# Assignment 1

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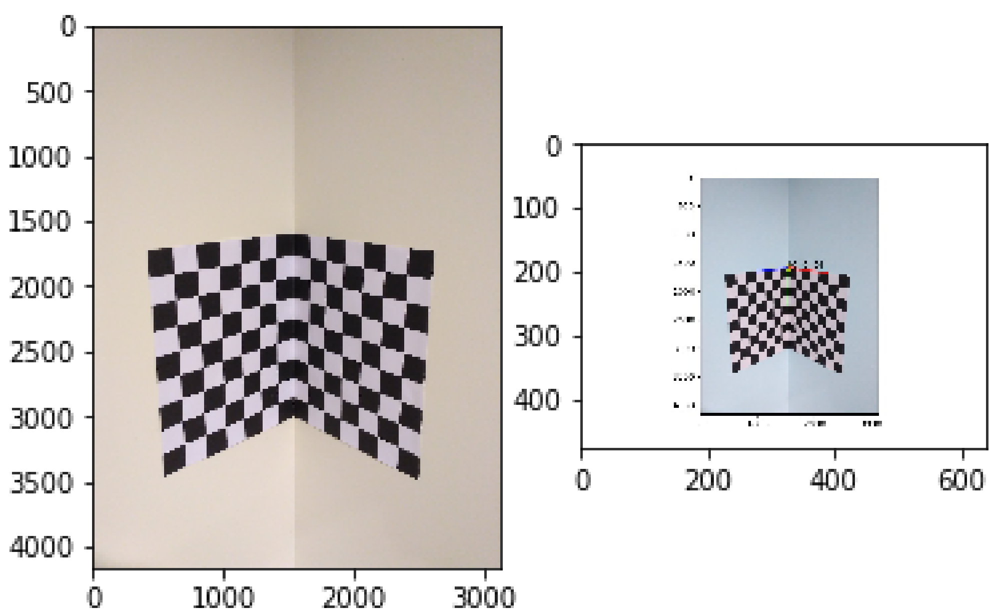
In [1]:
```
import cv2
import numpy as np
from matplotlib import pyplot as plt
%matplotlib inline
```

In [182]:
```
img = cv2.imread('calib-object.jpg')
img = cv2.cvtColor(img,cv2.COLOR_BGR2RGB)
img_ref = cv2.imread('calib-object-legend.jpg')
img_ref = cv2.cvtColor(img_ref,cv2.COLOR_BGR2RGB)
plt.subplot(121)
plt.imshow(img)
plt.subplot(122)
plt.imshow(img_ref)
```

Out[182]:
```
<matplotlib.image.AxesImage at 0x7f87601abac8>
```



```
In [183]: x1 = [(1548.2210910175404, 1606.9701081799199), (1666.64963533335, 1612.6095626711485)
          z1 = [(1407.2347287368152, 1623.8884716536068), (1277.5272754385483, 1640.806835127293
          img_coords = np.asarray(x1+z1).astype('float32')
```

```
In [184]: w1 = [[0,0,0],[1,0,0],[2,0,0],[3,0,0],[4,0,0],[5,0,0],[6,0,0],[7,0,0],
                    [0,1,0],[1,1,0],[2,1,0],[3,1,0],[4,1,0],[5,1,0],[0,0,1],[0,0,2],
                    [0,0,3],[0,0,4],[0,0,5],[0,0,6],[0,0,7],[0,1,1],[0,1,2],[0,1,3],
                    [0,1,4],[0,1,5]]
          world_coords = np.asarray(w1).astype('float32')
```

# 1 Direct Linear Transform

We will be using this method to find the 11 paramaters of the projected matrix P. (5 intrinsic and 6 extrinsic paramters). The projected matrix P maps the point from object space to camera space. P = KR[I|-RC]. The algorithm to compute DLT is as follows - + Define P + Get atleast 6 points + Restructure P to M + Formulate Least square error equation + Calculate SVD for M + Last column of V.T of decomposition is the solution for P + Calculate t + QR decomposition for K and R

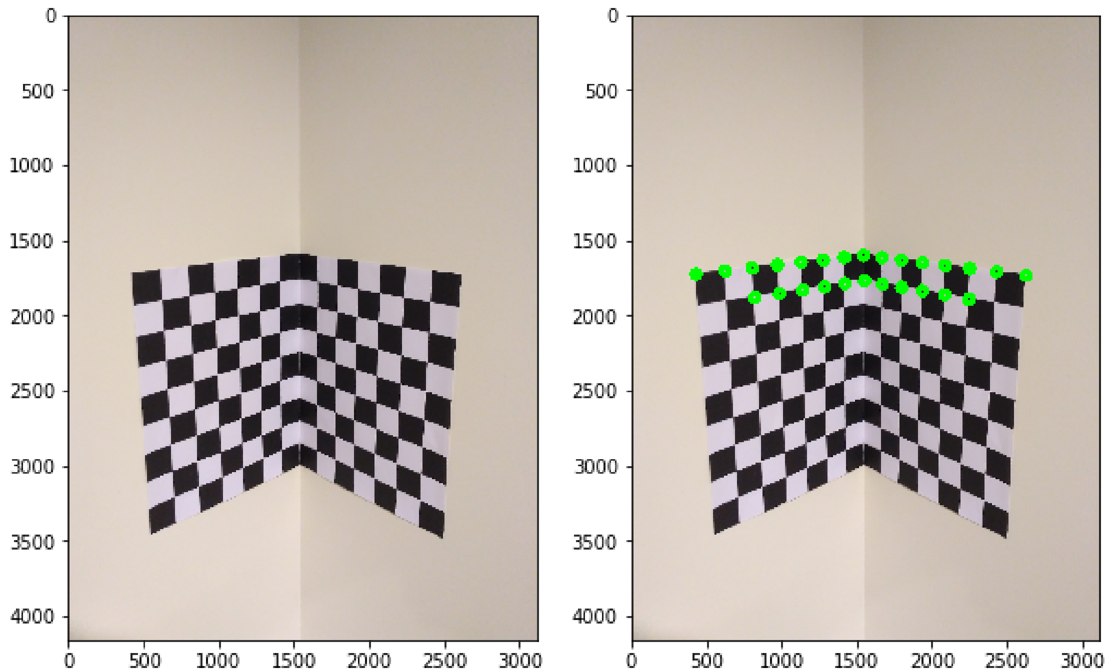
```
In [185]: def dlt(img,img_coords,world_coords):
              npts = img_coords.shape[0]
              M = np.zeros((npts*2,12))
              for i in range(npts):
                  X,Y,Z = world_coords[i]
                  u,v = img_coords[i]
                  M[2*i] = [0,0,0,0,-X,-Y,-Z,-1,u*X,u*Y,u*Z,u]
                  M[2*i+1] = [-X,-Y,-Z,-1,0,0,0,0,v*X,v*Y,v*Z,v]
              u1,s,vh1 = np.linalg.svd(M)
              Pt = vh1[-1]
              P = vh1[-1].reshape(3,4)
              nimg = img.copy()
              n = np.concatenate((world_coords.T,np.ones((1,npts))),axis=0)

          #     mse error between points
              img_pred = P@n
              img_pred = img_pred[[1,0],:]/img_pred[2,:]
              mse = np.mean((img_coords-img_pred.T)**2)
              for i in range(npts):
                  cv2.circle(nimg,(int(img_pred[0,i]),int(img_pred[1,i])  ),npts,(0,255,0),int(0

              hom = P[:,0:3]
              pt = P[:,3]
              hominv = np.linalg.inv(hom)
              t = hominv@pt
              R,K = np.linalg.qr(hom)
              K = K/K[2,2]
              x = M@Pt
          #     overall error
```

```
            error = x@x
            return P,K,R,t,error,mse,nimg
```

