University Jean Monnet

Faculty of Science and Technology

Computer Vision - Lab 4 Report

Author:
Allwyn Joseph
Rohil Gupta

Supervisor:
Ms. Rada Deeb

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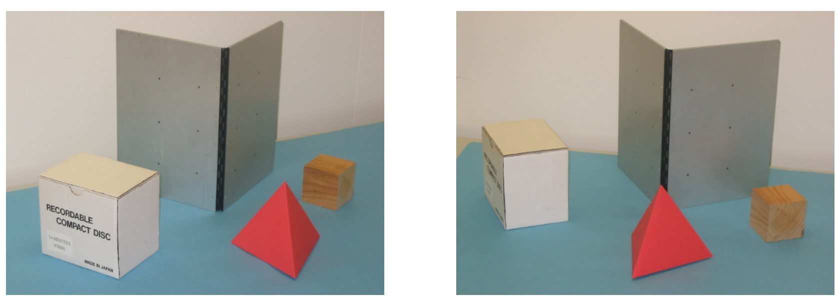
1 Introduction

In this lab session we put together the learnings from the previous lab sessions to realize a 3D reconstruction. The main objective of this lab session was to reconstruct a 3D scene, knowing the intrinsic and extrinsic parameters of each camera that the stereovision system used.

To realize a successful 3D reconstruction one would first have to first calibrate the cameras within the stereo setup and then use the intrinsic and extrinsic features along with selected points to successfully reconstruct a select scene in 2D to 3D. The following section would elaborate each step leading to the 3D construction in greater detail.
Figure 1 shows the stereo system we tried to reconstruct in this lab session.



(a) Left camera image (b) Right camera image

Figure 1: The stereo system

From the elements in Figure 1, only the pyramid and the big cube was reconstructed.

2 Objectives

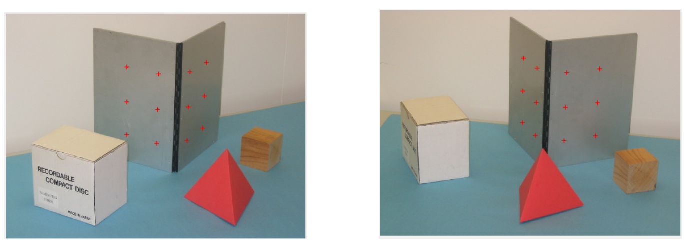
In this lab session we were tasked with the following objectives:

- Task 1: Re-project the 3D points into the both 2D images and ensure that calibration parameters are correct.
- Task 2: 3D Reconstruction of the Stereo system.
- Task 3: Projection of the reconstructed objects.

3 Procedure

- **Step 1** - The 3D points were re-projected into both the 2D images to ensure that the calibration parameters were correct.
  With prior knowledge of the intrinsic and extrinsic parameters the projection matrix was calculated (`M = K*RT`) for the left and the right cameras. The matrix was then multiplied with the homogeneous representation of the 3D points to obtain the 2D projective coordinates. The first and the second elements of these coordinates were then divided by the third element to obtain the 2D coordinates.

  The projection of the points obtained onto the two images in Figure 2 confirms that the calibration parameters are correct.



(a) Left Re-projection (b) Right Re-projection

Figure 2: Re-projection of points on the left and right images

- **Step 2** - For the first part of the 3D construction, the 4 vertices of the pyramid and 8 vertices of the cube were selected.
  Figure 3 displays the points selected for the cube and the pyramid.

```
Ppyrlpx =
  474.0000  384.0000  490.0000  532.0000
  290.0000  392.0000  452.0000  382.0000
Ppyrrpx =
  350.0000  298.0000  300.0000  434.0000
  296.0000  380.0000  452.0000  414.0000
Pcubelpx =
  132.0000   60.0000  190.0000  260.0000  128.0000   62.0000  192.0000  260.0000
  238.0000  278.0000  316.0000  276.0000  376.0000  408.0000  452.0000  402.0000
Pcuberpx =
  148.0000   48.0000   82.0000  190.0000  146.0000   52.0000   86.0000  190.0000
  184.0000  196.0000  246.0000  234.0000  304.0000  314.0000  372.0000  354.0000
```

