Gravity Model Report

DRAFT

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By

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Contents

1 Abstract

This report aims to provide a general review on the performance of the gravity model used on the PR37 surgical 7DOF arm MS7. The gravity model outputs joint torques (nominal) of all the arm actuators, and these values will be compared with joint torque sensors (experimental) to evaluate the gravity model. Assuming that torque sensor reading is reliable, the difference between nominal and experimental joint torques should be below a certain threshold. This report will present this threshold for each joint with experiments on pre-defined robot configurations.

The tests in this report are designed for a MS7 robot set, which includes the 7DOF arm and IDM, no extra load.

Robot configuration plays an important role in the gravity model. The pre-defined robot configurations can be divided in two groups. The first group includes robot configurations provided by Auris for different use cases. The second group includes robot configurations that maximize the load a certain joint. Therefore, the pre-defined robot configurations cover the general cases as well as the extreme cases.

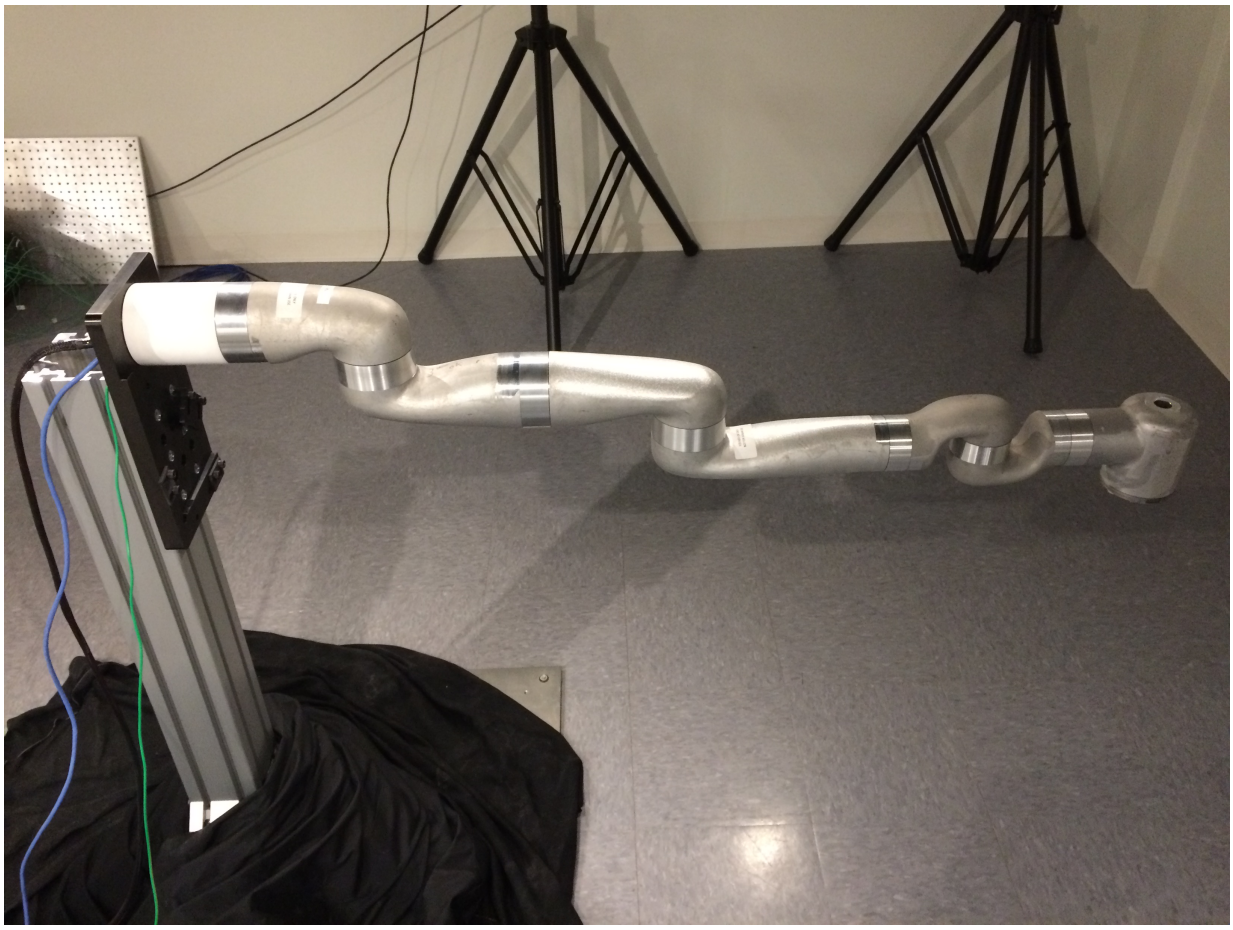


Figure 1: Test setup

2 Test Setup

2.1 Robot setup

The base of PR37 robot is horizontally attached to a vertical pole. At its initial position (also defined as Pose11 in pre-defined robot configurations), the robot is fully extended and the torque load at each actuator sensor is ideally zero. The user should reset joint torque sensor if the data from torque sensor is needed.

2.2 Pre-defined robot configurations

