EEN020
Computer Vision
Project
Rigid Body Pose Estimation

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1 Description Of Algorithm

1.1 RANSAC + P3P Minimal solver

The algorithm begins with looping over all the 9 given images for every 7 objects. The approach in this project has been to make the given measurement data get rid of the outliers using RANSAC method. This is done using the help of the given P3P minimal solver function which takes 3 pairs of correspondences and gives more than one camera solutions. The 3D points are normalized using the mean of the data before feeding them to the minimal solver function as the input. For every camera solution output of the minimal solver, the 2D homogeneous projections are computed using the given 3D points (converted into homogeneous coordinates). For the projections given by each camera solution, using the given 2D image points, a total squared root error is calculated in pixels. In order to set a criteria for the inliers, only those points that yields the projection squared root error below a threshold value (which is set to 5×10^{-3} pixels) are considered as the set of inliers. The camera solution corresponding to the highest number of inliers is registered as the pose estimation of the object given by the P3P minimal in the given image.

1.2 Resectioning - DLT + Enforcing Rotation matrix constraints

Once the measurement are filtered from outliers, a resectioning method i.e DLT is applied on the outlier free data to obtain the calibrated camera solutions. The camera matrix $P = [R \ t]$ where R is the rotation matrix needs to be orthogonal in nature i.e $\det(R) = 1$. In order to ensure that the R matrix in the camera matrix computed using DLT is always orthogonal, it needs to be constrained accordingly. This is done by applying

singular value decomposition (SVD) on the rotation matrix of the camera solution which decomposes the matrix R into U, S and V matrices such that

$$R = USV^T \tag{1}$$

where S is a diagonal matrix consisting the singular values of R. Setting these singular values 1 i.e setting setting the matrix S as an identity matrix and then replacing R in the camera matrix as shown in Equation 1 using the new S as identity matrix will ensure that the rotation matrix has the determinant value as 1 or -1. In order to deal with the sign to be always positive, multiplying the new rotation matrix with the sign of the determinant ensures that the determinant of R is always 1. Additionally , it was also found that the translation vector t in the camera matrix was scaled up by a certain factor when compared to the given ground truth pose estimates. Since the scale is arbitrary and the last element of the vector t depicts the scale, dividing the translation vector with its last element scales down the obtained translation vector in the camera solution given by DLT method.

1.3 Levenberg-Marquardt method for filtering noise

To improve the camera solutions given by the P3P minimal solver and those given by DLT method, the Levenberg-Marquardt method was used. The solutions given by minimal solver and DLT were found to be improved when the value of penalty i.e λ was set as 10×10^{-16} which was made to run for 25 iterations.

2 Results

Following are the results for RANSAC + Minimal solver, RANSAC + DLT, RANSAC + Minimal Solver + LM and RANSAC + DLT + LM.

2.1 Table of Scores

2.1.1 RANSAC + Minimal Solver(P3P)

	Img1	Img2	Img3	Img4	Img5	Img6	Img7	Img8	Img9
Ape	5.24	4.79	6.5	6.54	8.61	7.02	37.43	31.62	17.75
Can	10.8	4.65	8.72	4.78	19.84	6.35	9.4	53.37	27.96
Cat	4.41	8.2	3.86	4.72	9.67	13.98	43.66	23.59	67.18
Duck	10.27	9.97	9.95	13.42	8.47	7.87	57.24	25.71	33.38
Eggbox	4.07	36.85	5	6.18	65.55	67.66	76.88	6.75	21.27
Glue	8.33	4.72	11.88	12.11	27.88	10.04	45.35	10.34	55.16
Holepuncher	4.86	5.72	10.51	10.32	4.58	4.39	18.63	10.04	60.29
Average	6.85	10.7	8.06	8.3	20.66	16.76	41.23	23.06	40.43

2.1.2 RANSAC + Minimal Solver + LM

	Img1	Img2	Img3	Img4	Img5	Img6	Img7	Img8	Img9
Ape	6.3	6.89	7.05	5.81	10.29	7.34	31.72	30.4	21.52
Can	13.85	3.82	10.43	9.2	20.44	14.91	13.51	44.92	27.29
Cat	4.18	14.05	8.77	7.09	10.61	22.76	34.18	22.38	53.76
Duck	12.49	10	6.88	11.25	11.42	13.55	44.17	24.49	28.79
Eggbox	5.61	33.26	4.63	8.34	47.62	65.41	71.63	11.43	24.56
Glue	6.06	12.8	29.45	9.9	14.49	13.27	40.04	14.7	32.52
Holepuncher	7.67	9.6	13.5	7.58	6.29	9.48	18.4	13.72	52.78
Average	8.02	12.92	11.53	8.45	17.31	20.96	36.24	23.15	34.46

2.1.3 RANSAC + DLT

	Img1	Img2	Img3	Img4	Img5	Img6	Img7	Img8	Img9
Ape	73.1	17.8	83.5	67.5	12.2	25.9	122.6	96.8	263.3
Can	17.4	151.9	30.2	15.8	150.1	161.1	50.3	413.3	90.3
Cat	15.6	11.4	26.3	176.2	42.3	222.2	37.8	55.9	75.4
Duck	85.1	614	26.7	71.5	25.4	60.8	79.9	293.8	351.6
Eggbox	22.9	90.8	97.2	25.4	376.1	133.6	67	13.4	123.8
Glue	103.1	23.2	51.2	103.6	45	93	59.3	84.2	51.6
Holepuncher	15.7	47.7	27.6	16.4	101.2	105.8	24.5	6.1	28.4
Average	47.6	136.7	48.9	68.1	107.5	114.6	63.1	137.6	140.6

2.1.4 RANSAC + DLT +LM

	Img1	Img2	Img3	Img4	Img5	Img6	Img7	Img8	Img9
Ape	49.1	12.3	59.4	45.4	9.4	18.6	77.1	54.2	140
Can	28.4	101.3	38	25.7	100.6	99.7	48.9	223.3	77
Cat	31.8	17.1	44.8	110.7	52	54.2	55.2	46.5	57.4
Duck	58.7	369.7	17.7	47.3	16.9	46.5	65	133.3	101
Eggbox	7.7	54.8	65.7	10.8	223.6	97.3	39.3	12.5	88.6
Glue	68	25.5	61.8	67.9	33.4	54.8	47.9	47.6	37.8
Holepuncher	14	31	19	16.2	69.2	72	19.8	9.4	38.6
Average	36.8	87.4	43.8	46.3	72.2	63.3	50.5	75.3	77.2

3 Histogram of scores

The histogram of all the scores for each method is as shown in Figure 1.

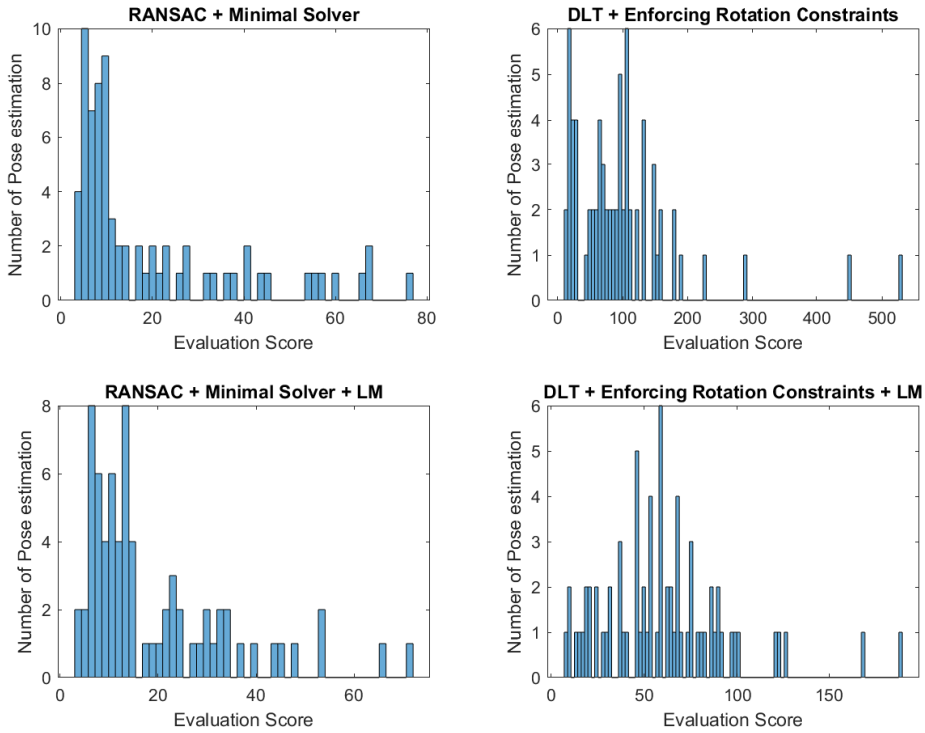

Figure 1: Histogram of scores for all the pose estimate solutions for every method

As it can be seen, using Minimal solver on the inliers gives better results compared to the DLT approach. Moreover, the LM method of optimization seems to improve the Minimal solver solutions by some degree since more Pose estimations are found to be piled up at the lower score region in the histogram pertaining to RANSAC + Minimal Solver + LM method approach.

Note: The scores reported in this document are based on the results given by the submitted algorithm when this document was being written. One can find the scores to be different than the reported numbers on running the code but pretty close to the reported data in this document. This is due to the fact that the set of inliers given by the RANSAC are different everytime since it randomly selects the correspondences to its consensus set in its iterations. Also the LM iterations give different results everytime the code is run but again, its close to the numbers reported here.

4 Bounding Boxes and Total Average Score

4.1 RANSAC + Minimal solver

The bounding boxes generated for the solutions given by Minimal solver on outlier free data using RANSAC are as follows. The average of scores of all $7 \times 9 = 63$ solutions was found to be 19.56.