In [186]:
```
P,K,R,t,e,m,ni = dlt(img,img_coords,world_coords)
print("Projected Matrix")
print(P)
print("Intrinsic Matrix")
print(K)
print("Rotation Matrix")
print(R)
print("Translation Matrix")
print(t)
print("Error")
print(e)
plt.figure(figsize=(10,20))
plt.subplot(121)
plt.imshow(img)
plt.subplot(122)
plt.imshow(ni)
```

```
Projected Matrix
[[ 1.89129965e-02 -8.55115557e-02  1.44162009e-02 -7.15221120e-01]
 [-2.71613663e-02 -1.06964917e-02  7.65585212e-02 -6.88380297e-01]
 [ 1.58017646e-05 -5.72722382e-06  1.29859662e-05 -4.45585664e-04]]
Intrinsic Matrix
[[-6.77956379e+02  8.21109676e+02  1.11819591e+03]
 [ 0.00000000e+00  1.56264060e+03 -1.13845489e+03]
 [ 0.00000000e+00  0.00000000e+00  1.00000000e+00]]
Rotation Matrix
[[-5.71433564e-01 -8.20648320e-01 -1.28551984e-04]
 [ 8.20648191e-01 -5.71433551e-01  4.92260192e-04]
 [-4.77431417e-04  1.75798043e-04  9.99999871e-01]]
Translation Matrix
[-15.62932847   2.5157958  -14.18501829]
Error
0.00016126513070145794
```

Out[186]:
```
<matplotlib.image.AxesImage at 0x7f8766ffa7b8>
```



## 1.1 RANSAC

We implement DLT using RANSAC. The idea behind RANSAC is to find a model that is not an outlier and this mode of sampling is very efficient in making the model robust. In this case we choose a subset of data and compute the Projection matrix and do this step for N times. N is chosen such that the probability of having atleast one inlier is 0.99. In this case we run it for 250 times. We only store the best P so far on the basis of error measured. The algorithm is as follows - + Take n points + Sample atleast 6 points + Calculate error by calibrating against those 6 points + Store the best cases + Repeat

In [187]:
```
N = 250
y1 = [(1542.5816365263122, 2858.9290052327624), (1661.010180842121, 2920.9630046362818
y2 = [[0,8,0],[1,8,0],[2,8,0],[3,8,0],[4,8,0],[5,8,0],[6,8,0],[7,8,0],[0,8,1],[0,8,2]]
img_rcoords = np.asarray(x1+z1+y1).astype('float32')
world_rcoords = np.asarray(w1+y2).astype('float32')
```

In [188]:
```
best = {}
least_error = 1e10
batch_size = img_rcoords.shape[0]
for i in range(N):
    mini = np.random.choice(batch_size, 6, replace=False)
    img_ncood = img_rcoords[mini]
    world_ncood = world_rcoords[mini]
    try:
        P1,K1,R1,t1,e1,m1,n1 = dlt(img,img_ncood,world_ncood)
```

```python
                print(e1)
                if e1 < least_error:
                    least_error = e1
                    best['P'] = P1
                    best['R'] = R1
                    best['K'] = K1
                    best['t'] = t1
                    best['e'] = e1
                    best['ni'] = n1
#       incase of singular matrices (all pts are on the same plane)
            except Exception as e:
                pass
```

```
9.931281339061423e-06
1.8884143649585162e-23
1.1683534508936293e-05
5.831873663106932e-06
2.6719907550557183e-06
3.1744048626345613e-07
1.1756530250013521e-07
1.6716745995189835e-06
1.8118014184044934e-06
1.384739354103538e-07
1.379241570685423e-05
5.099975527373689e-24
8.115290020960666e-27
1.1423206592246811e-24
1.6953197261436567e-26
6.237336373551789e-08
4.7231112885523925e-07
8.012987262589273e-11
3.362393928894647e-06
3.471219364481657e-24
8.51487697038911e-26
5.725100274479089e-08
1.5029378664266617e-06
9.078729603849803e-06
1.4762821567983307e-06
4.62899885286555e-07
1.7505851685412062e-28
4.1520822781908965e-07
1.2999067279701943e-23
6.20890563748057e-08
3.5208144083662747e-10
1.9736545737245593e-24
3.2525792203972227e-07
7.994343881364557e-07
```

```
2.5476144823422273e-08
1.6500552871583969e-06
1.4869649813268983e-25
```

```
/home/gera/anaconda3/lib/python3.6/site-packages/ipykernel_launcher.py:17: RuntimeWarning: inval
```

```
5.151009919032142e-06
3.0334324900978013e-06
8.703015623005071e-06
7.675150658810472e-25
5.242125686474661e-06
6.848132857280573e-06
3.518194816339007e-06
8.797312953781924e-08
1.231830715644743e-06
8.340875465340576e-26
8.244153261599644e-06
5.007753095737926e-27
1.2133468889709407e-05
1.9987115163129505e-23
1.1281623605607003e-06
6.134622600192102e-24
1.472492402619945e-06
1.0758184954017093e-07
8.360466306053502e-08
3.3910733153233035e-06
3.6398496388893025e-24
7.422688945901756e-07
3.0201507003557725e-07
1.307141246398575e-07
8.459130197805409e-07
2.1211655560241024e-27
7.525367306131662e-06
2.8468586619118216e-05
7.001525337740956e-08
4.695528288143053e-06
7.382185873422803e-07
9.208375410797181e-07
1.1291693253429536e-26
2.870029768750646e-07
5.454699087941237e-07
3.620561575899655e-06
9.051775771605661e-06
1.2739795245265702e-06
2.2601391581488753e-07
6.28244530478368e-07
```

