower
```

1.1 Naive

[608]:
```
image = cv2.imread("Livro.jpg")

gray = cv2.cvtColor(image, cv2.COLOR_BGR2RGB)

plt.imshow(gray)
plt.title('my picture')
plt.show()
```



The image above have:

```
width=3021px
heigth=3021px
```

The book in the image have:

```
width=1938px
heigth=2542px
```

The real size of the book is:

```
width=22.85cm
height=28.4cm
```

And its center is located about 37cm from the camera position.

That being, we can aproximate:

fx = 37*(1938/22.85)

[609]:
```
fx = 37*(1938/22.85)
fx
```

[609]: 3138.1181619256013

[610]:
```
fy = 37*(2542/28.4)
fy
```

[610]: 3311.760563380282

[611]:
```
cx = 3021/2
cx
```

[611]: 1510.5

[612]:
```
cy = 3021/2
cy
```

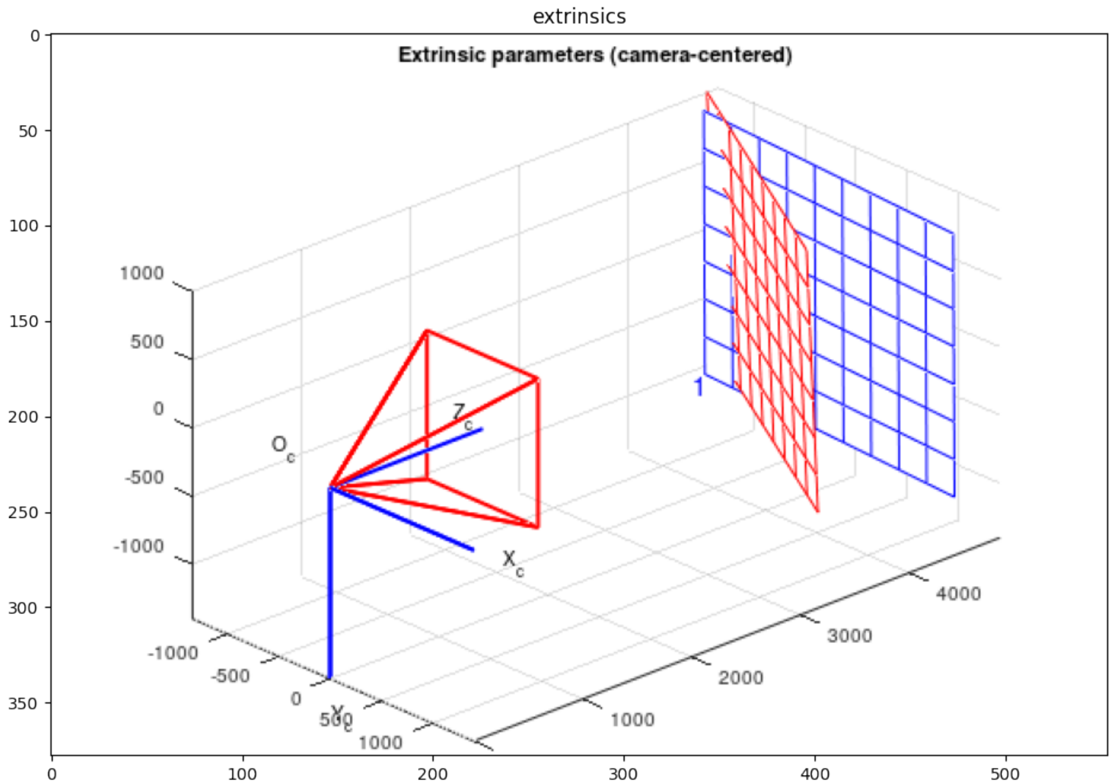
[612]: 1510.5

1.2 Octave

Using the Octave Calibration Toolbox (https://github.com/nghiaho12/camera_calibration_toolbox_octave) we obtain:

[642]:
```
octave1 = cv2.imread("octave1.png")
octave2 = cv2.imread("octave2.png")
image1  = cv2.imread("image1.jpg")
image1 = cv2.rotate(image1, cv2.cv2.ROTATE_90_CLOCKWISE)

octave3 = cv2.imread("octave3.png")
octave4 = cv2.imread("octave4.png")
octave5 = cv2.imread("octave5.png")