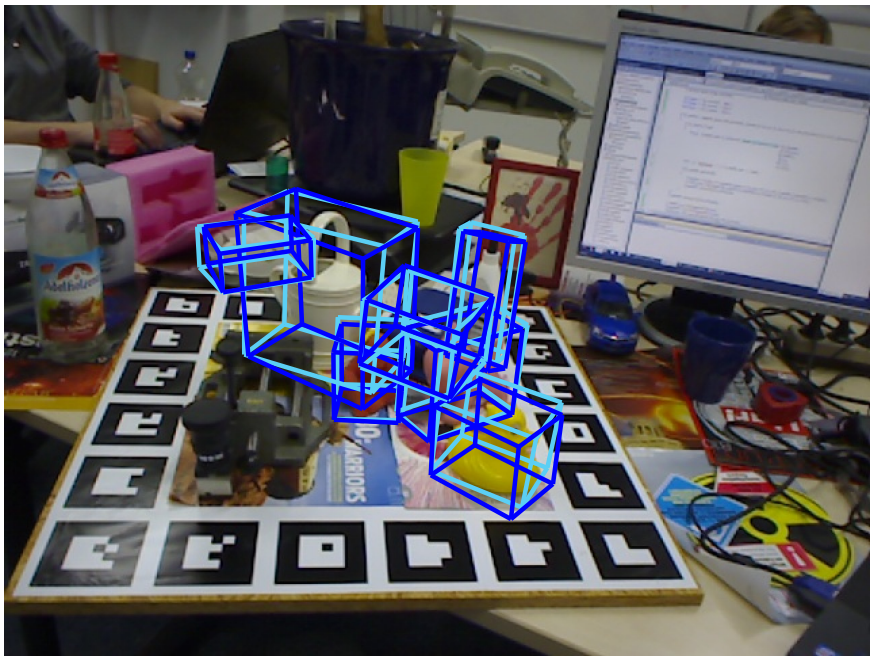

Figure 2: Bounding boxes for RANSAC + Minimal Solver in Image 1

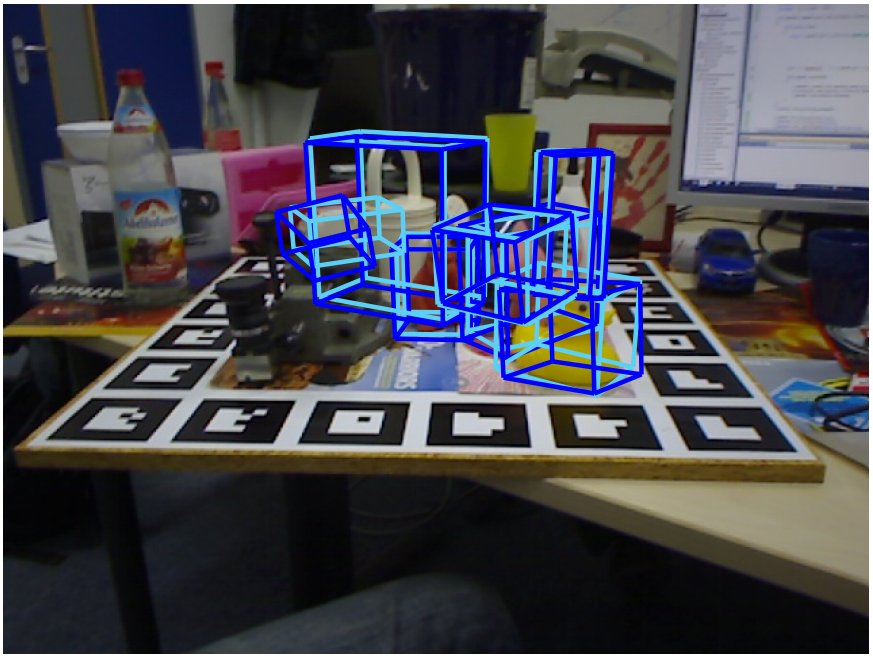

Figure 3: Bounding boxes for RANSAC + Minimal Solver in Image 2

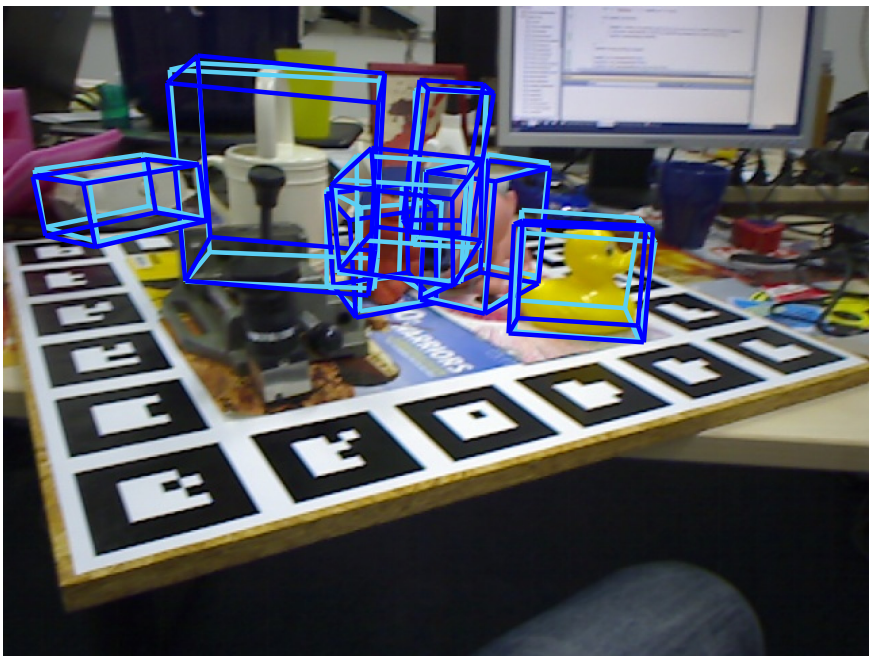

Figure 4: Bounding boxes for RANSAC + Minimal Solver in Image 3

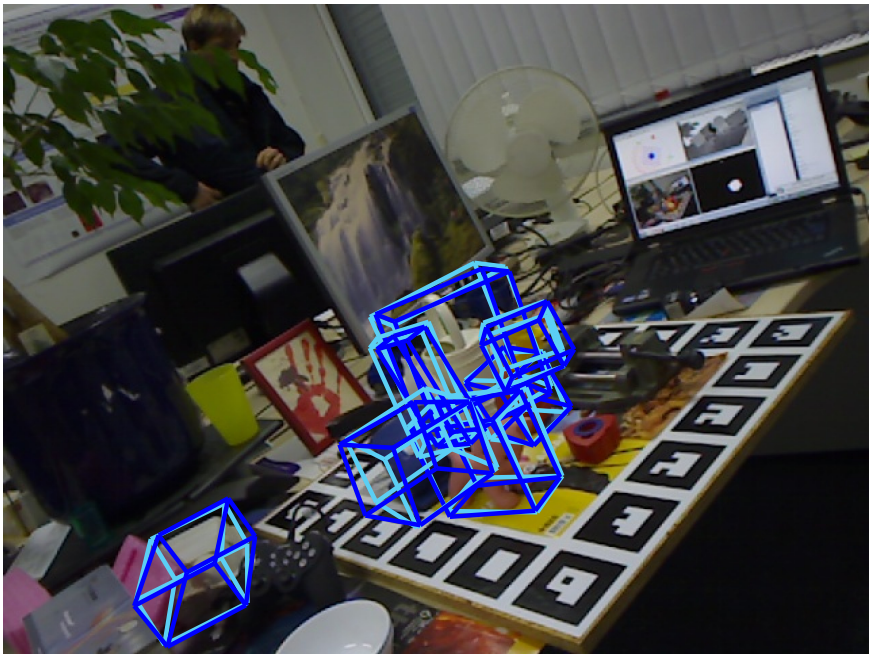

Figure 5: Bounding boxes for RANSAC + Minimal Solver in Image 4

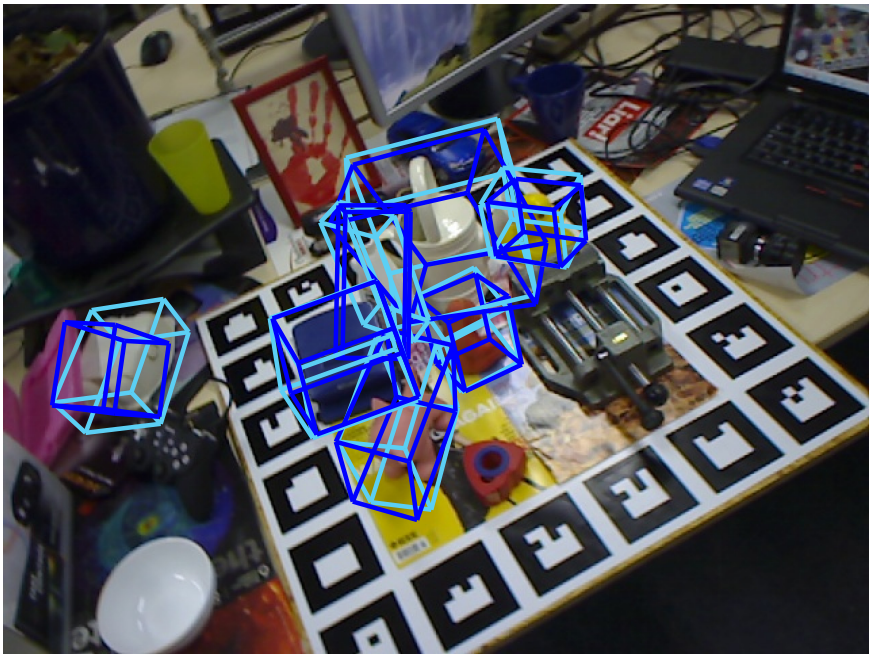

Figure 6: Bounding boxes for RANSAC + Minimal Solver in Image 5

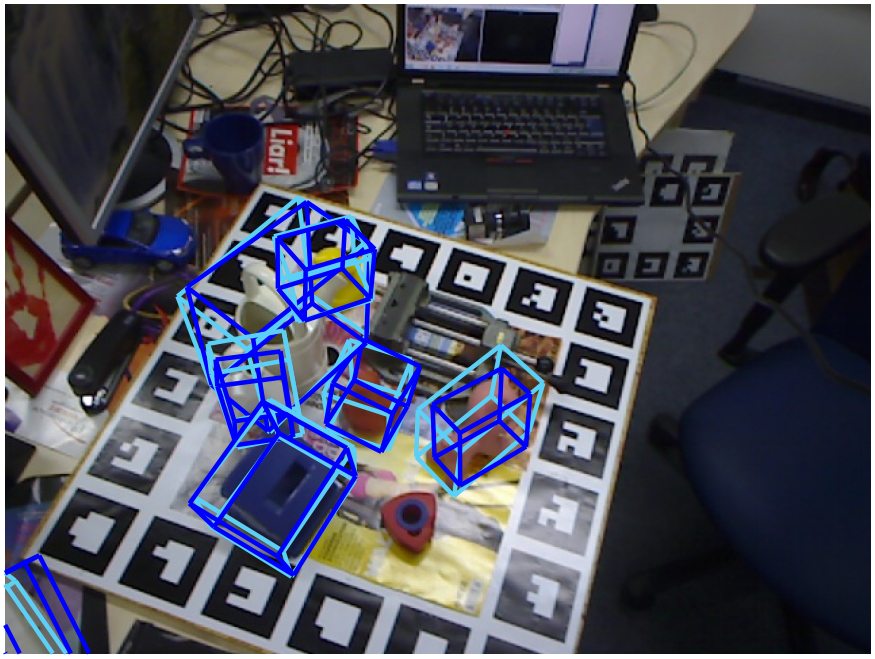