4.412566057425295e-25
4.196865753989493e-07
8.333539639376783e-06
7.193523814886108e-08
7.873954827370312e-08
7.699598481920415e-25
3.2883593092333443e-06
2.4777922556204226e-07
1.8227584808485587e-05
8.201913199022122e-24
2.3096795824327754e-24
1.6966880245145013e-05
5.844431992290797e-07
1.3499309788949239e-24
1.009472480001893e-06
4.08808971692903e-24
7.349602086195182e-08
1.6542831684403802e-06
1.0640147069999745e-07
4.796247893783055e-06
5.692252243611462e-06
3.824660183350646e-06
9.495336327593013e-07
2.042441878379317e-24
2.7367596307008546e-09
1.4759334539327477e-07
2.1705651847561553e-24
1.5975570956150318e-06
1.308373131067603e-06
3.2271959453829434e-07
7.717800424774898e-26
3.716214706723876e-07
1.6241083611189448e-07
7.611094536990991e-06
4.294304369926118e-06
3.0378923825582484e-06
1.704463210440211e-24
9.558757661229412e-06
1.5514968934647491e-06
3.191851952764192e-25
7.77304904076563e-06
6.335449208878183e-06
2.7674196051120095e-07
1.6841671859834023e-24
1.8782921972656715e-06
1.2957663570489324e-06
1.8036389518712182e-06
9.036359454550053e-06

4.829848221044139e-23
2.0917298398524622e-23
3.139062577849051e-08
2.594847341412004e-26
4.6533709925211e-06
3.4463894531874064e-24
3.753965156164593e-08
3.596815339005693e-27
3.967960962904318e-08
5.446744702372022e-24
1.8585947092610592e-06
6.670502634294815e-27
8.096876797471169e-06
1.4064516461813224e-06
5.777028991119323e-25
6.626727569694229e-06
2.619626434768665e-06
1.0373401204093148e-23
3.9162966565599393e-23
3.0472805790936636e-06
3.8634869646079905e-07
5.263459885339694e-24
4.462697446894647e-08
1.604750529353753e-23
5.23056058341205e-24
3.6547570142256815e-07
9.193974691547218e-06
3.496476407937698e-07
6.868179306314577e-26
8.106942991616034e-08
1.4370499623117433e-05
7.2868271811801305e-06
6.360236479971865e-24
7.2106738910116e-06
2.849002139856798e-06
1.8926877180882843e-05
1.7961682346322584e-26
1.2131599239480726e-06
4.221255395143901e-24
1.4151836006727934e-06
1.3162978687614552e-06
2.3821120401284e-06
1.4030782043992057e-24
2.0638440543166402e-23
4.0593425344928333e-07
4.825677988497084e-06
4.262149524961937e-06
3.440253924428448e-06

1.3648025525354523e-06
1.3477661278357273e-06
7.284527207642363e-07
1.3256832379381746e-27
4.707687591897253e-08
2.02551548495633e-06
4.749818620424219e-07
3.750187202902063e-07
3.523416977515891e-25
8.394849371977038e-06
3.9965930405095536e-24
1.8929229815440153e-06
6.262588847776957e-24
9.147571338894968e-06
4.5792213446481094e-07
2.0034526900125772e-07
2.6203025577034177e-06
3.393478985117026e-25
4.0655138953564824e-26
3.387451401825543e-06
2.2764123754045946e-06
5.4503316102108615e-06
1.5018292975799868e-05
1.912313130799154e-24
1.3165572002751542e-26
4.532647321866222e-06
1.1394283913493738e-06
8.402188702349518e-26
1.3047497054712845e-05
3.7417786047721026e-07
1.2459750998463963e-25
1.3615649296193247e-23
1.6578973092739941e-06
3.3523740886376545e-07
8.956434029078083e-24
1.858570122331919e-06
1.350267434049969e-05
9.393149112681612e-06
3.958231255247117e-26
1.1497676733905814e-24
1.858652526373438e-06
7.58960044377836e-16
2.7350960457131495e-05
4.199773285775835e-25
7.832647197786586e-26
2.6183409491637884e-06
1.8441576959646118e-07
3.0503009464822356e-07

```
1.041561381885772e-23
3.505817600952297e-07
1.2643125404528377e-06
1.2198659493331052e-24
1.6332279985019352e-26
2.2643846963215587e-07
5.240517835429381e-09
9.482775451689672e-06
7.859983024299374e-07
3.1576609914220726e-06
4.383008348394199e-23
4.517878823353699e-25
7.5177954823592484e-06
4.1388092599496886e-07
9.523397370626179e-06
5.6594800024924865e-08
6.606136374808977e-06
3.659858563346785e-24
6.027942903404431e-07
4.213937951961351e-06
1.1408674753612964e-23
```