At each pre-defined robot configuration, the sensor data will be recorded and compared with the gravity model output. Their difference will be used to evaluate the gravity model performance. At different robot configurations, the torque at each actuator may vary widely. Therefore, the choice of robot configuration for gravity model evaluation is important. The pre-defined robot configurations used in this report can be categorized into two groups.

Group A In the first group (see in Table 1), the robot configurations are provided by Auris from some

Table 1: Pre-defined Robot Configuration of Group A (Degrees)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Pose 1	115.00	236.85	138.20	264.09	63.00	235.28	155.28
Pose 2	140.00	245.42	90.92	281.41	353.62	295.06	265.40
Pose 3	293.00	137.05	220.52	87.40	217.98	307.70	103.13
Pose 4	10.00	176.73	147.59	43.32	142.68	275.00	205.12
Pose 5	85.00	255.93	141.29	236.09	65.84	228.26	130.50
Pose 6	140.00	205.51	96.12	275.16	313.20	260.62	229.57
Pose 7	120.00	240.31	140.20	239.88	66.74	239.24	115.38
Pose 8	285.00	113.25	129.73	289.67	7.89	195.54	83.44
Pose 9	285.00	121.22	234.46	131.94	356.65	77.01	227.27
Pose 10	340.00	141.74	22.27	67.95	16.12	61.73	153.11

Table 2: Pre-defined Robot Configuration of Group B (Degrees)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7	Maximum Load
Pose 11	180	180	180	180	180	180	180	No load to all (Figure 1)
Pose 12	270	180	180	180	180	180	180	Joint 2, 4, 6, 7 (Figure 2)
Pose 13	180	180	180	180	180	90	180	Joint 5 (Figure 3)
Pose 14	180	180	180	90	180	180	180	Joint 3 (Figure 4)
Pose 15	180	90	180	180	180	180	180	Joint 1 (Figure 5)

real user cases. The robot is in a normal operating condition, and these statuses present most common cases.

Group B In the second group (see in Table 2), the robot configurations are defined to have a maximum load on one or several joints. Since there is no extra load on the robot end-effector, the load only takes robot arm and IDM into account.