Figure 7: Bounding boxes for RANSAC + Minimal Solver in Image 6

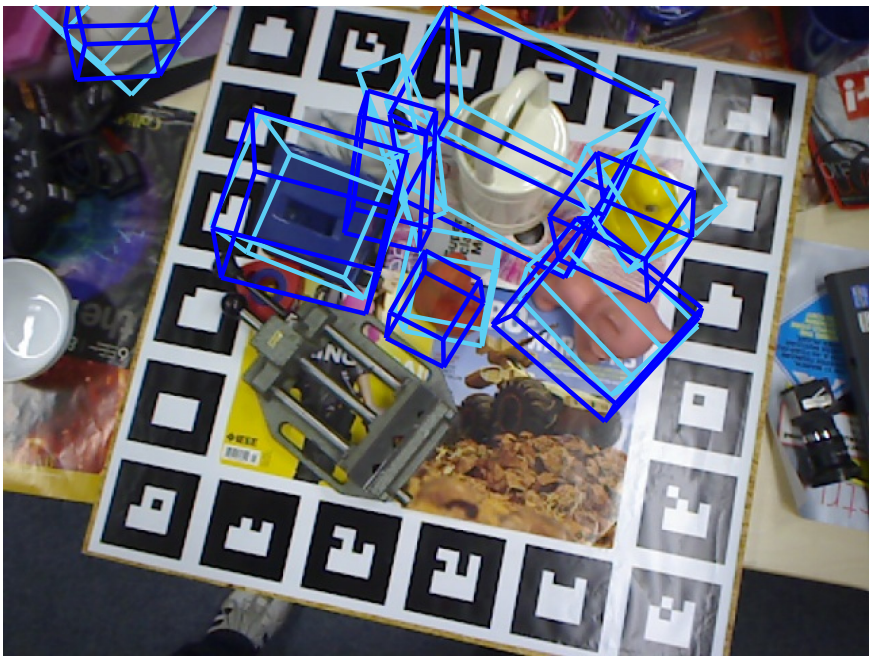

Figure 8: Bounding boxes for RANSAC + Minimal Solver in Image 7

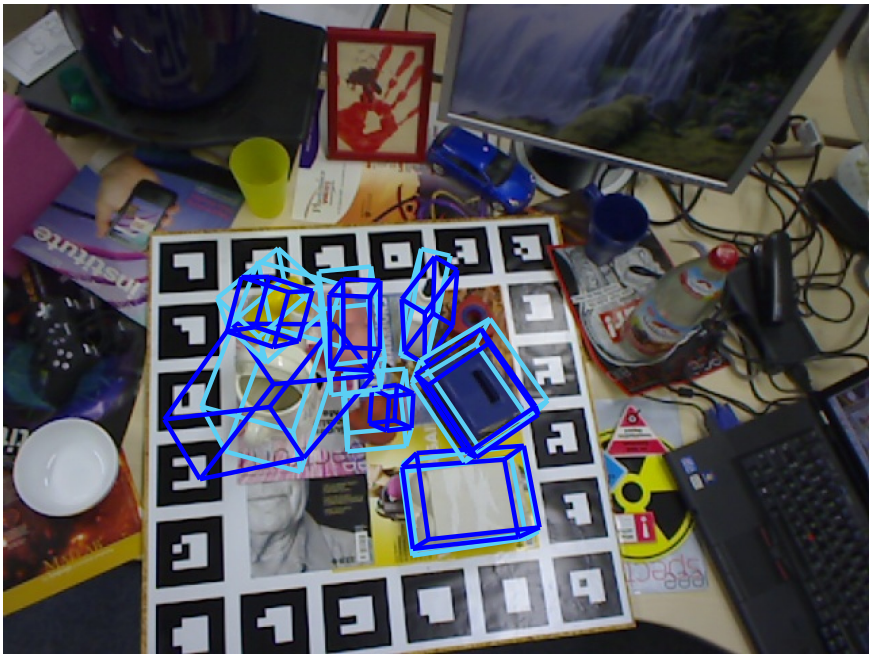

Figure 9: Bounding boxes for RANSAC + Minimal Solver in Image 8

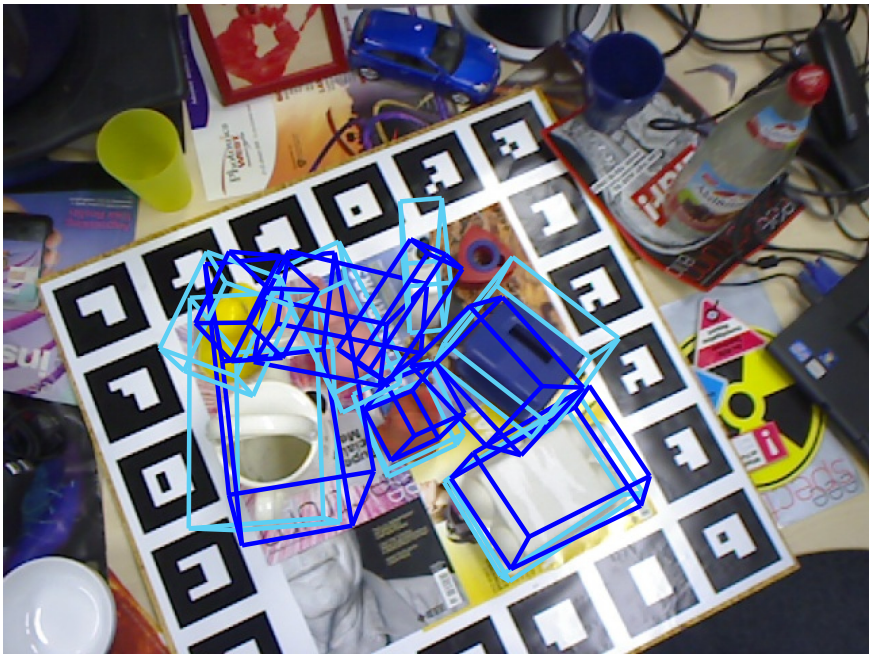

Figure 10: Bounding boxes for RANSAC + Minimal Solver in Image 9

4.2 RANSAC + DLT

The average score of all 63 solutions achieved after applying DLT on outlier free data was found to be 96.07. The bounding boxes for the 9 images given by this approach are as follows.