In [189]:
```python
print("Projected Matrix")
print(best['P'])
print("Intrinsic Matrix")
print(best['K'])
print("Rotation Matrix")
print(best['R'])
print("Translation Matrix")
print(best['t'])
print("Error")
print(best['e'])
```

```
Projected Matrix
[[-8.22066674e-01 -1.22154890e-13  8.04445486e-15 -8.24591544e-13]
 [-5.69391179e-01 -2.04613531e-14  8.66013823e-14 -8.06985671e-13]
 [-2.59863199e-04 -1.49213324e-17  7.86724201e-18 -5.10213684e-16]]
Intrinsic Matrix
[[-4.06434445e+16 -4.55491010e+03  2.27290918e+03]
 [-0.00000000e+00  2.14326394e+03  2.70732758e+03]
 [-0.00000000e+00 -0.00000000e+00  1.00000000e+00]]
Rotation Matrix
[[-8.22066674e-01  5.69391236e-01 -6.02829884e-05]
 [-5.69391179e-01 -8.22066633e-01 -3.69353360e-04]
 [-2.59863199e-04 -2.69308487e-04  9.99999930e-01]]
Translation Matrix
[ 2.85325285e-12 -1.20163952e+01  6.60219983e+00]
```

```
Error
1.7505851685412062e-28
```

### 1.2 Correction of Radial Distortion

We use opencv functions to remove radial distortion

```
In [196]: img = cv2.imread('Fig1.png')
          img = cv2.cvtColor(img,cv2.COLOR_BGR2RGB)
          img_coords = [(986.9155301900606, 190.11806252202905), (1102.2491527261886, 218.533592
          world_coords = [(0,0,0),(1,0,0),(2,0,0),(0,0,1),(0,0,2),(0,1,0),(0,2,0)]
          img_coords = np.asarray(img_coords).astype('float32')
          world_coords = np.asarray(world_coords).astype('float32')
```

```
In [199]: img_gray = cv2.cvtColor(img,cv2.COLOR_RGB2GRAY)
          ret, mtx, dist, rvecs, tvecs = cv2.calibrateCamera([world_coords[:,:3]], [img_coords[:
                                                              (img_gray.shape[1], img_gray.shape[
                                                              None, None, flags=(cv2.CALIB_USE_IN
          h,w = img_gray.shape
          newcameramtx, roi=cv2.getOptimalNewCameraMatrix(mtx,dist,(w,h),1,(w,h))

          mapx,mapy = cv2.initUndistortRectifyMap(mtx,dist,None,newcameramtx,(w,h),5)
          dst = cv2.remap(img,mapx,mapy,cv2.INTER_LINEAR)
          # crop the image
          x,y,w,h = roi
          dst = dst[y:y+h, x:x+w]
          plt.imshow(dst)
```

## 2 Zhangs method for calibration

```
In [113]: imgs = []
          for i in range(5456,5471):
              ik = cv2.imread('IMG_'+str(i)+'.jpg')
              ik = cv2.cvtColor(ik,cv2.COLOR_BGR2RGB)
              imgs.append(ik)
```

```
In [7]: x,y = np.meshgrid(range(6),range(8))
        world_pts = np.hstack((x.reshape(48,1),y.reshape(48,1),np.zeros((48,1)))).astype('float3
```

```
In [8]: pts3d = []
        pts2d = []
        for i in imgs:
            ret,corners = cv2.findChessboardCorners(i,(6,8))
            if ret:
                pts2d.append(corners)
                pts3d.append(world_pts)
```

```
In [12]: ret, mtx, dist, rvecs, tvecs = cv2.calibrateCamera(pts3d,pts2d, (i.shape[1],i.shape[0])
```

```
In [13]: print('Reprojection Error:', ret)
         print ('Camera Calibration Matrix:')
         print(mtx)
         print('Distortion Parameters:')
         print(dist)
         print('Rotation Vectors for the images are:')
         print(rvecs)
         print('Translation Vectors for the images are:')
         print(tvecs)
```

```
Reprojection Error: 2.4725032641802036
Camera Calibration Matrix:
[[1.36605338e+04 0.00000000e+00 3.34309802e+03]
 [0.00000000e+00 1.36769123e+04 1.49295626e+03]
 [0.00000000e+00 0.00000000e+00 1.00000000e+00]]
Distortion Parameters:
[[ 8.55247426e-02  1.06525955e+01 -1.54799725e-02  2.90279746e-02
  -1.70546664e+02]]
Rotation Vectors for the images are:
[array([[-0.0515688 ],
       [-0.03040108],
       [ 1.56722899]]), array([[-0.18258784],
       [ 0.17120664],
       [-1.52825193]]), array([[-0.33278926],
       [-0.31771999],
       [ 1.51029625]]), array([[-0.46693175],
       [-0.49234411],
       [ 1.43912067]]), array([[-0.23592159],
       [ 0.24248566],
       [-1.4920106 ]]), array([[-0.08059999],
       [-0.43195458],
       [-1.56581372]]), array([[ 0.15141525],
       [-0.45320542],
       [-1.54813848]]), array([[-0.06250215],
       [-0.44688962],
       [ 1.57204911]]), array([[ 0.19038303],
       [ 0.292541  ],
       [-1.48597461]]), array([[-0.16711843],
       [-0.70958726],
       [ 1.44806386]]), array([[-0.14145049],
       [-0.49092103],
       [ 1.48336775]]), array([[ 0.14527751],
       [-0.32304253],
       [-1.55132422]]), array([[-0.30176846],
       [-0.29026138],
       [-1.48124448]]), array([[ 0.08791642],
       [-0.672259  ],
       [-1.48848808]]), array([[-0.01214851],
```

```
       [-0.67432881],
       [-1.46500554]])]
Translation Vectors for the images are:
[array([[ 1.8309542 ],
       [-2.06215737],
       [31.22720754]]), array([[-5.2721484 ],
       [ 3.04357627],
       [32.33043391]]), array([[ 1.85095285],
       [-1.98985387],
       [31.85125574]]), array([[ 1.5129647 ],
       [-2.26969457],
       [32.40522392]]), array([[-5.14594732],
       [ 2.87414377],
       [32.75262101]]), array([[-4.90641715],
       [ 2.88883432],
       [34.39111489]]), array([[-3.40581566],
       [ 2.8872514 ],
       [31.02405229]]), array([[ 0.97017473],
       [-1.30195802],
       [37.2186607 ]]), array([[-5.62473418],
       [ 3.06824145],
       [32.05283685]]), array([[ 3.7317209 ],
       [-2.36522034],
       [32.94094765]]), array([[ 1.70904198],
       [-1.5763743 ],
       [41.41610762]]), array([[-4.14610303],
       [ 3.04760352],
       [38.03437473]]), array([[-4.62030507],
       [ 2.38092428],
       [33.22547177]]), array([[-4.88735062],
       [ 2.62984596],
       [32.94240865]]), array([[-4.31183898],
       [ 2.25728734],
       [31.20307334]])]
```