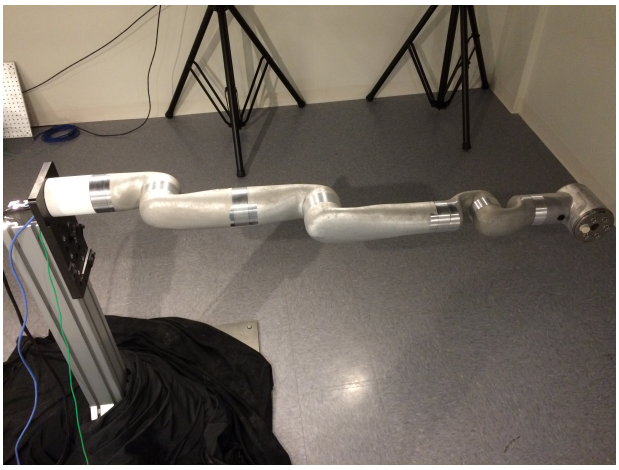


Figure 2: Pose12

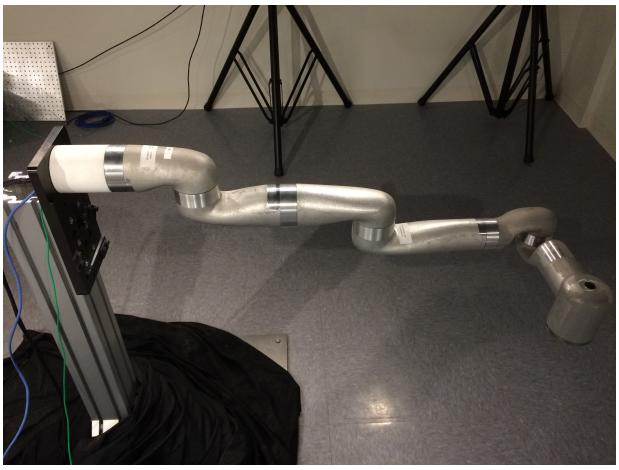


Figure 3: Pose13

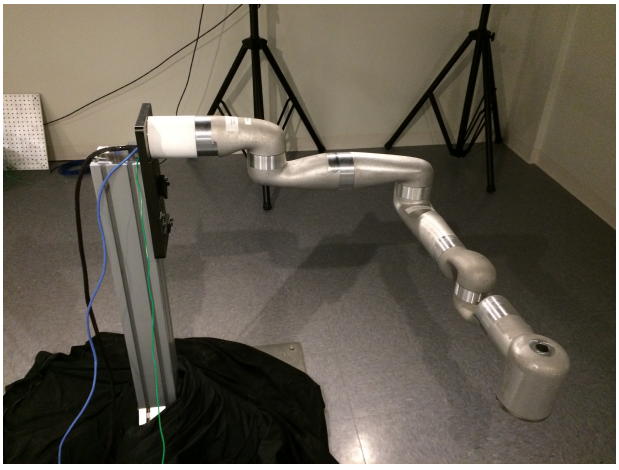


Figure 4: Pose14

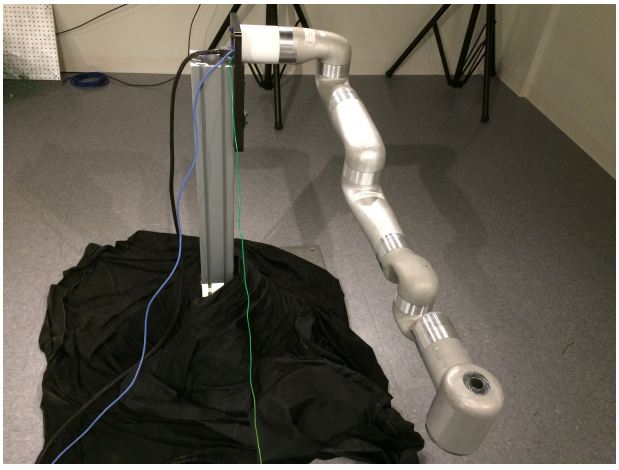


Figure 5: Pose15

3 Test Procedure

3.1 Source Code Repository

PR37 MS7 arm uses a different architecture than MS5/6 arm. The branch of each repository is listed below:

- keos: release/1.8
- bitwin: development (commit ID: 971e7b7, small changes on feature/SWPreleaseKit3_CTRL_Update)
- rtcontrol_nextgen: feature/UpdateControlCOnfigFunction
- sdk_assitive: feature/SWPrelease_CTRL_Update

3.2 Data acquisition

1. run executable rtcontrol on QNX
2. run sdk_assitive to get NOVA interface on PC (as in Figure 6)
3. select AURIS in NOVA
4. select AURIS Control in NOVA
5. set IP of QNX, Run Mode in "run", and then click Connect
6. release robot break
7. input a pre-defined robot configuration in Custom Configuration in NOVA and send it to robot
8. click Live Data to view data in real time
9. make a screenshot of Live Data to collect data
10. input a new pre-defined robot configuration and repeat the steps to get data for all pre-defined robot configurations