octave1_d = cv2.cvtColor(octave1, cv2.COLOR_BGR2RGB)
octave2_d = cv2.cvtColor(octave2, cv2.COLOR_BGR2RGB)
octave3_d = cv2.cvtColor(octave3, cv2.COLOR_BGR2RGB)
octave4_d = cv2.cvtColor(octave4, cv2.COLOR_BGR2RGB)
octave5_d = cv2.cvtColor(octave5, cv2.COLOR_BGR2RGB)
```

[643]:
```
plt.imshow(octave1_d)
plt.title('extrinsics')
plt.show()
```



[644]:
```
plt.title('image1')
plt.imshow(image1)
plt.show()
plt.title('image2')
plt.imshow(octave2_d)
plt.show()
```

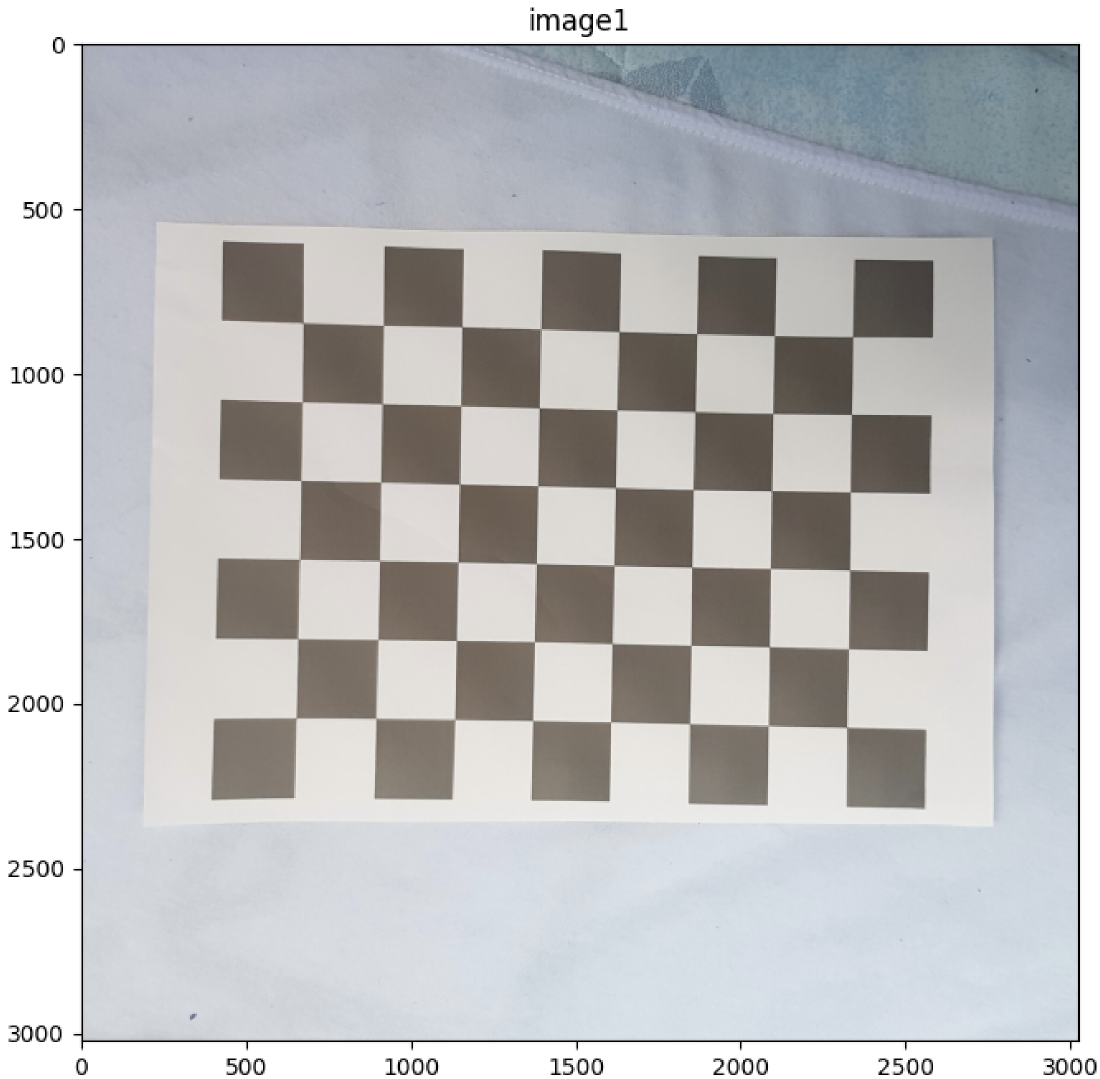
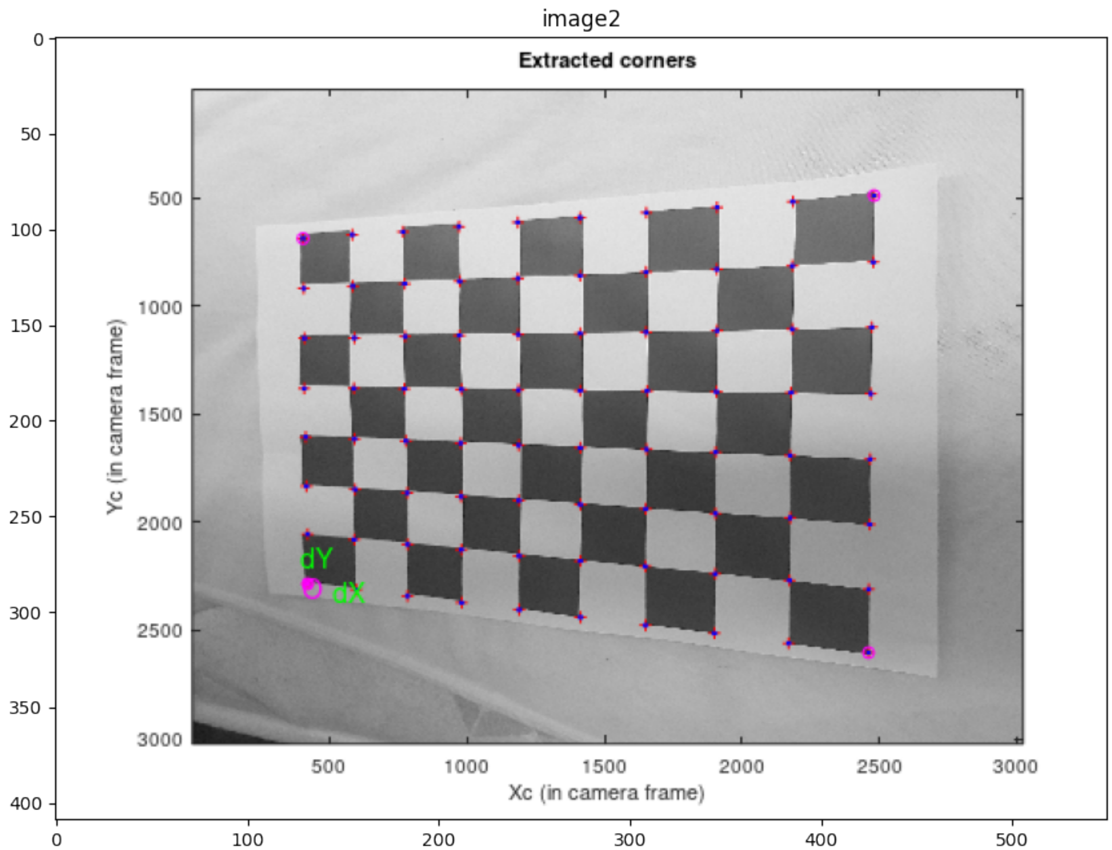
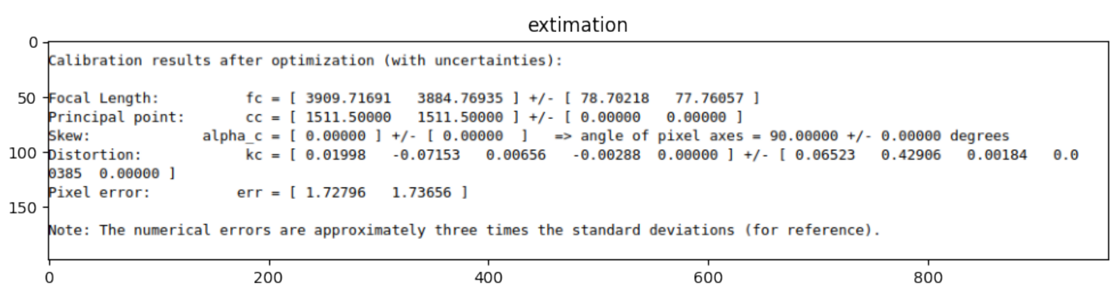


image1
0
500
1000
1500
2000
2500
3000
0
500
1000
1500
2000
2500
3000