### 2.0.1 Wireframe over the computed points

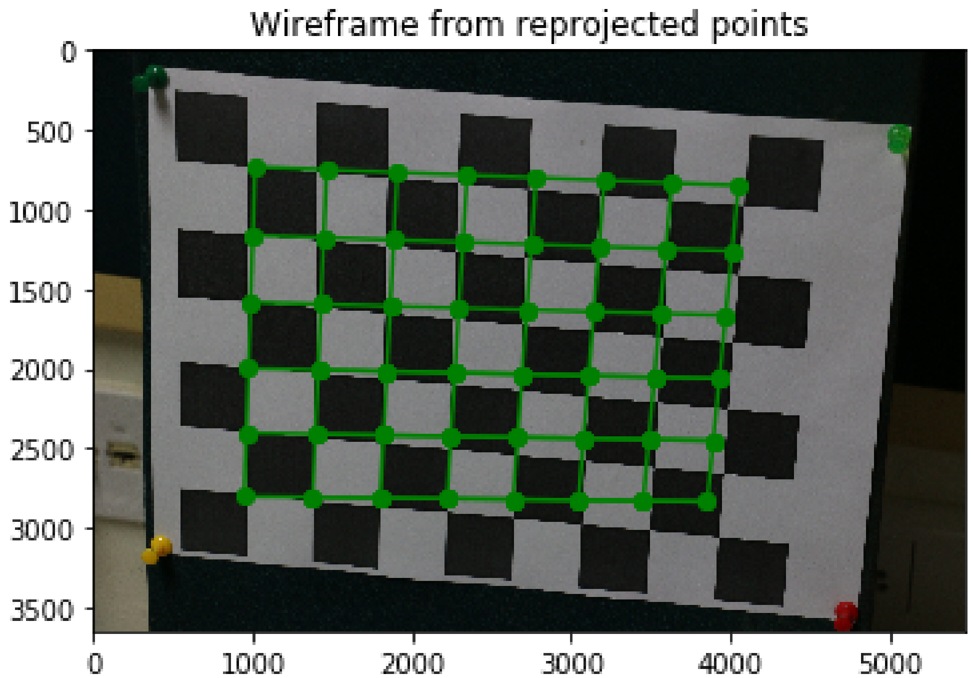
Following tutorials code

```
In [24]: # Function to convert the Rotation Matrix into the Euler Angles
         def eulerAnglesToRotationMatrix(theta) :
             R_x = np.array([[1,0,0],[0,np.cos(theta[0]),-np.sin(theta[0])],[0,np.sin(theta[0]),
             R_y = np.array([[np.cos(theta[1]),0,np.sin(theta[1])],[0,1,0],[-np.sin(theta[1]),0,
             R_z = np.array([[np.cos(theta[2]),-np.sin(theta[2]),0],[np.sin(theta[2]),np.cos(the
             R = np.dot(R_z,np.dot(R_y,R_x))
             return R
```

```
In [78]: def makeP(r,t):
```

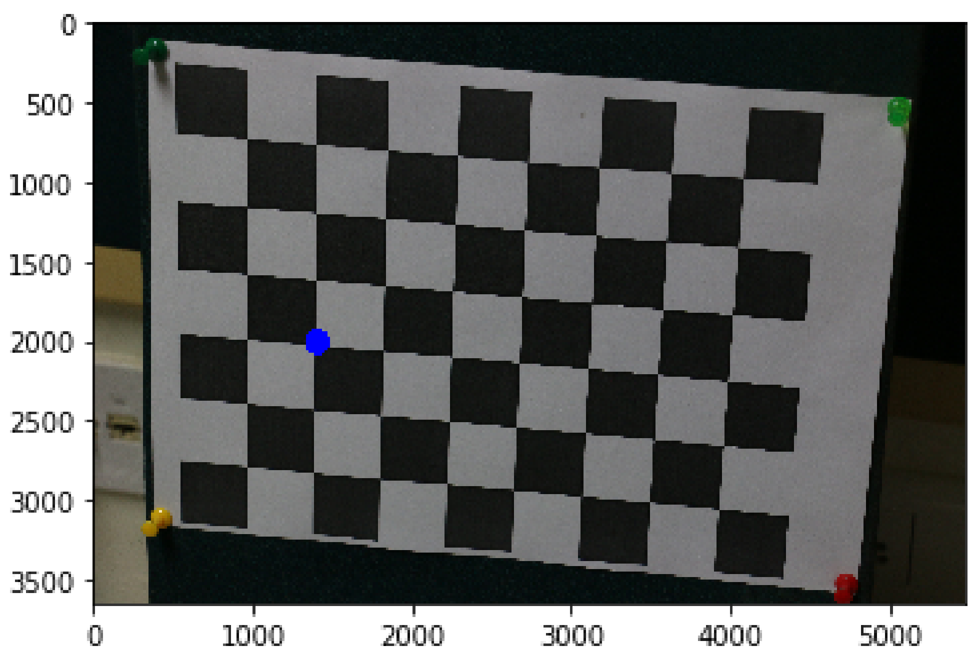
```
#     r =  rvecs[4]
    R = (eulerAnglesToRotationMatrix(r))
    R = R.astype('float32')
    temp1 = np.concatenate((R,t),axis=1)
    P = mtx@temp1
    P = P/P[2,3]
    world_pts_1 = np.hstack((x.reshape(48,1),y.reshape(48,1),np.zeros((48,1)),np.ones((
    pred1 = []
    for i in range(48):
        projection = np.matmul(P,np.transpose(world_pts_1[i,:]))
        projection = projection/projection[2]
        pred1.append(projection[0:2])
    pred1 = np.asarray(pred1)
    return pred1
```

```
In [114]: index = 8

          pred1 = makeP(rvecs[index],tvecs[index])
          idx = [5,11,17,23,29,35,41,47,53]
          idx1 = [8,17,26,35,44,53]
          q = 0
          p = 0
          for i in range(pred1.shape[0]):
              if (i == idx[q]):
                  q = q + 1
                  continue
              plt.plot([pred1[i][0],pred1[i+1][0]],[pred1[i][1],pred1[i+1][1]],'go-')
          for i in range(9):
              i1 = i
              j =  i + 6
              while(j < 48):
                  plt.plot([pred1[i1][0],pred1[j][0]],[pred1[i1][1],pred1[j][1]],'go-')
                  i1 = j
                  j = j + 6


          plt.title('Wireframe from reprojected points')
          plt.imshow(imgs[index])
          plt.show()
```




```
In [115]: plt.imshow(cv2.circle(imgs[index],(int(pred1[index][0]),int(pred1[index][1])),20,(0,0,
```

```
Out[115]: <matplotlib.image.AxesImage at 0x7f8762bb4b00>
```