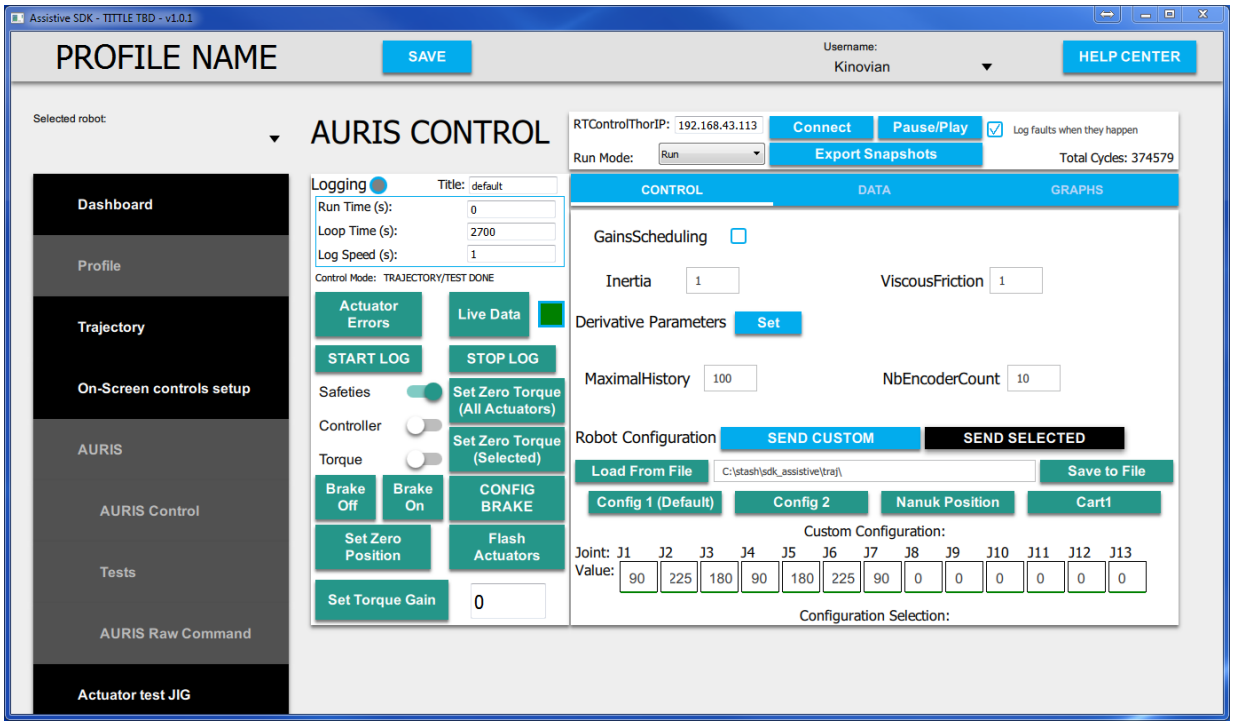


Figure 6: NOVA interface

4 Test Results

With the predefined poses in Table 1 and Table 2, we obtained the computed joint wrench from offline PC (JointWrench_PC) and computed joint wrench from reading robot base in real time (JointWrech_Base). The i^{th} joint wrench contains force and torque along x, y and z axis of i^{th} joint frame. The difference of these two joint wrench values is defined as: $JointWrench\_Error = JointWrench\_PC - JointWrech\_Base$

The Figure 7 to Figure 12 shows the error distribution of all the tests in 15 poses (horizontal axis). The vertical axis indicates the joint index, with base with index 1 and joint 7 with index 8. The color of each cell demonstrates the error of the corresponding test according to the colorbar on the right. It is obvious that JointWrench_Error is very small, in the scale of 10^{-3} N (Force) or Nm(Torque). In other words, the JointWrench_PC and JointWrech_Base have very close values. The sightly differences may due to the residue between robot position command and feedback, as well as numerical errors in the computation. Notable errors happened to the robot base (index 1 of the vertical axis). The cause is NOVA provide 2 decimal values for the wrench at the base, while 4 decimal values at other joints. The omitted decimal values cause error in the scale of 10^{-3}.

In conclusion, the joint wrench data from robot base matches with the data from offline PC. The computed joint wrench in robot base performs as designed.