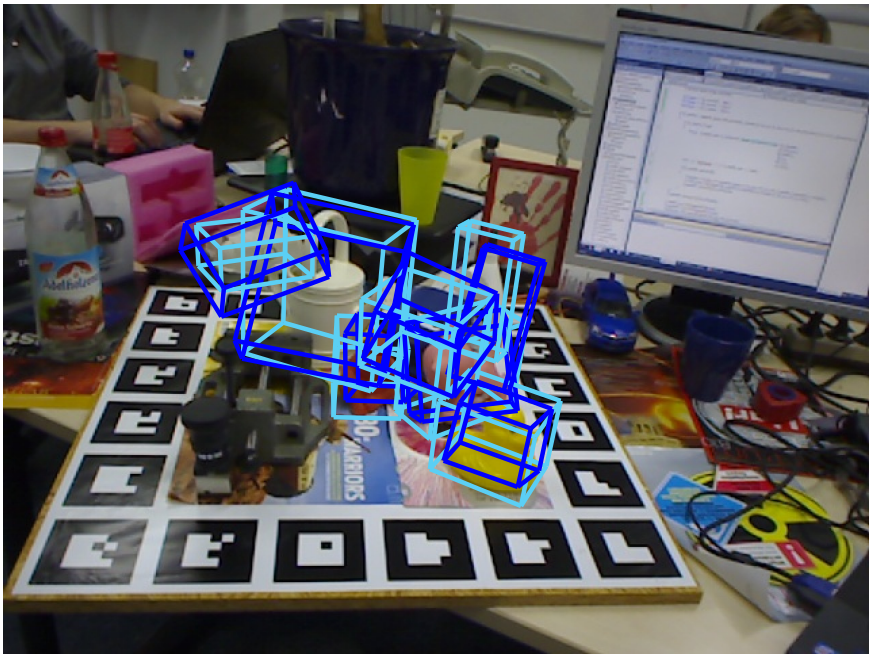

Figure 11: Bounding boxes for RANSAC + DLT in Image 1

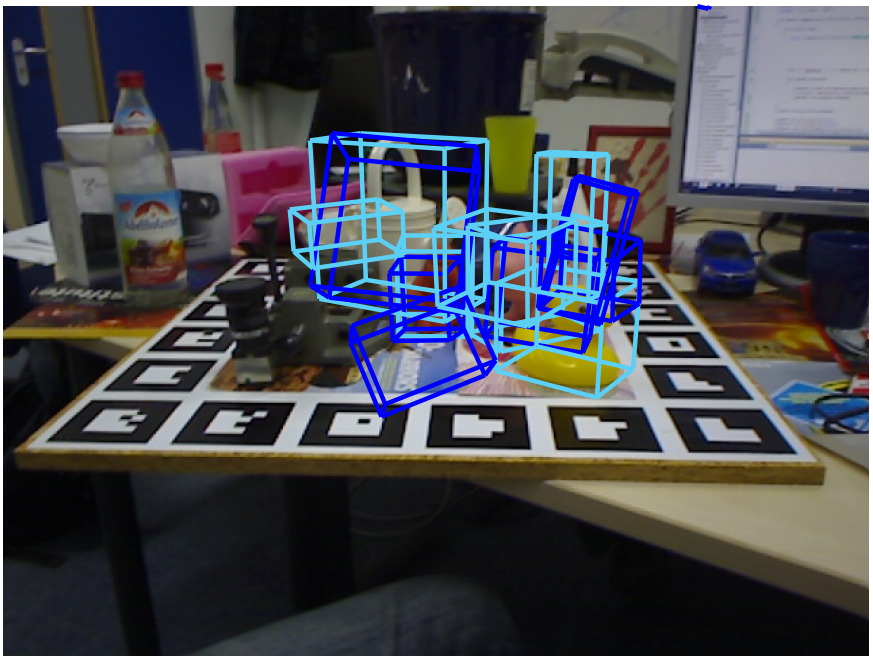

Figure 12: Bounding boxes for RANSAC + DLT in Image 2

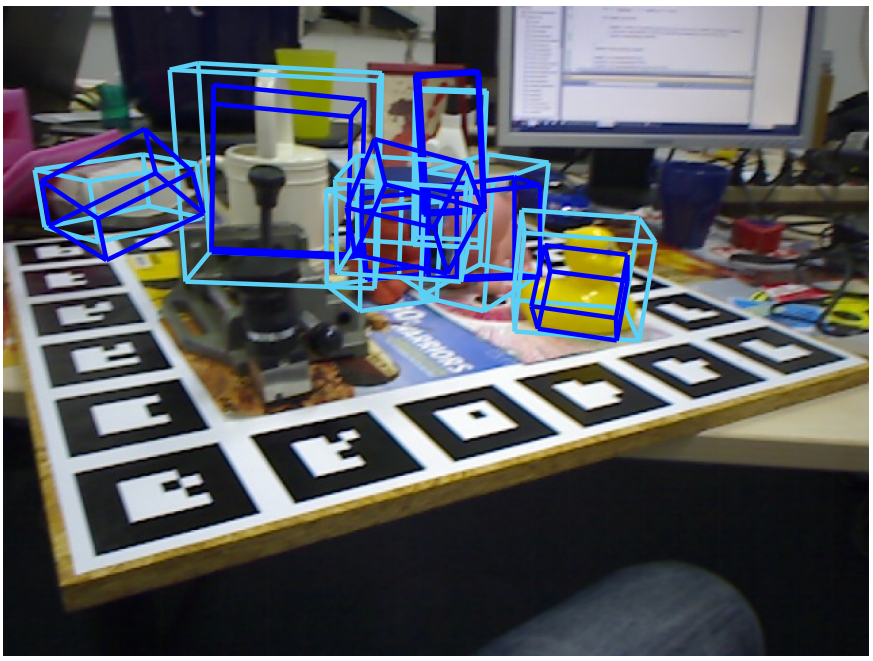

Figure 13: Bounding boxes for RANSAC + DLT in Image 3

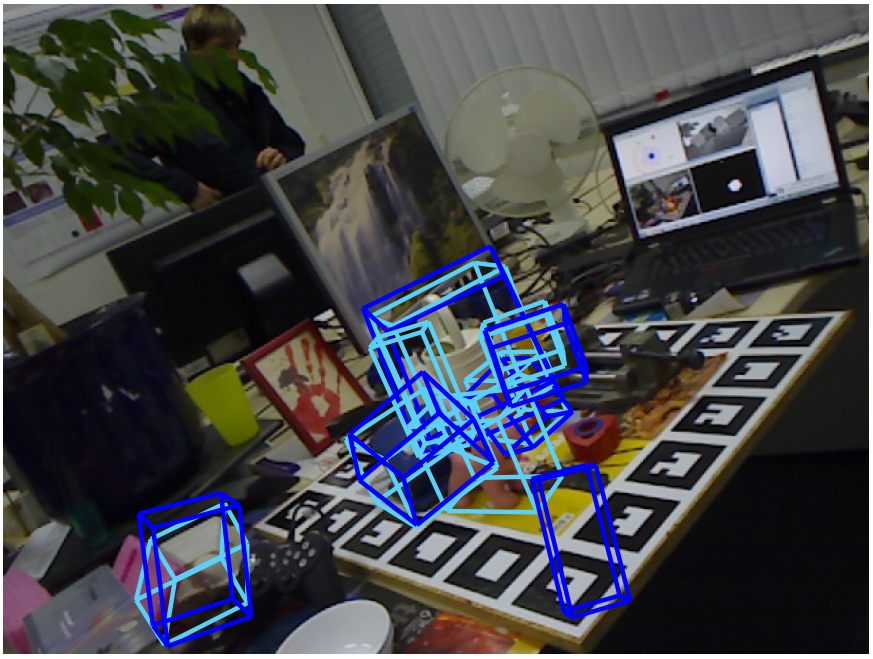

Figure 14: Bounding boxes for RANSAC + DLT in Image 4

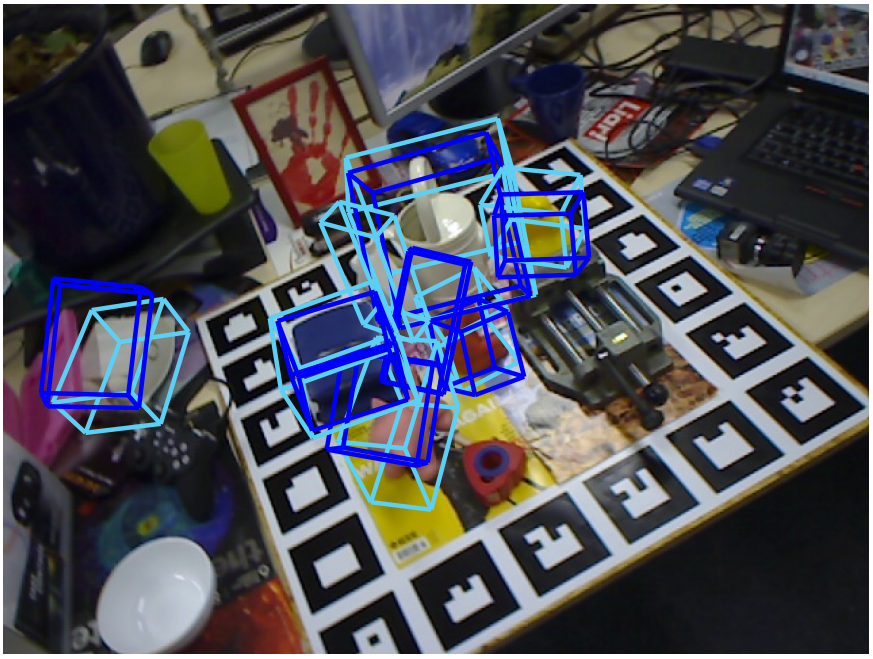

Figure 15: Bounding boxes for RANSAC + DLT in Image 5

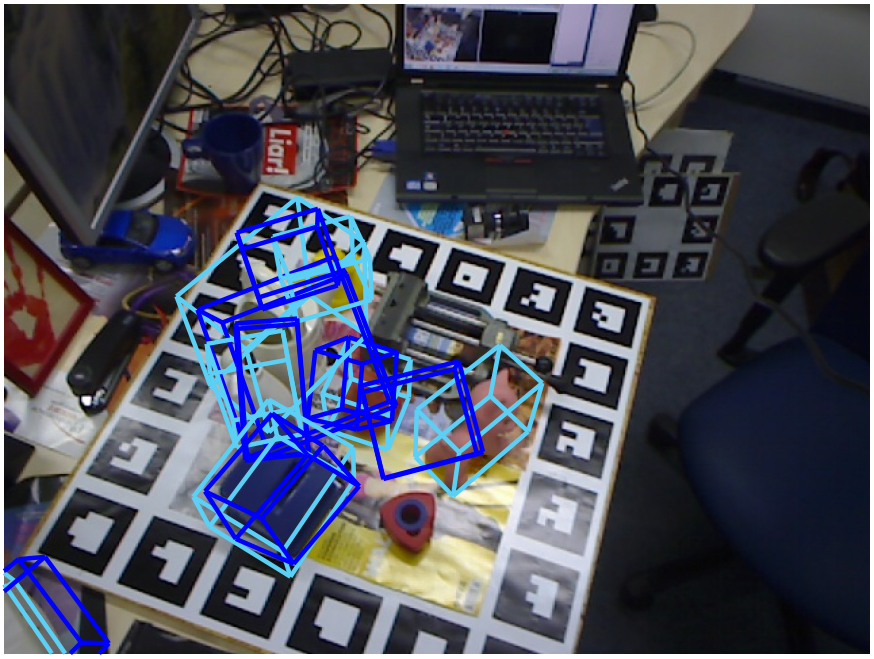