```python
plt.imshow(octave3_d)
plt.title('extimation')
plt.figure(figsize=(20, 20))
plt.show()
```

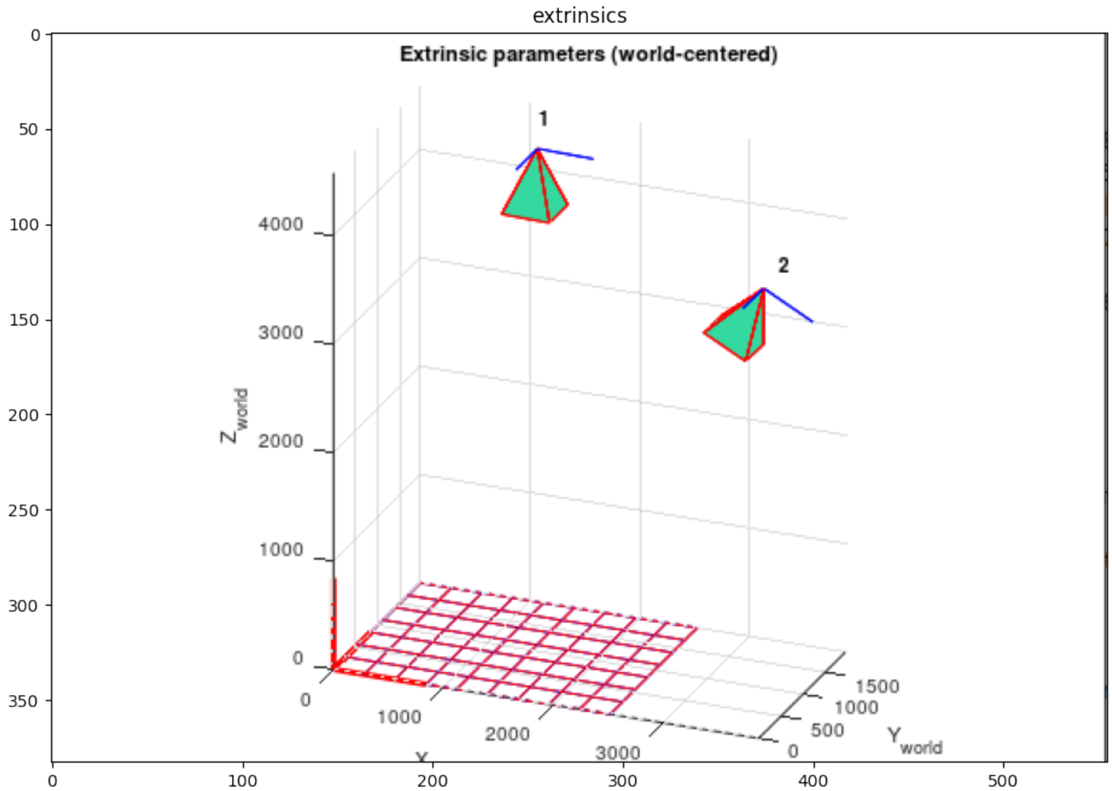