Figure 3: Selected points for the pyramid and the cube

- **Step 3** - The selected points were then converted to a homogeneous coordinate system and then projected onto camera coordinate system by using individual camera matrix `K1_sf` and `K2_sf`.
  `K1_sf` and `K2_sf` is the intrinsic parameters obtained by extracting all the elements within the first three column of matrices K1 and K2. Once the intrinsic parameters were extracted, their inverses were computed and then multiplied with the homogeneous coordinates of the selected points to obtain the corresponding 3D points in camera coordinate system.
  Figure 4 displays the camera coordinates for the cube and the pyramid.

```
cam_pyr_l =
   -0.1353   -0.0562   -0.1494   -0.1863
   -0.0435   -0.1323   -0.1845   -0.1236
    1.0000    1.0000    1.0000    1.0000
cam_pyr_r =
   -0.0224    0.0164    0.0149   -0.0850
   -0.0414   -0.1036   -0.1568   -0.1287
    1.0000    1.0000    1.0000    1.0000
cam_cube_l =
    0.1652    0.2284    0.1142    0.0527    0.1687    0.2267    0.1125    0.0527
    0.0017   -0.0331   -0.0661   -0.0313   -0.1184   -0.1462   -0.1845   -0.1410
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
cam_cube_r =
    0.1282    0.2028    0.1774    0.0969    0.1297    0.1998    0.1745    0.0969
    0.0414    0.0326   -0.0044    0.0044   -0.0473   -0.0547   -0.0977   -0.0843
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

Figure 4: Camera coordinates for the pyramid and the cube

- **Step 4** - The next step entails calculating the global rotation and translation matrices.
  To do so, the rotation and translation matrices of the left and right cameras were extracted from the variables `RT1` and `RT2`. Once this was done, using the formulas `R = R_r*R_l'` and `T = T_l - R'*T_r` the global rotation and translation matrices are calculated.

- **Step 5** - In the following step we went on to calculate the 3D camera coordinates.
  The calculation began with assigning pl and pr the homogeneous coordinates computed in step 3. Further on formulas `P1 = a0*pl`, `P2 = T + b0*R'*pr` and `P = P1 + 0.5*(P2-P1)` was used to compute the 3D camera coordinates. This was followed by converting P to a homogeneous coordinate system.
  Figure 5 shows the calculated camera coordinate matrices.

```
Pcam_pyr =
   1.0e+03 *
   -0.1374   -0.0610   -0.1471   -0.2056
   -0.0460   -0.1456   -0.1863   -0.1375
    1.0149    1.0824    0.9819    1.1033
    0.0010    0.0010    0.0010    0.0010
Pcam_cube =
   1.0e+03 *
    0.1759    0.2216    0.1040    0.0528    0.1901    0.2333    0.1083    0.0554
    0.0008   -0.0341   -0.0641   -0.0328   -0.1329   -0.1559   -0.1848   -0.1518
    1.0655    0.9704    0.9122    1.0030    1.1268    1.0300    0.9656    1.0530
    0.0010    0.0010    0.0010    0.0010    0.0010    0.0010    0.0010    0.0010
```

Figure 5: 3D Camera coordinates for the pyramid and the cube

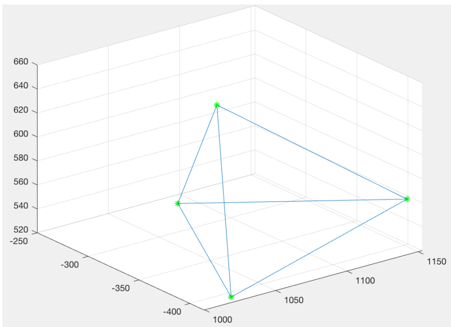
- **Step 6** - Finally, using the global rotation and translation matrices in combination with the homogeneous 3D camera coordinates computed in step 5, the world coordinates of the selected points were calculated. With prior knowledge of the formula `Xw = inv(RT) * Xc`, where Xw is the world coordinates and Xc the Camera coordinates, first the global extrinsic parameters were calculated by putting together matrices R and T. Once this was done, the inverse of the matrix was calculated and multiplied with the camera position vector to obtain the world position vector. These vectors were appended together to finally obtain the world coordinates matrix.
  Figure 6 shows the calculated camera coordinate matrices.

```
PW_pyr =
   1.0e+03 *
    1.0763    1.1526    1.0189    1.0497
   -0.2812   -0.3990   -0.4136   -0.3566
    0.5321    0.5573    0.5244    0.6523
    0.0010    0.0010    0.0010    0.0010
PW_cube =
   1.0e+03 *
    1.3665    1.3430    1.2097    1.2256    1.3818    1.3580    1.2156    1.2285
   -0.3143   -0.3557   -0.3538   -0.3145   -0.4496   -0.4789   -0.4739   -0.4323
    0.3994    0.2990    0.3174    0.4176    0.4568    0.3550    0.3722    0.4703
    0.0010    0.0010    0.0010    0.0010    0.0010    0.0010    0.0010    0.0010
```

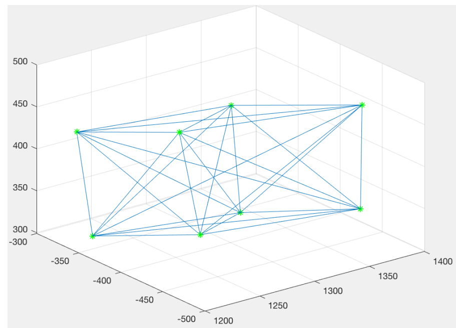
Figure 6: 3D World coordinates for the pyramid and the cube

- **Step 7** - To visualize our 3D reconstruction a plot was realized as seen in figure 7.
  We observer that the images aren't upright as in figure 1, but rather slanted. This can be remedied to a certain extent by rotating the image construction. However, there might still remain a little discrepancy as result of some imprecisions that were introduced during calculation of the extrinsic and intrinsic parameters. With more precise computations

these anomalies can be corrected to obtain a more robust construction.



(a) Pyramid 3D reconstruction



(b) Cube 3D reconstruction

Figure 7: 3D reconstruction of the pyramid and the cube

4 Conclusion

Over the lab sessions we gained a holistic insight on how to effectuate a 3D reconstruction for a given 2D image. With the knowledge acquired over the four lab session on camera calibration, epipolar geometry and 3D reconstruction, we seek to successfully conduct the project tasks assigned to us and obtain promising results.