Figure 16: Bounding boxes for RANSAC + DLT in Image 6

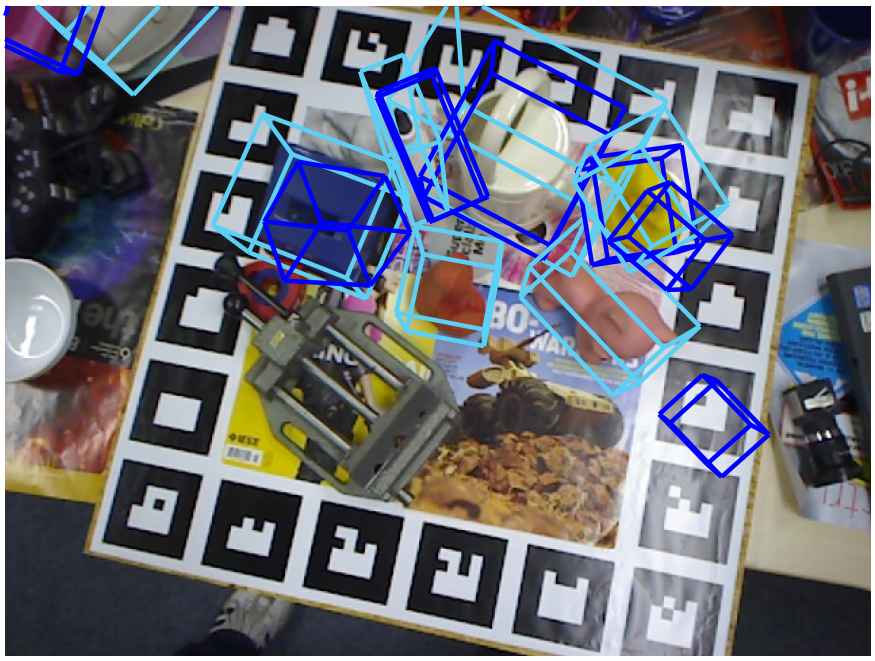

Figure 17: Bounding boxes for RANSAC + DLT in Image 7

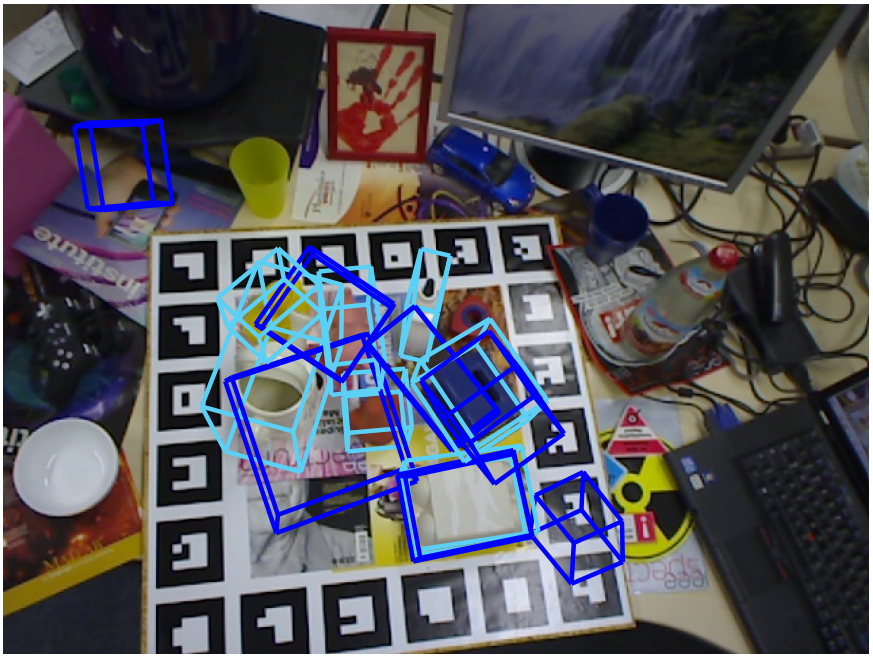

Figure 18: Bounding boxes for RANSAC + DLT in Image 8

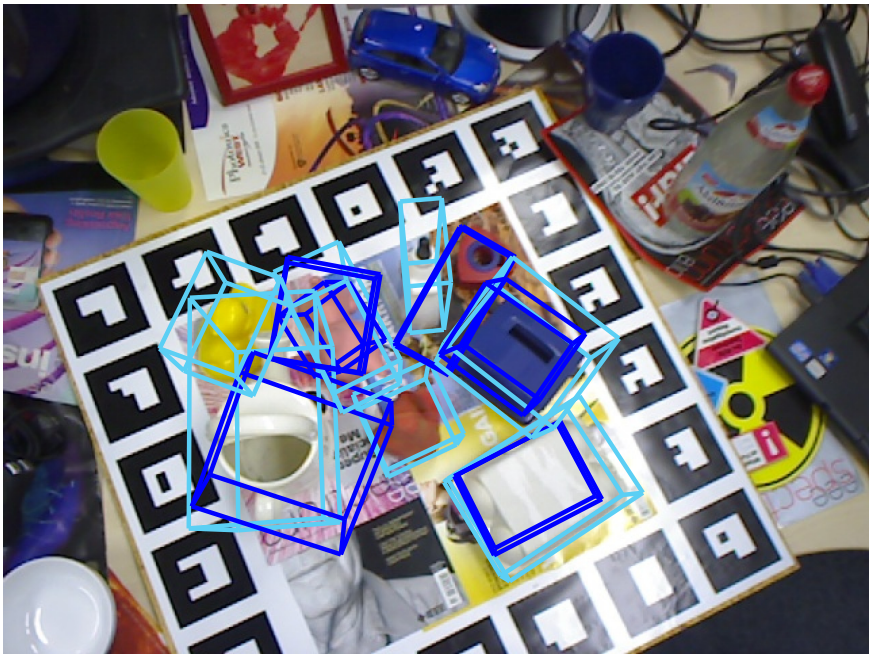

Figure 19: Bounding boxes for RANSAC + DLT in Image 9

4.3 RANSAC + P3P Minimal solver + LM

The average score achieved after trying to improve the solution given by RANSAC + P3P minimal solver approach was found to be 19.56. Following are the bounding boxes generated for the 9 images.