```
Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 3909.71691   3884.76935 ] +/- [ 78.70218   77.76057 ]
Principal point:       cc = [ 1511.50000   1511.50000 ] +/- [ 0.00000   0.00000 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.01998   -0.07153   0.00656   -0.00288  0.00000 ] +/- [ 0.06523   0.42906   0.00184   0.0
0385  0.00000 ]
Pixel error:          err = [ 1.72796   1.73656 ]

Note: The numerical errors are approximately three times the standard deviations (for reference).
```

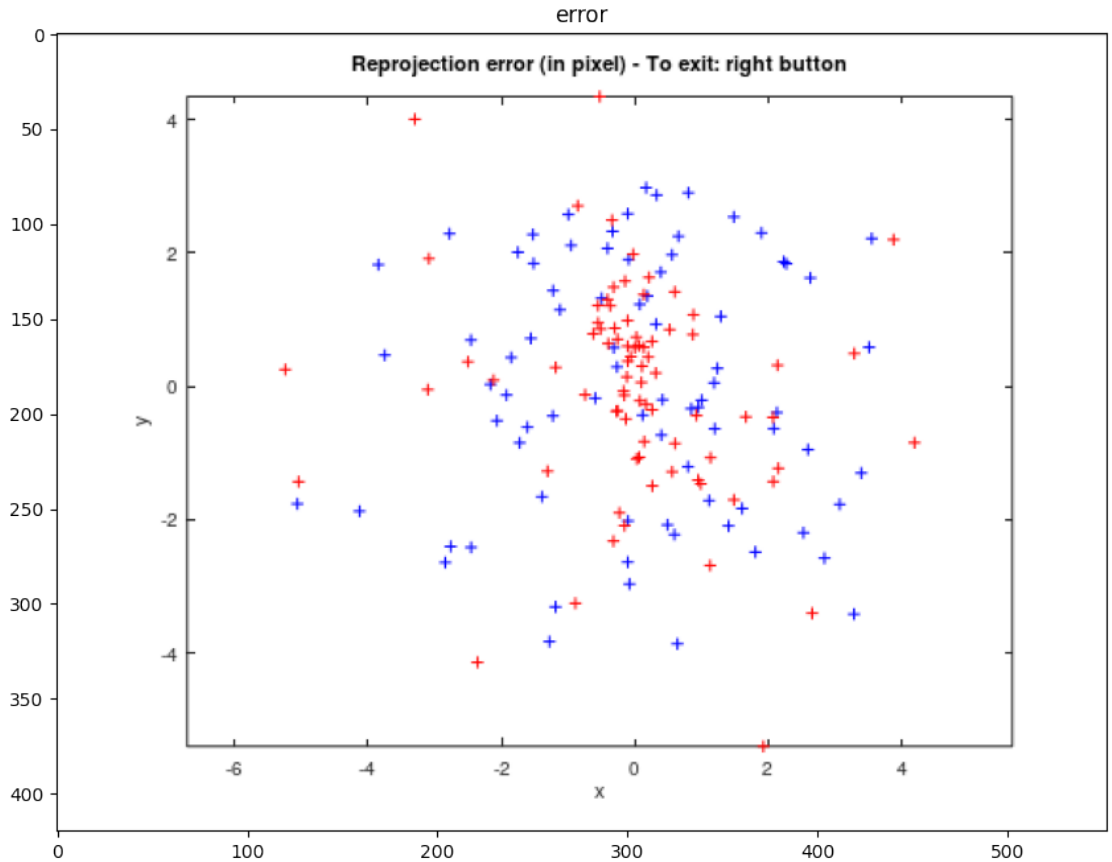
```
<Figure size 2000x2000 with 0 Axes>
```