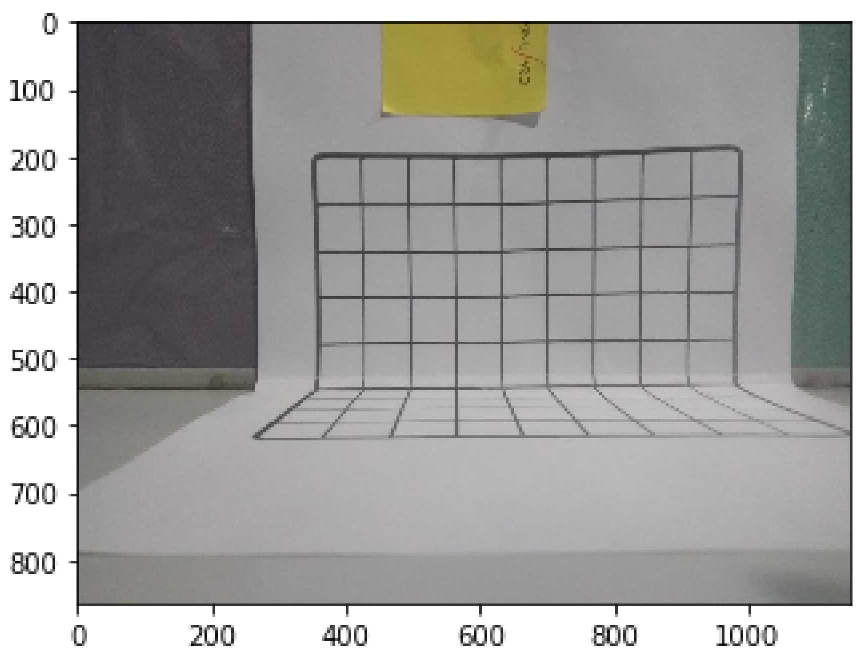
### 2.0.2 World Origin

The world origin is given in the blue point in above image.

# 3 On own image

In [167]:
```python
img = cv2.imread('Own/img0.jpeg')
img = cv2.cvtColor(img,cv2.COLOR_BGR2RGB)
plt.imshow(img)
```

Out[167]: <matplotlib.image.AxesImage at 0x7f87602c4048>




### 3.0.1 DLT Calibration

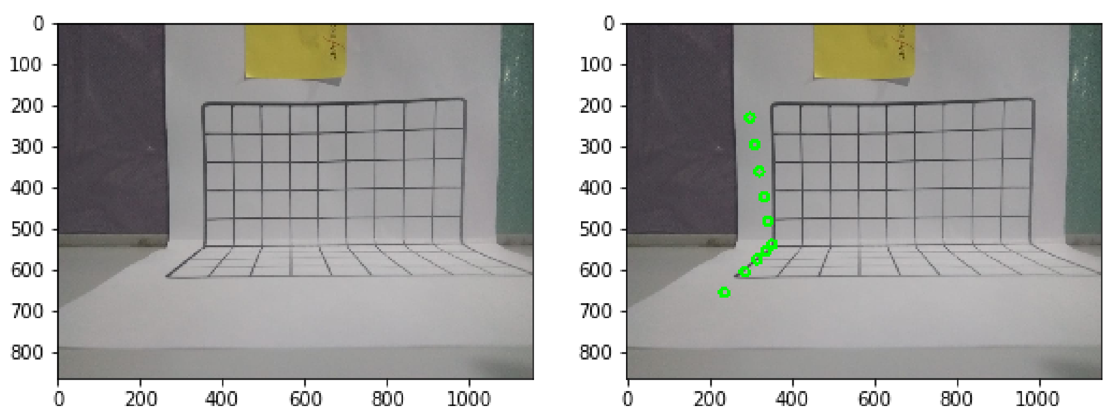
In [168]:
```python
img_coords = [(355.30099232708835, 543.0167421305208), (363.49989154895206, 479.768090
world_coords = [(0,0,0),(1,0,0),(2,0,0),(3,0,0),(0,0,1),(0,0,2),(0,0,3),(0,0,4),(4,0,0
img_coords = np.asarray(img_coords).astype('float32')
world_coords = np.asarray(world_coords).astype('float32')
```

In [170]:
```python
P,K,R,t,e,m,ni = dlt(img,img_coords,world_coords)
print("Projected Matrix")
print(P)
print("Intrinsic Matrix")
print(K)
print("Rotation Matrix")
print(R)
```

```
print("Translation Matrix")
print(t)
print("Error")
print(m)
plt.figure(figsize=(10,20))
plt.subplot(121)
plt.imshow(img)
plt.subplot(122)
plt.imshow(ni)
```

```
Projected Matrix
[[ 1.13743379e-29  2.34569352e-17  1.08694969e-29 -9.37327926e-29]
 [ 2.76402958e-30  6.49737133e-15  1.07763042e-29 -6.13833473e-29]
 [ 3.08148791e-33 -1.00000000e+00  2.42049063e-32 -1.73333695e-31]]
Intrinsic Matrix
[[-1.48077218e+00  3.33026839e+25 -1.65805574e+00]
 [ 0.00000000e+00 -1.26503777e+29  2.62552170e-03]
 [ 0.00000000e+00  0.00000000e+00  1.00000000e+00]]
Rotation Matrix
[[-9.71720543e-01 -2.55809770e-04 -2.36133694e-01]
 [-2.36133686e-01 -6.21632468e-05  9.71720576e-01]
 [-2.63254454e-04  9.99999965e-01  6.38664197e-15]]
Translation Matrix
[-3.70569591e+00  4.70463408e-32 -4.74566172e+00]
Error
629.3302600524468
```