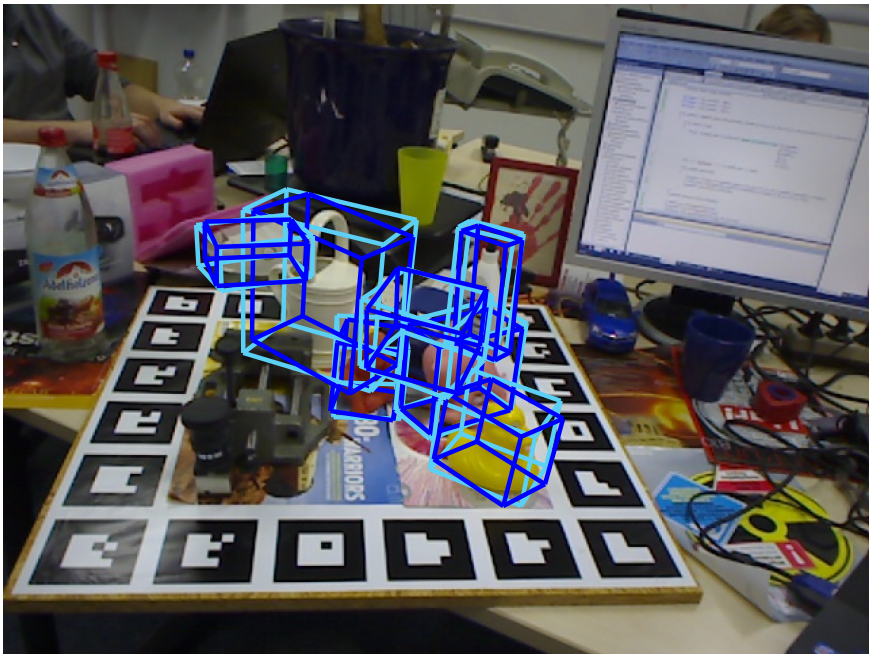

Figure 20: Bounding boxes for RANSAC + Minimal solver + LM in Image 1

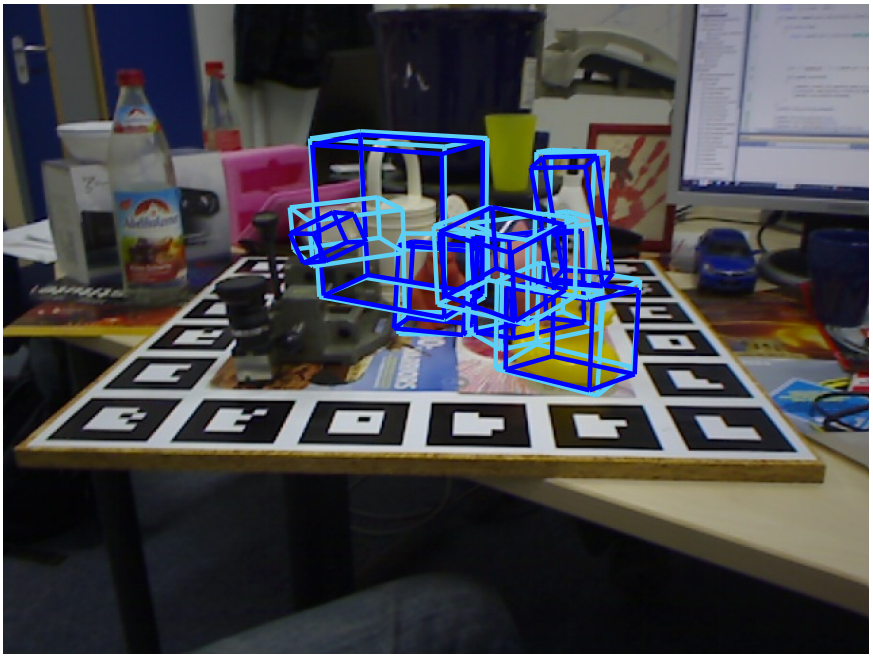

Figure 21: Bounding boxes for RANSAC + Minimal solver + LM in Image 2

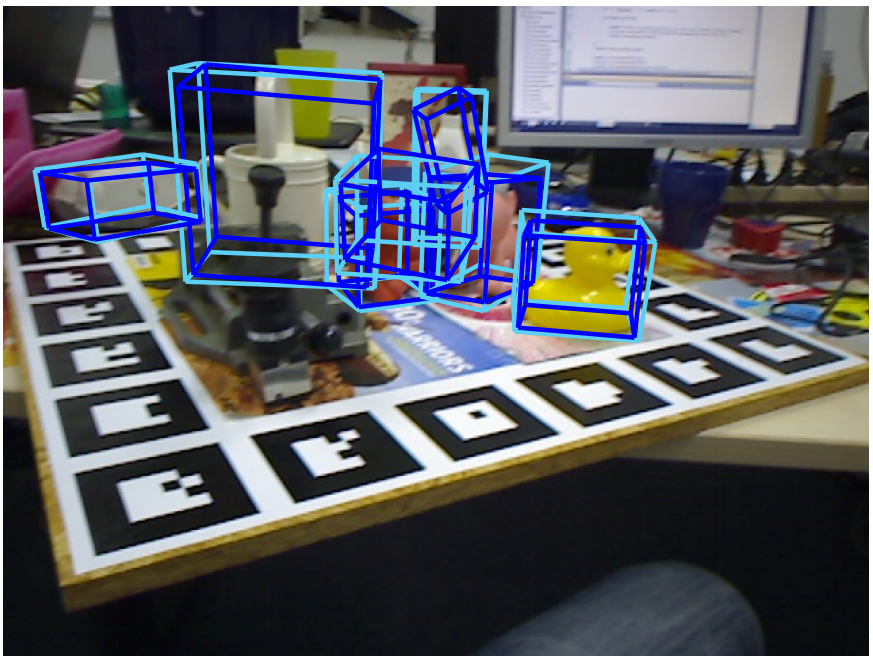

Figure 22: Bounding boxes for RANSAC + Minimal solver + LM in Image 3

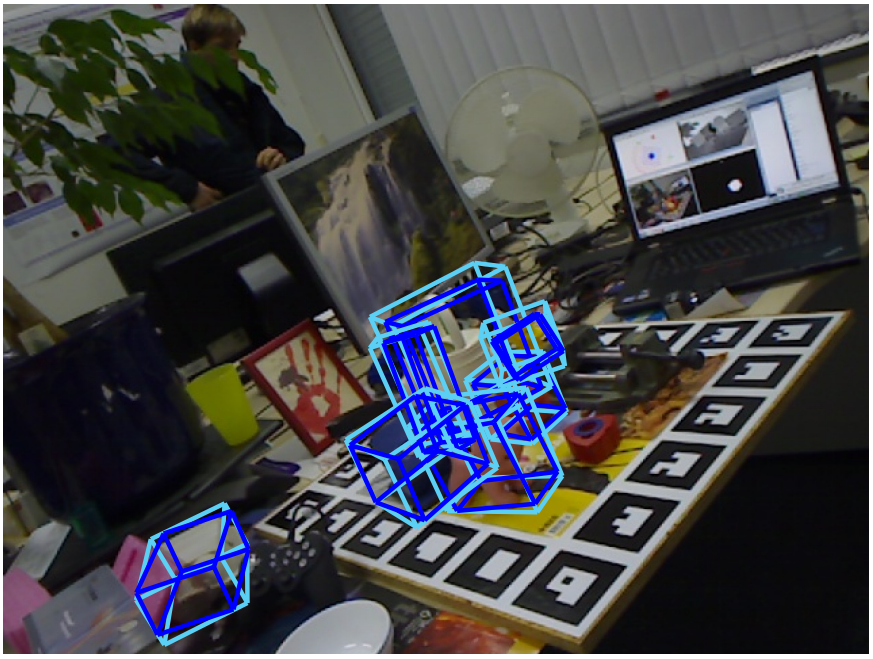

Figure 23: Bounding boxes for RANSAC + Minimal solver + LM in Image 4

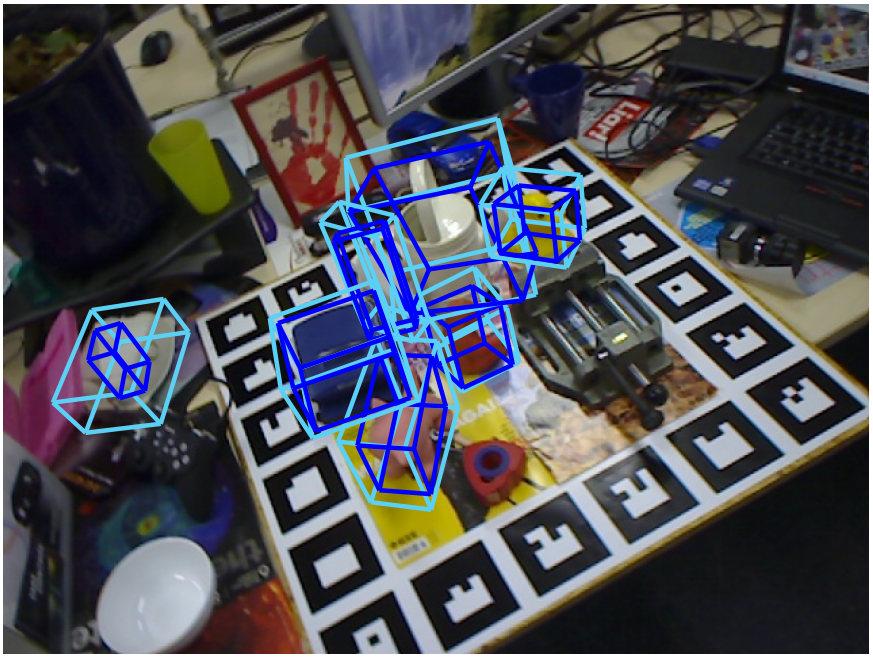

Figure 24: Bounding boxes for RANSAC + Minimal solver + LM in Image 5

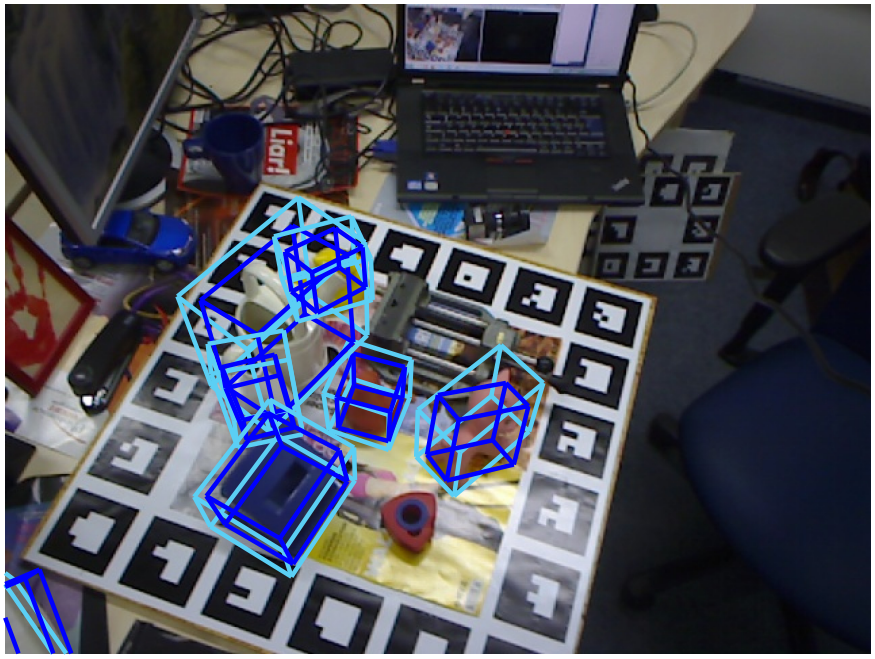

Figure 25: Bounding boxes for RANSAC + Minimal solver + LM in Image 6

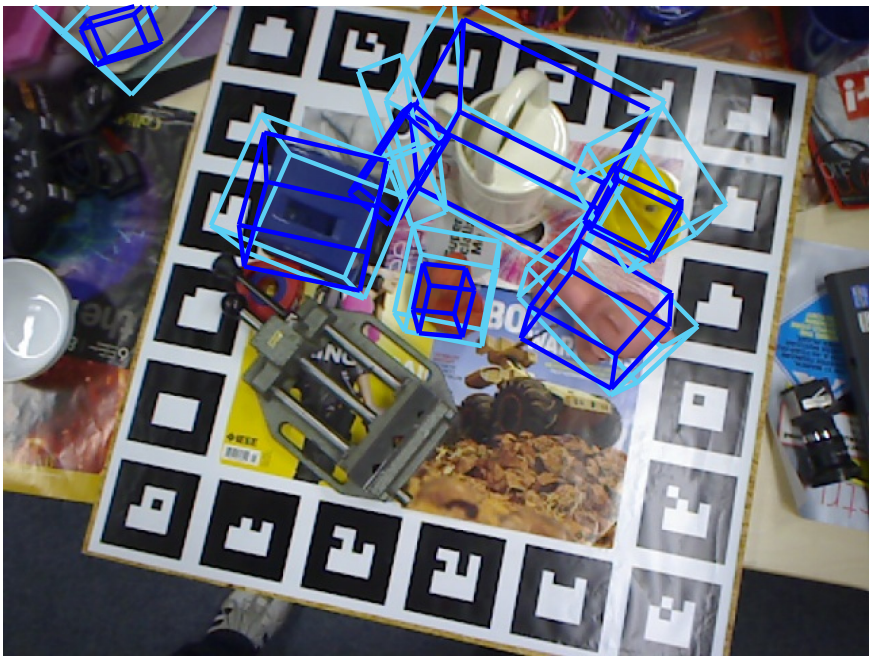