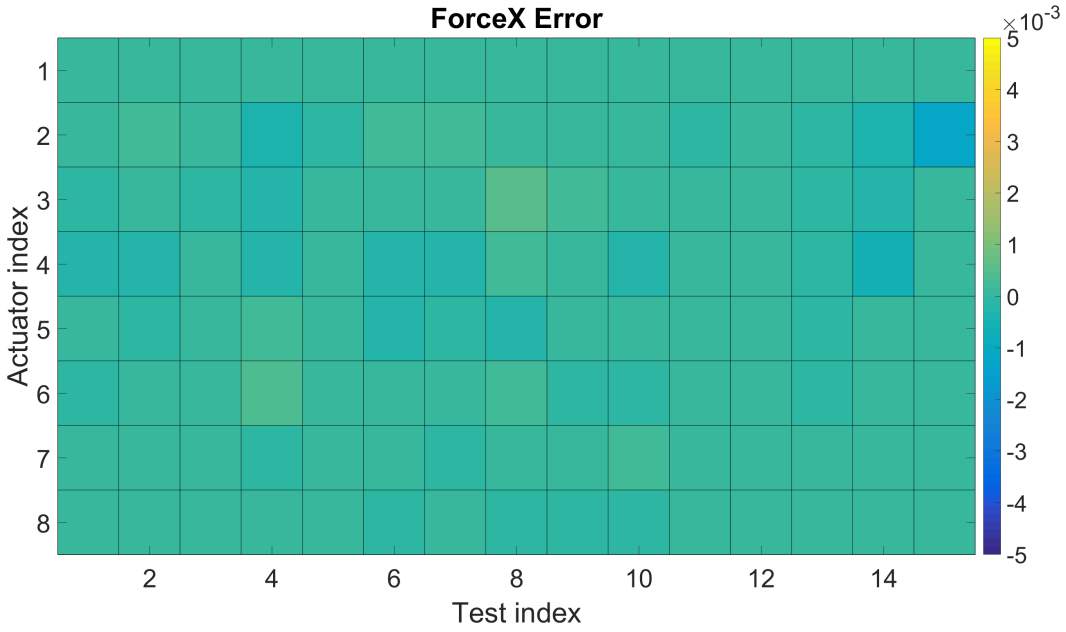


Figure 7: Difference of Force along X axis

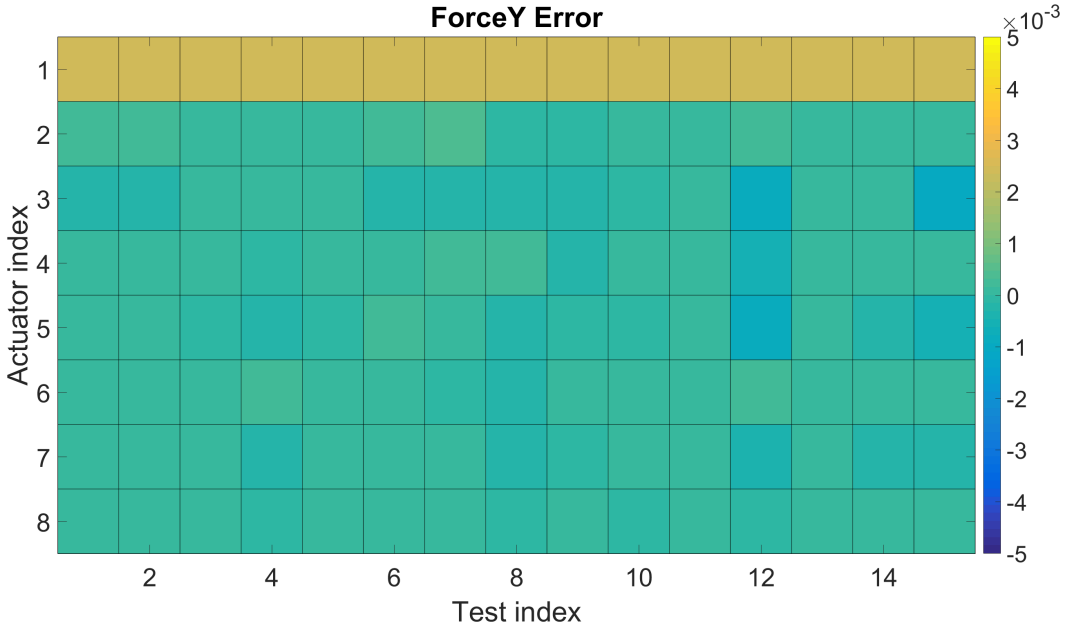


Figure 8: Difference of Force along Y axis