Out[170]: <matplotlib.image.AxesImage at 0x7f8760589c88>




#### 3.0.2 Different Scales

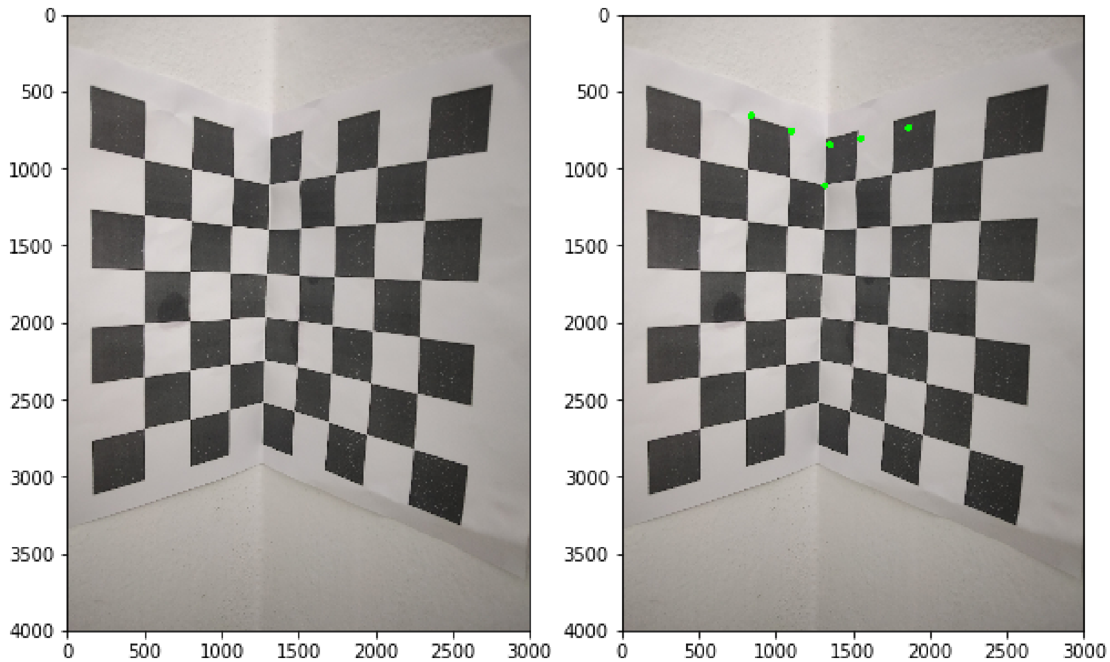
In [173]:
```
img = cv2.imread('Own/img11.jpg')
img = cv2.cvtColor(img,cv2.COLOR_BGR2RGB)
```

```
img_coords = [(1325.9783233467983, 813.0997614076946), (1532.0353143724737, 769.719342
world_coords = [(0,0,0),(1,0,0),(2,0,0),(0,0,1),(0,0,2),(0,1,0)]
img_coords = np.asarray(img_coords).astype('float32')
world_coords = np.asarray(world_coords).astype('float32')
```

In [174]:
```
P,K,R,t,e,m,ni = dlt(img,img_coords,world_coords)
print("Projected Matrix")
print(P)
print("Intrinsic Matrix")
print(K)
print("Rotation Matrix")
print(R)
print("Translation Matrix")
print(t)
print("Error")
print(m)
plt.figure(figsize=(10,20))
plt.subplot(121)
plt.imshow(img)
plt.subplot(122)
plt.imshow(ni)
```

```
Projected Matrix
[[-7.01707085e-13  6.47277927e-01 -4.24110371e-13  3.21741852e-12]
 [-2.79898527e-13  7.62253862e-01 -1.05980315e-12  5.09584235e-12]
 [-6.66133815e-16  5.79602031e-04 -1.08055546e-16  3.77475828e-15]]
Intrinsic Matrix
[[ 3.24296535e+03 -3.79308739e+15  3.37650654e+03]
 [ 0.00000000e+00 -2.00978825e+15  3.55108943e+03]
 [ 0.00000000e+00  0.00000000e+00  1.00000000e+00]]
Rotation Matrix
[[-9.28833888e-01  3.70495147e-01 -9.76891467e-04]
 [-3.70495386e-01 -9.28834304e-01  6.91613817e-05]
 [-8.81746350e-04  4.26173216e-04  9.99999520e-01]]
Translation Matrix
[6.72361810e+00 1.50276681e-11 4.22448722e+00]
Error
1260.2968529718494
```