Figure 26: Bounding boxes for RANSAC + Minimal solver + LM in Image 7

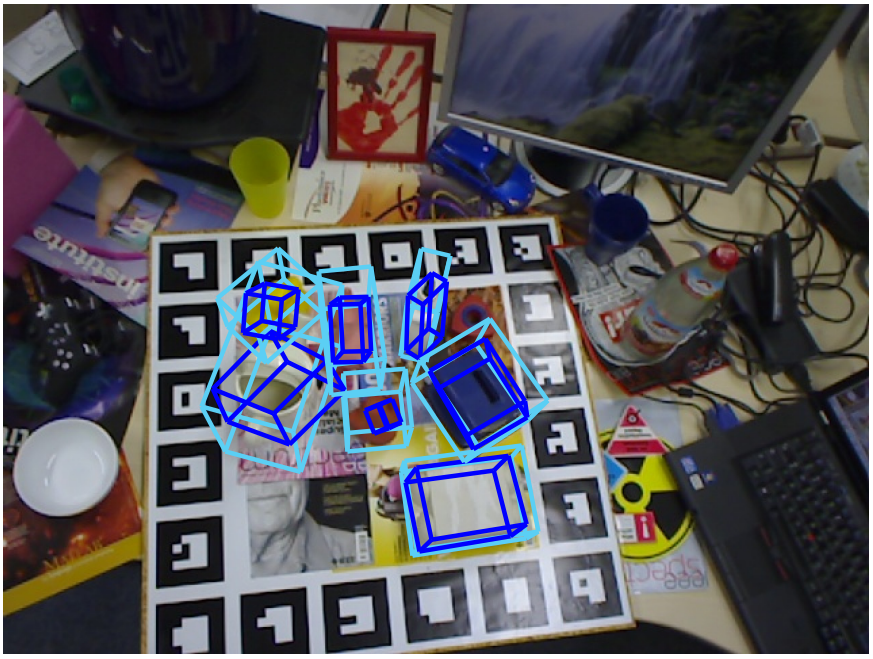

Figure 27: Bounding boxes for RANSAC + Minimal solver + LM in Image 8

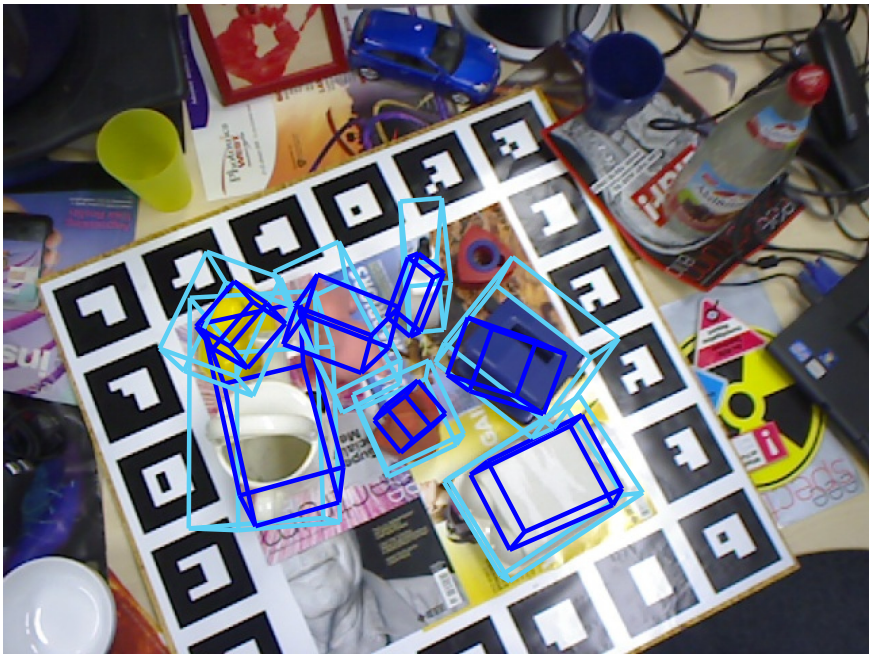

Figure 28: Bounding boxes for RANSAC + Minimal solver + LM in Image 9

4.4 RANSAC + DLT + LM

The average score achieved after trying to improve the solutions given by DLT on inliers using LM method was found to be 61.4. This is a good improvement compared to solutions given by DLT without applying LM which had an average score of 96.07 but few of the bounding boxes seem to be very small compared to the ground truth. The following are the bounding boxes generated for the 9 images.