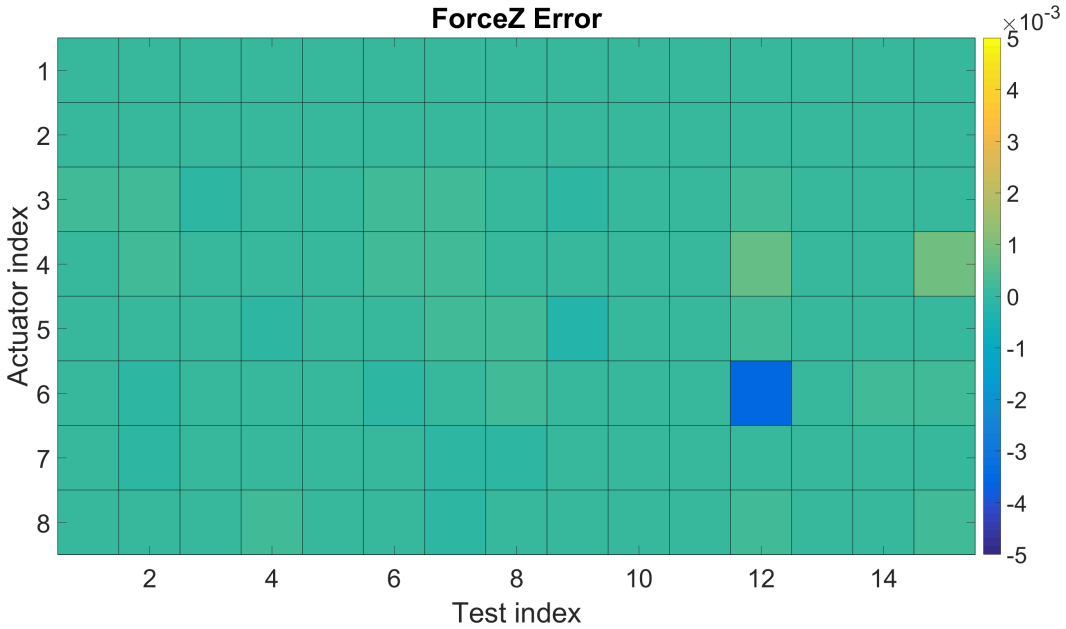


Figure 9: Difference of Force along Z axis

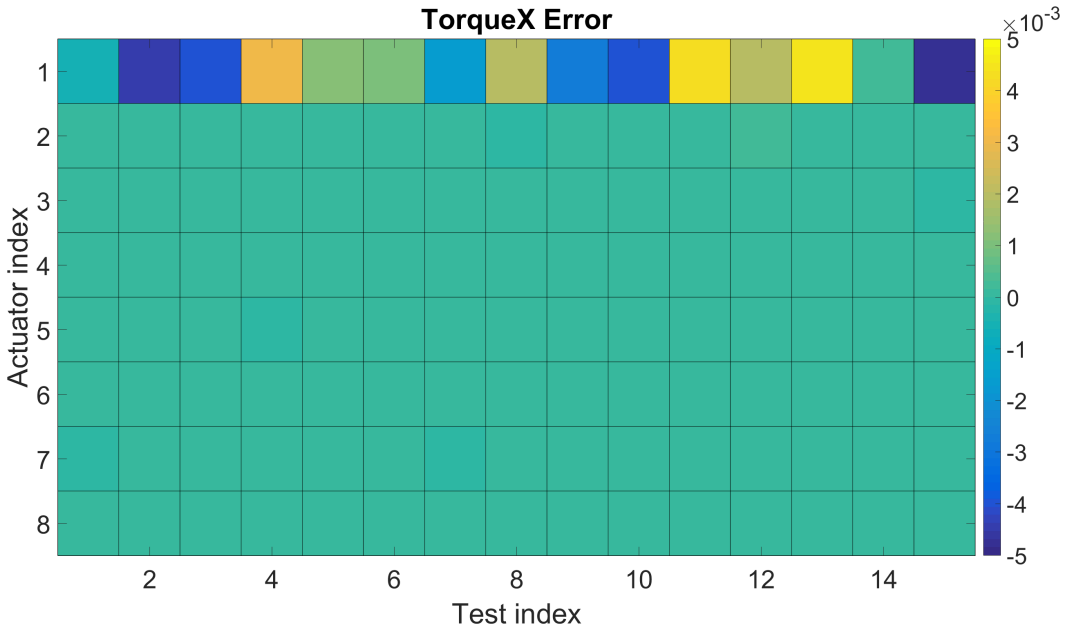


Figure 10: Difference of Torque along X axis