```python
plt.imshow(octave4_d)
plt.title('extrinsics')
```

```
plt.show()
```



[647]:
```
plt.imshow(octave5_d)
plt.title('error')
plt.show()
```

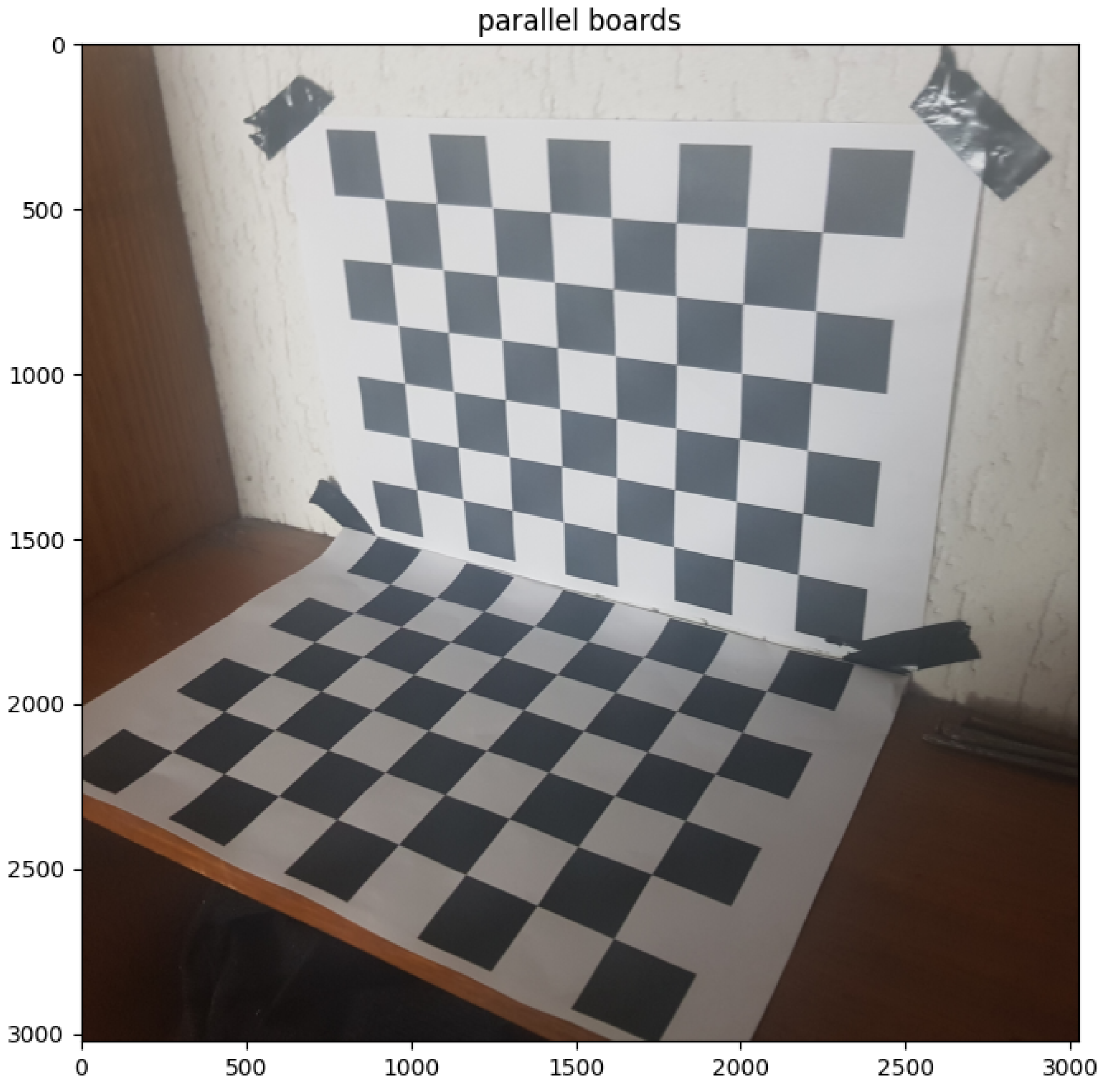


so we obtain fx = 3909 and fy = 3884 using Octave

1.3 Python

We are gonna use the following image for our calibration

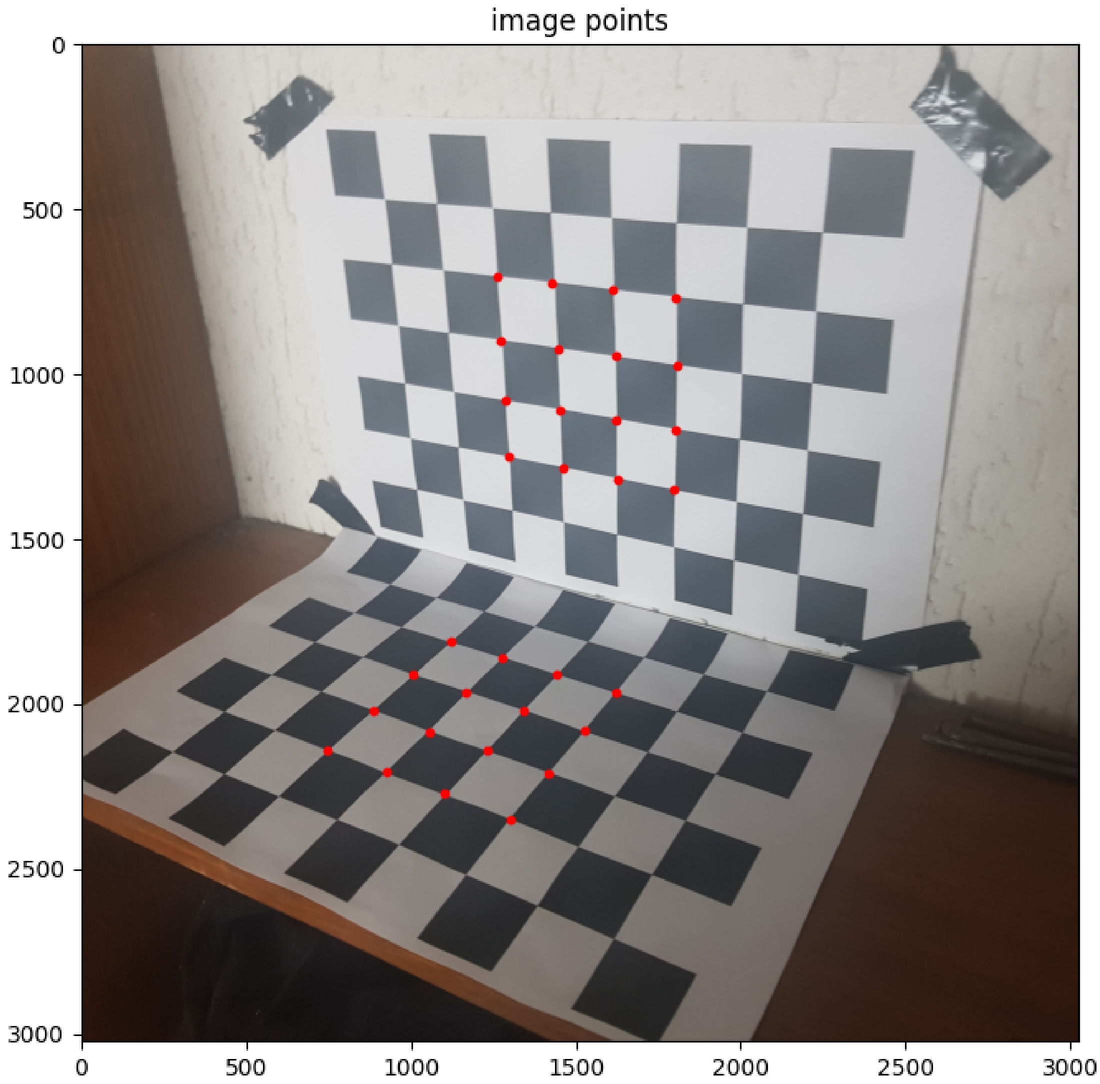
[677]:
```
parallel_boards = cv2.imread("image7.jpg")
parallel_boards = cv2.cvtColor(parallel_boards, cv2.COLOR_BGR2RGB)
plt.imshow(parallel_boards)
plt.title('parallel boards')
plt.show()
```



The image points are:

[649]:
```
image_points = [
    [748, 2140],
    [884, 2020],
    [1008, 1912],
    [1120, 1812],