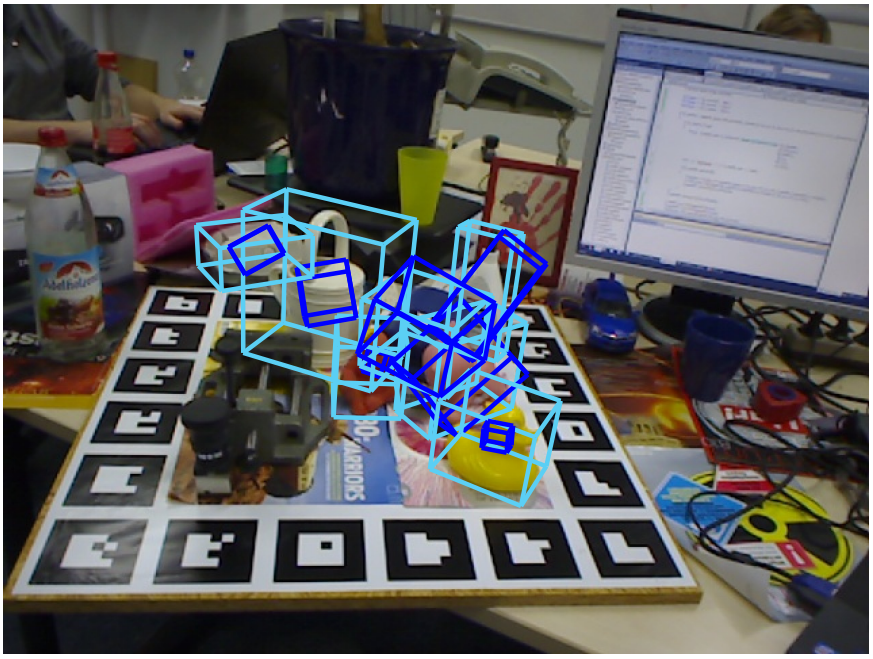

Figure 29: Bounding boxes for RANSAC + DLT + LM in Image 1

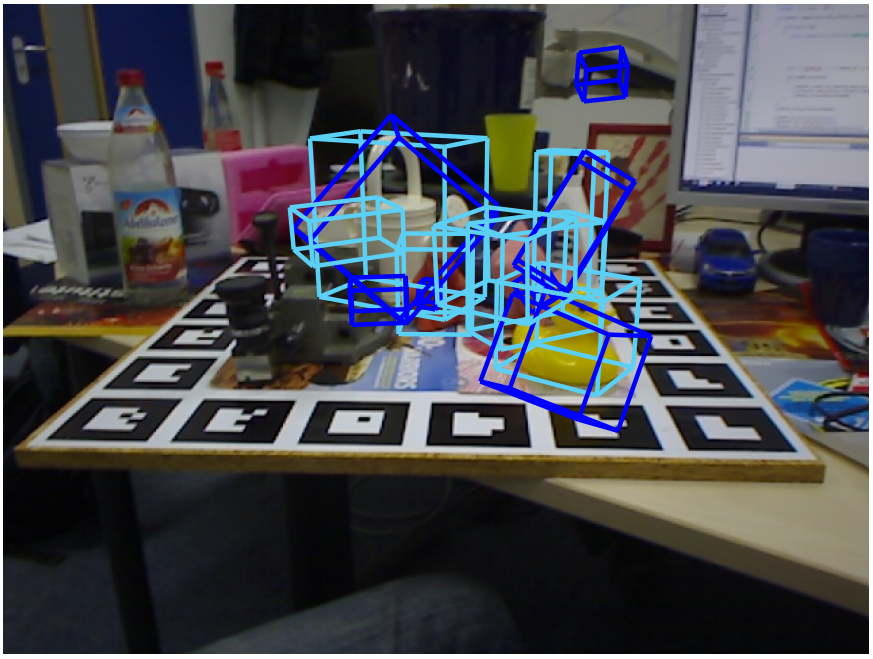

Figure 30: Bounding boxes for RANSAC + DLT + LM in Image 2

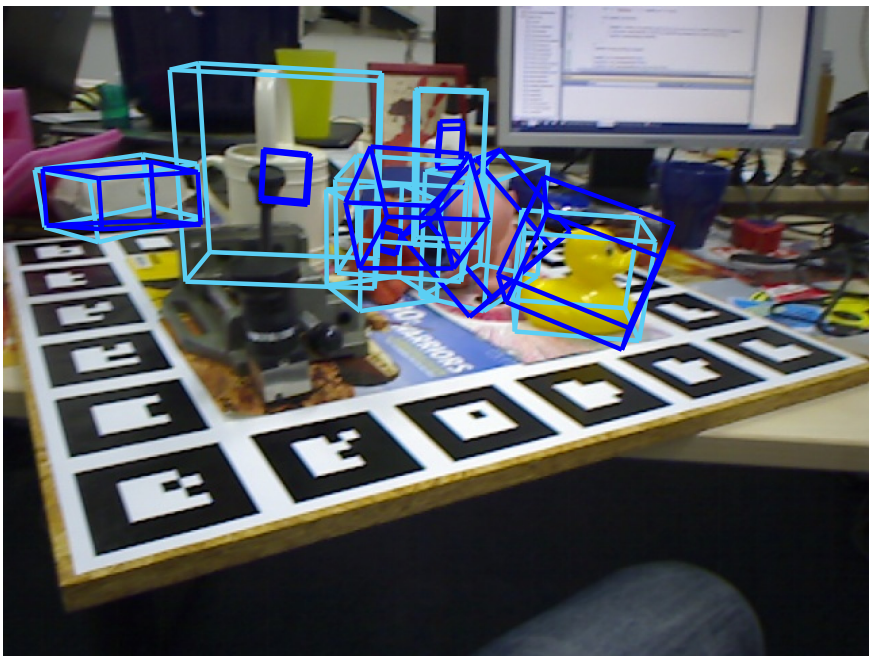

Figure 31: Bounding boxes for RANSAC + DLT + LM in Image 3

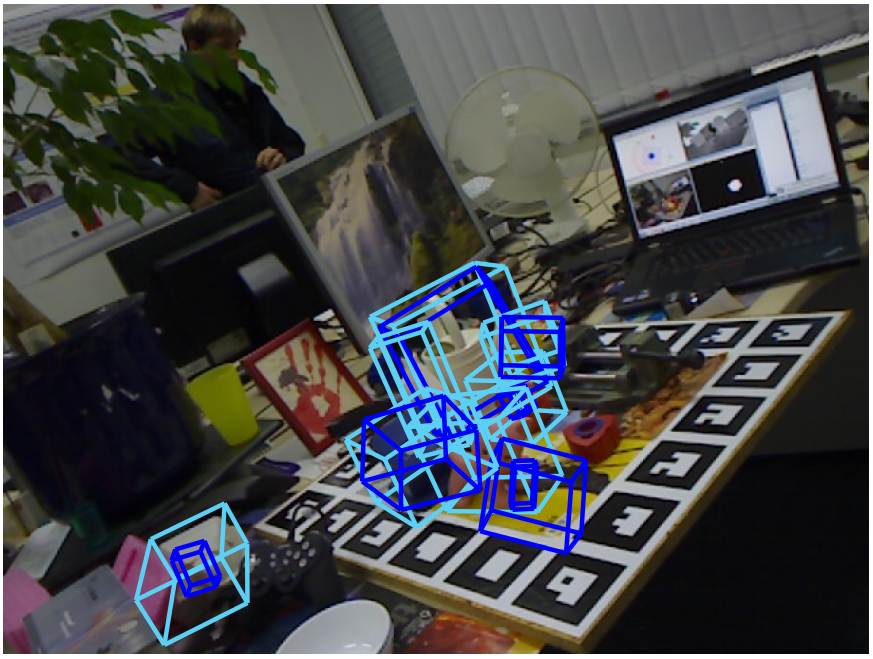

Figure 32: Bounding boxes for RANSAC + DLT + LM in Image 4

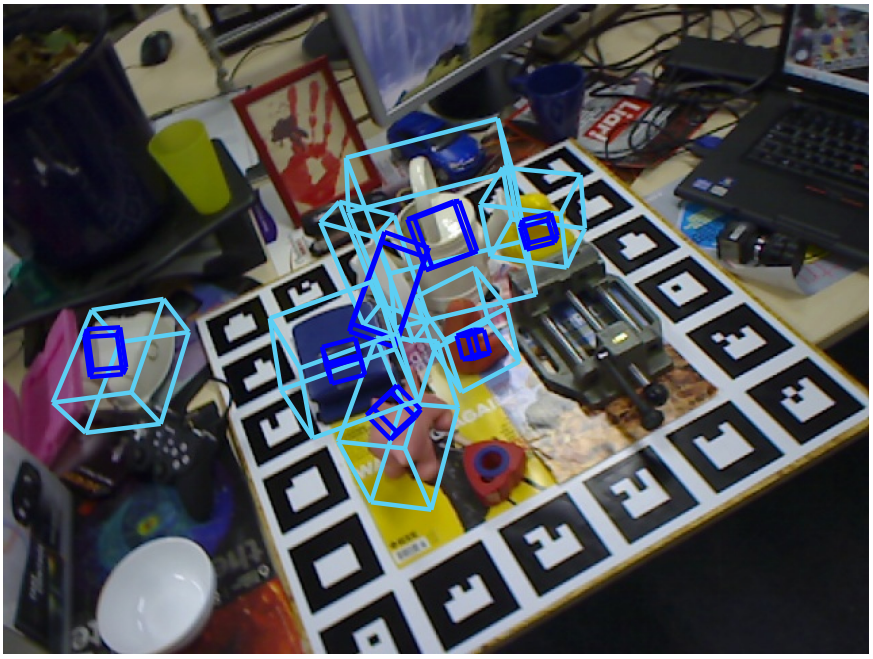

Figure 33: Bounding boxes for RANSAC + DLT + LM in Image 5

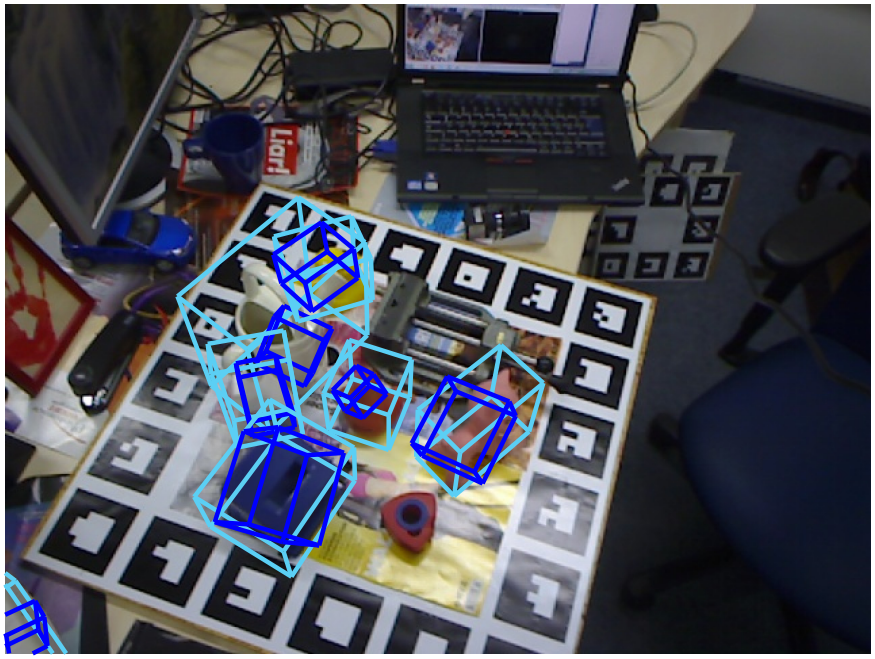

Figure 34: Bounding boxes for RANSAC + DLT + LM in Image 6

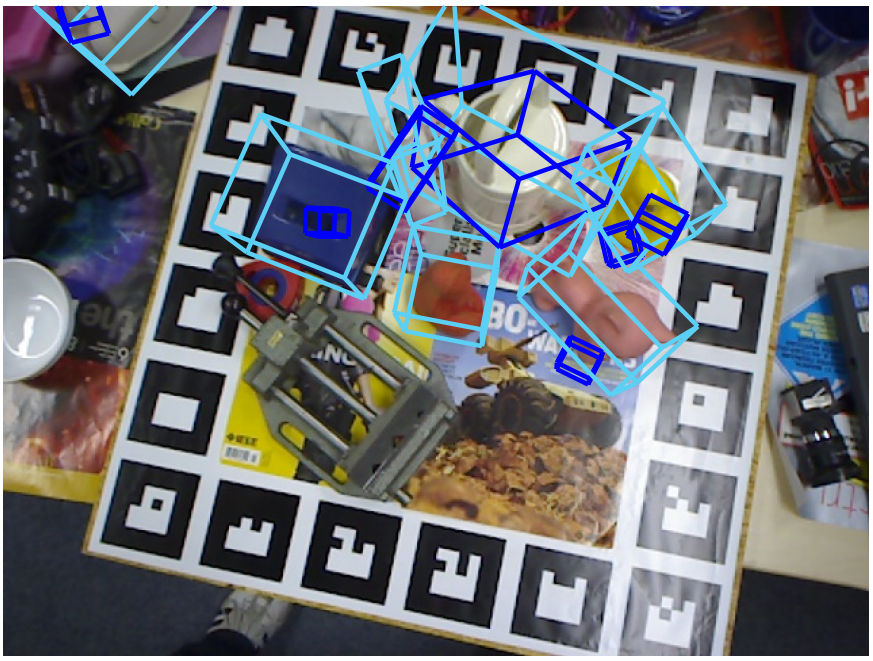

Figure 35: Bounding boxes for RANSAC + DLT + LM in Image 7

Figure 36: Bounding boxes for RANSAC + DLT + LM in Image 8

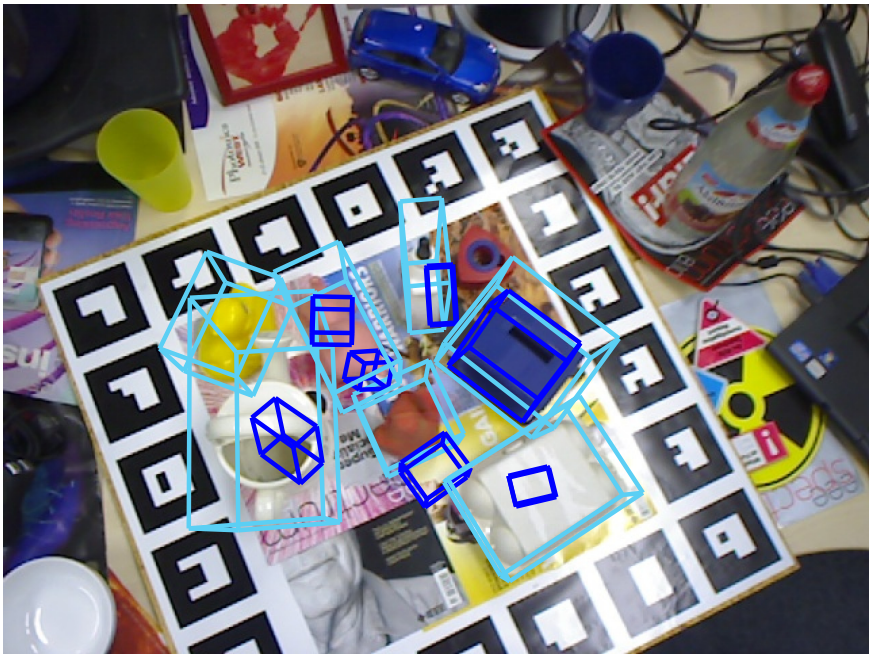

Figure 37: Bounding boxes for RANSAC + DLT + LM in Image 9