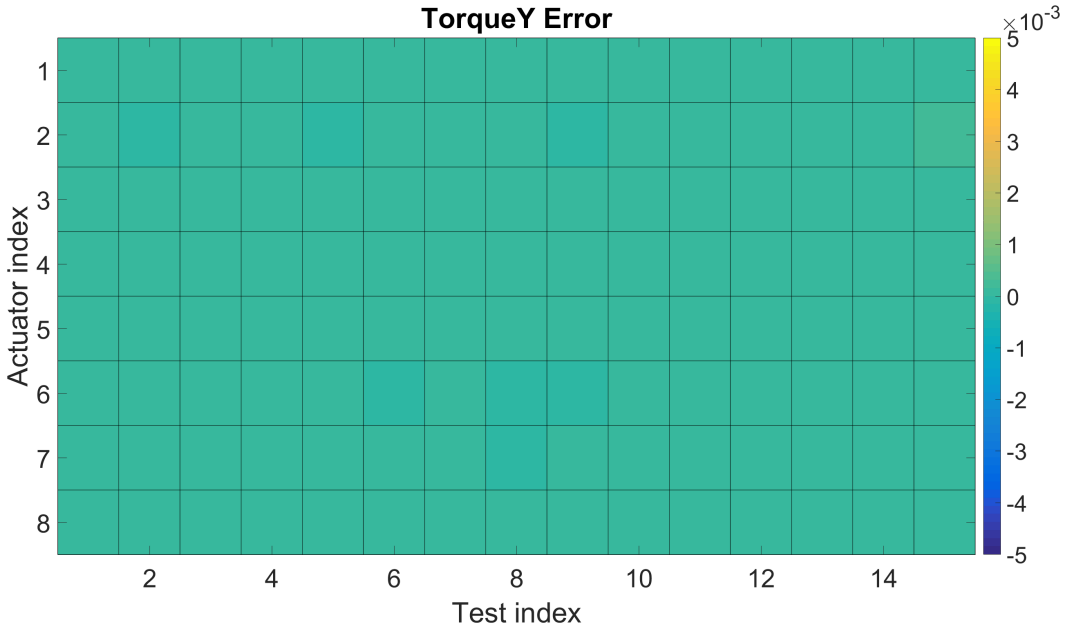


Figure 11: Difference of Torque along Y axis

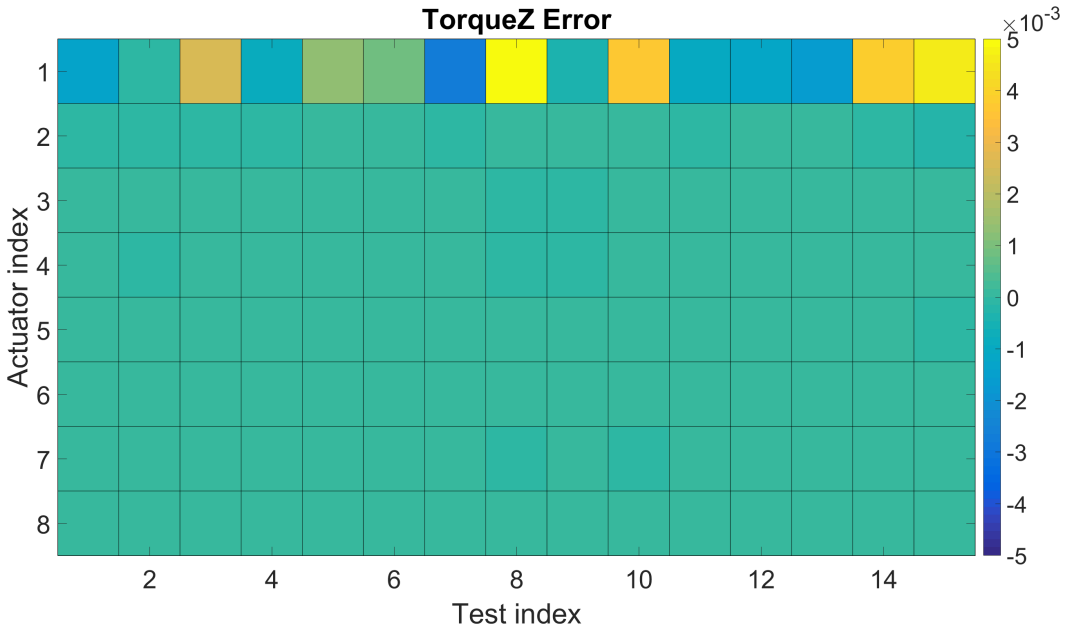
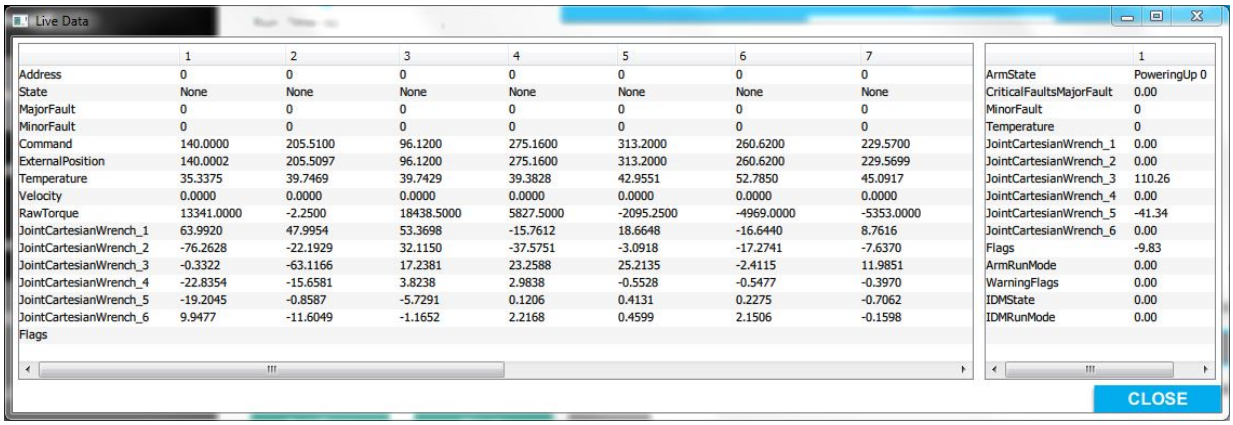