Out[174]: <matplotlib.image.AxesImage at 0x7f876036a240>



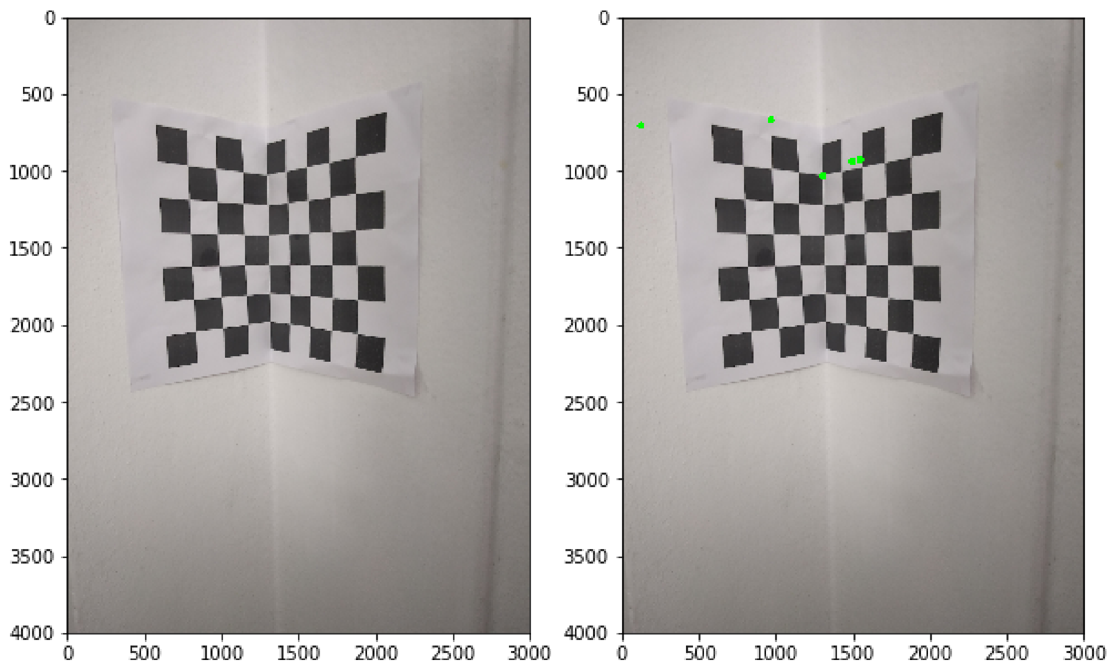

```
In [175]: img = cv2.imread('Own/img12.jpg')
          img = cv2.cvtColor(img,cv2.COLOR_BGR2RGB)
          img_coords = [(1309.7106661605608, 834.7899709893445), (1423.5842664642237, 802.254656
          world_coords = [(0,0,0),(1,0,0),(2,0,0),(0,0,1),(0,0,2),(0,1,0)]
          img_coords = np.asarray(img_coords).astype('float32')
          world_coords = np.asarray(world_coords).astype('float32')
```

```
In [176]: P,K,R,t,e,m,ni = dlt(img,img_coords,world_coords)
          print("Projected Matrix")
          print(P)
          print("Intrinsic Matrix")
          print(K)
          print("Rotation Matrix")
          print(R)
          print("Translation Matrix")
          print(t)
          print("Error")
          print(m)
          plt.figure(figsize=(10,20))
          plt.subplot(121)
          plt.imshow(img)
          plt.subplot(122)
          plt.imshow(ni)
```

```
Projected Matrix
[[-8.47785206e-13  6.23750426e-01  8.74047322e-14 -3.18025771e-14]
```

```
 [-1.27359554e-12  7.81623341e-01  1.94420353e-13 -1.84820090e-13]
 [-8.88178420e-16  5.99272008e-04  1.33543026e-16 -5.55111512e-17]]
Intrinsic Matrix
[[ 7.66379427e+04 -4.99052854e+16 -1.05329815e+04]
 [ 0.00000000e+00  4.31376082e+15 -1.75187968e+03]
 [ 0.00000000e+00  0.00000000e+00  1.00000000e+00]]
Rotation Matrix
[[-5.54121455e-01  8.32435666e-01 -5.23760630e-04]
 [-8.32435629e-01 -5.54121649e-01 -3.48730596e-04]
 [-5.80522890e-04  2.42757904e-04  9.99999802e-01]]
Translation Matrix
[1.20162014e+00 1.40254572e-12 1.28224997e+00]
Error
438423.1241872798
```

Out[176]: <matplotlib.image.AxesImage at 0x7f87670f1b00>




### 3.0.3 Zhangs Calibration

In [163]:
```
imgs = []
for i in range(1,6):
    ik = cv2.imread('Own/img'+str(i)+'.jpeg')
    ik = cv2.cvtColor(ik,cv2.COLOR_BGR2RGB)
    imgs.append(ik)
```

In [164]:
```
x,y = np.meshgrid(range(6),range(8))
world_pts = np.hstack((x.reshape(48,1),y.reshape(48,1),np.zeros((48,1)))).astype('floa
```

In [165]:
```
pts3d = []
pts2d = []
for i in imgs:
    ret,corners = cv2.findChessboardCorners(i,(6,8))
    if ret:
        pts2d.append(corners)
        pts3d.append(world_pts)
ret, mtx, dist, rvecs, tvecs = cv2.calibrateCamera(pts3d,pts2d, (i.shape[1],i.shape[0]
```

In [166]:
```
print('Reprojection Error:', ret)
print ('Camera Calibration Matrix:')
print(mtx)
print('Distortion Parameters:')
print(dist)
print('Rotation Vectors for the images are:')
print(rvecs)
print('Translation Vectors for the images are:')
print(tvecs)
```

```
Reprojection Error: 2.2775225405922876
Camera Calibration Matrix:
[[987.99789828   0.         362.4744494 ]
 [  0.         982.59388936 619.9885207 ]
 [  0.           0.           1.        ]]
Distortion Parameters:
[[ 0.1819742  -0.61803462 -0.00376678  0.01351287  0.70875399]]
Rotation Vectors for the images are:
[array([[ 0.0575766 ],
       [ 0.39870349],
       [-0.01472371]]), array([[ 0.02624925],
       [-0.77616394],
       [ 0.00754543]]), array([[ 0.05299469],
       [-0.12727665],
       [ 0.00176436]]), array([[ 0.00353041],
       [-0.10591087],
       [ 0.00338543]]), array([[ 0.02650615],
       [-0.08551728],
       [ 0.00079721]])]
Translation Vectors for the images are:
[array([[-2.2931373 ],
       [-5.34907031],
       [16.55435457]]), array([[-3.41610575],
       [-5.10854248],
       [15.63930712]]), array([[-4.89466589],
       [-7.81454241],
```

```
[17.51461527]]), array([[-3.72374922],
[-0.84914217],
[15.40994873]]), array([[-3.20623473],
[-3.57510803],
[12.16040872]])]
```

In [171]:
```python
plt.figure(figsize=(10,50))
for i in range(len(imgs)):
    plt.subplot(1,5,i+1)
    plt.imshow(imgs[i])
```