    [924, 2204],
    [1056, 2084],
    [1168, 1964],
    [1276, 1860],

    [1104, 2272],
```

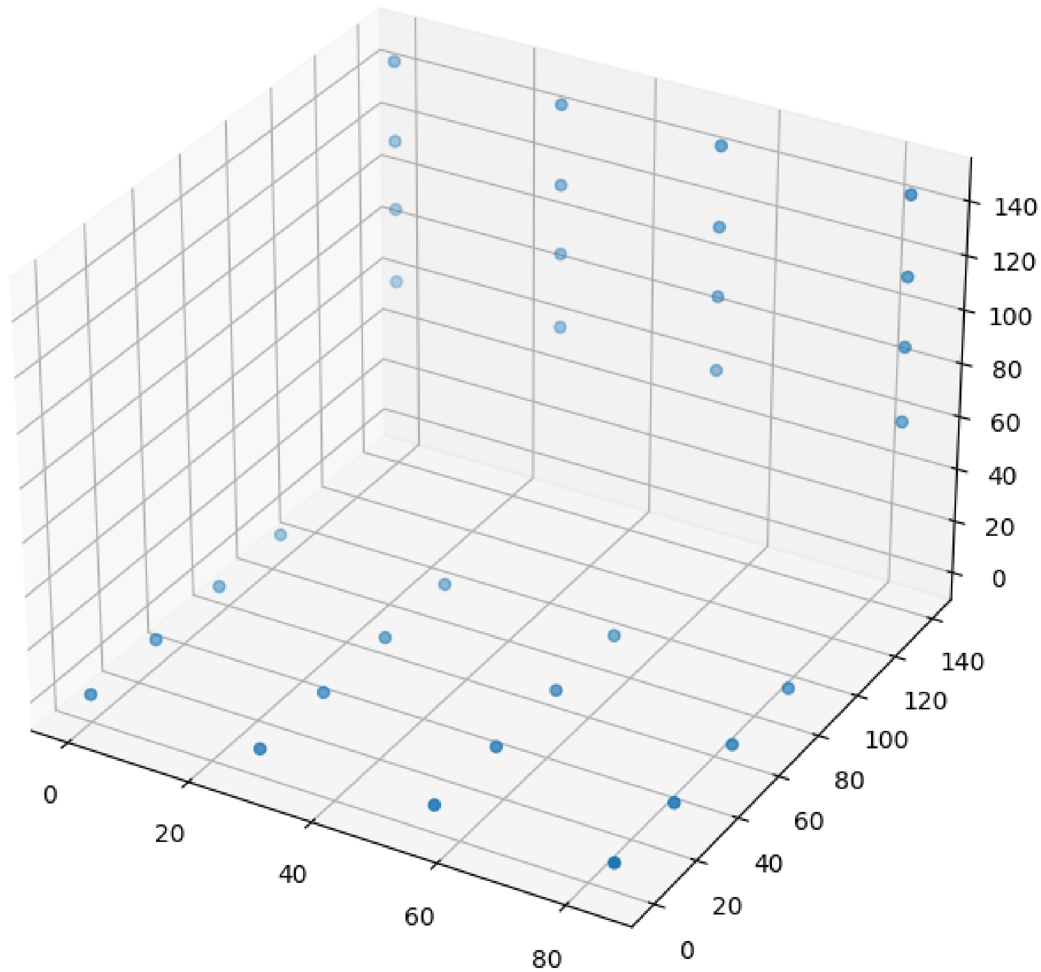
```
    [1232, 2140],
    [1342, 2020],
    [1444, 1912],

    [1300, 2349],
    [1419, 2211],
    [1525, 2083],
    [1621, 1966],

    [1296, 1252],
    [1286, 1080],
    [1274, 898],
    [1262, 706],

    [1460, 1284],
    [1452, 1108],
    [1446, 922],
    [1428, 724],

    [1625, 1318],
    [1624, 1138],
    [1621, 946],
    [1614, 746],

    [1800, 1352],
    [1803, 1168],
    [1806, 974],
    [1805, 768],
]

x = []
y = []

for i in range(len(image_points)):
    x.append(image_points[i][0])
    y.append(image_points[i][1])

plt.imshow(parallel_boards)
plt.title('image points')
plt.scatter(x=x, y=y, c='r', s=10)
plt.show()
```



The world points, using the first point as the (0,0,0) and units in mm are:

[650]:
```
#margin = -23
margin = 7

world_points = [
    [0, 0,  0],
    [0, 28, 0],
    [0, 56, 0],
    [0, 84, 0],

    [28, 0,  0],
    [28, 28, 0],
    [28, 56, 0],
```

```
    [28, 84, 0],

    [56, 0,  0],
    [56, 28, 0],
    [56, 56, 0],
    [56, 84, 0],

    [84, 0,  0],
    [84, 28, 0],
    [84, 56, 0],
    [84, 84, 0],

    [0, 140, 0  + 54 + margin],
    [0, 140, 28 + 54 + margin],
    [0, 140, 54 + 54 + margin],
    [0, 140, 84 + 54 + margin],

    [28, 140, 0  + 54 + margin],
    [28, 140, 28 + 54 + margin],
    [28, 140, 54 + 54 + margin],
    [28, 140, 84 + 54 + margin],

    [54, 140, 0  + 54 + margin],
    [54, 140, 28 + 54 + margin],
    [54, 140, 54 + 54 + margin],
    [54, 140, 84 + 54 + margin],

    [84, 140, 0  + 54 + margin],
    [84, 140, 28 + 54 + margin],
    [84, 140, 54 + 54 + margin],
    [84, 140, 84 + 54 + margin],
]

x = []
y = []
z = []

for i in range(len(world_points)):
    world_points[i] = [world_points[i][0], world_points[i][1], world_points[i][2]]
    x.append(world_points[i][0])
    y.append(world_points[i][1])
    z.append(world_points[i][2])

ax = plt.axes(projection='3d')

ax.scatter3D(x, y, z);
```



Building the Matrix A as describen in the book by Trucco and Verry, and taking its SVD we have:

[664]:
```
A = []

def build_line(image_points, world_points, i):
    return [
        image_points[i][0]*world_points[i][0],
        image_points[i][0]*world_points[i][1],
        image_points[i][0]*world_points[i][2],
        image_points[i][0],
        -1*image_points[i][1]*world_points[i][0],
        -1*image_points[i][1]*world_points[i][1],
        -1*image_points[i][1]*world_points[i][2],
        -1*image_points[i][1],
```

```
    ]

for i in range(len(image_points)):
    A.append(build_line(image_points, world_points, i))

SVD = np.linalg.svd(A, full_matrices=True)
```

[665]:
```
v = SVD[2][SVD[1].argmin()]
```

The minimum eigen value is

[678]:
```
min(SVD[1])
```

[678]:
```
21.962894235209138
```

The corresponding eigen vector is:

[679]:
```
v
```

[679]:
```
array([-1.26663782e-04, -4.31845159e-04, -3.53728068e-03,  9.43094446e-01,
        2.17897154e-03,  2.69185466e-03, -2.99920859e-04,  3.32487694e-01])
```

The gamma parameter, given by Trucco and Verri, is given by:

[680]:
```
y = np.sqrt(v[0]**2 + v[1]**2 + v[2]**2)
y
```

[680]:
```
0.0035657942450506293
```

The alpha*gamma parameter, given by Trucco and Verri, is given by:

[669]:
```
ay = np.sqrt(v[4]**2 + v[5]**2 + v[6]**2)
ay
```

[669]:
```
0.0034761977784463077
```

The alpha(aspect ratio) parameter is given by:

[670]:
```
a = ay/y
a
```

[670]:
```
0.9748733492604957
```

The rows of the intrinsic matrix can by recovered by:

[671]:
```
r = np.zeros((3,3))

r[1,0] = v[0]/y
r[1,1] = v[1]/y
```

```
r[1,2] = v[2]/y

Ty     = v[3]/y

r[0,0] = v[4]/ay
r[0,1] = v[5]/ay
r[0,2] = v[6]/ay

Tx     = v[7]/ay

l0 = [r[0,0], r[0,1], r[0,2]]
l1 = [r[1,0], r[1,1], r[1,2]]

l3 = np.cross(l0, l1)

r[2,0] = l3[0]
r[2,1] = l3[1]
r[2,2] = l3[2]

print(r)

print("Tx=",Tx,"Ty", Ty)
```

```
[[ 0.62682611  0.77436752 -0.08627842]
 [-0.0355219  -0.12110771 -0.99200359]
 [-0.77862434  0.62487853 -0.04840647]]
Tx= 95.64694402485662 Ty 264.4836974021597
```

[672]:
```
print(image_points[0][0]*(r[0,0]*world_points[0][0] + r[0,1]*world_points[0][1]␣
↪* r[0,2]*world_points[0][2] + Tx))
```

```
71543.91413059275
```

Because the value is positive we need to invert the values of the first two rows of r and Tx and Ty

[673]:
```
r[0,0] = -1 * r[0,0]
r[0,1] = -1 * r[0,1]
r[0,2] = -1 * r[0,2]
r[1,0] = -1 * r[1,0]
r[1,1] = -1 * r[1,1]
r[1,2] = -1 * r[1,2]

Tx = -1*Tx
Ty = -1*Ty
print(r)
```

```
[[-0.62682611 -0.77436752  0.08627842]
 [ 0.0355219   0.12110771  0.99200359]
```

```
[-0.77862434  0.62487853 -0.04840647]]
```

The Tz and fx parameters of the third row can be approximated by:

[674]:
```python
def build_A_line(image_points, world_points, r, i):
    return [
        image_points[i][0], (r[0,0]*world_points[i][0] +␣
 ↪r[0,1]*world_points[i][1] + r[0,2]*world_points[i][2] + Tx),
    ]

A = []
b = []

for i in range(len(image_points)):
    A.append(build_A_line(image_points, world_points, r, i))

A = np.reshape(A,(len(image_points),2))

def build_b_line(image_points, world_points, r, i):
    return [
        -1*image_points[i][0]*(r[2,0]*world_points[i][0] +␣
 ↪r[2,1]*world_points[i][1] + r[2,2]*world_points[i][2]),
    ]

for i in range(len(image_points)):
    b.append(build_b_line(image_points, world_points, r, i))

C = np.matmul(np.matmul(np.linalg.inv(np.matmul(A.T,A)),A.T), b)

print("Tz =", C[0])
print("fx =", C[1])
fx = C[1][0]
Tz = C[0]
```

```
Tz = [508.28775991]
fx = [3861.17492679]
```

And fy is given by:

[675]:
```python
fy = fx/a
fy
```

[675]:
```
3960.693899077562
```

As we can see, the focal lenght in the x direction (~3960, ~3861) is very close from the value found by octave (~3909, ~3884)

[676]:
```python
print("fy = ", fy, "fx = ", fx)
```

```
fy =  3960.693899077562 fx =  3861.1749267893547
```

1.3.1 Conclusions

The difference, and the margin of error in the Octave can be explained by little distortions and the fact that the points where all collected from a check board printed in a piece of paper that can suffer from small ondulations on its surface.

The most error prone of all the methods addressed was the naive method, and the one that give the bigger difference in absolute value when compared to all the other methods.