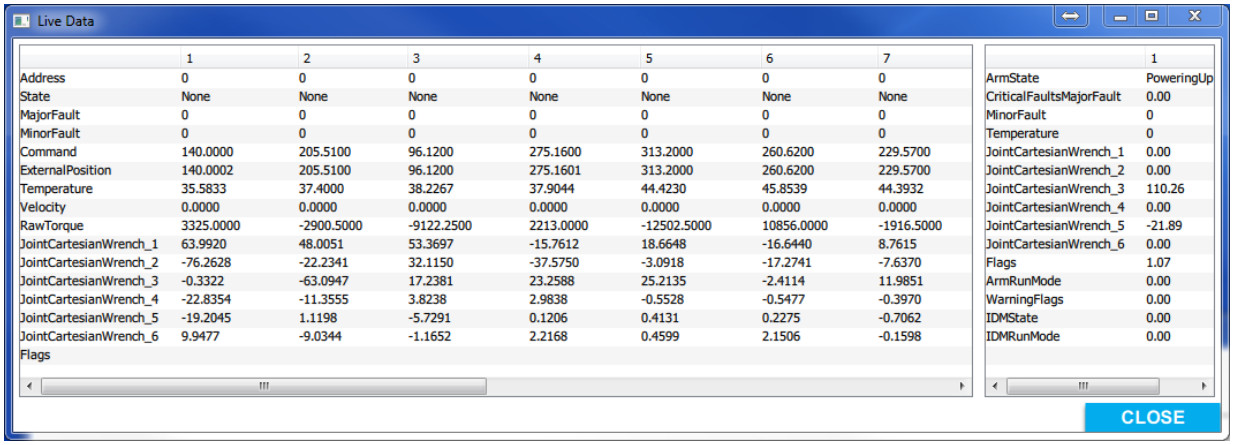
Figure 12: Difference of Torque along Z axis



	1	2	3	4	5	6	7
Address	0	0	0	0	0	0	0
State	None	None	None	None	None	None	None
MajorFault	0	0	0	0	0	0	0
MinorFault	0	0	0	0	0	0	0
Command	140.0000	205.5100	96.1200	275.1600	313.2000	260.6200	229.5700
ExternalPosition	140.0002	205.5097	96.1200	275.1600	313.2000	260.6200	229.5699
Temperature	35.3375	39.7469	39.7429	39.3828	42.9551	52.7850	45.0917
Velocity	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RawTorque	13341.0000	-2.2500	18438.5000	5827.5000	-2095.2500	-4969.0000	-5353.0000
JointCartesianWrench_1	63.9920	47.9954	53.3698	-15.7612	18.6648	-16.6440	8.7616
JointCartesianWrench_2	-76.2628	-22.1929	32.1150	-37.5751	-3.0918	-17.2741	-7.6370
JointCartesianWrench_3	-0.3322	-63.1166	17.2381	23.2588	25.2135	-2.4115	11.9851
JointCartesianWrench_4	-22.8354	-15.6581	3.8238	2.9838	-0.5528	-0.5477	-0.3970
JointCartesianWrench_5	-19.2045	-0.8587	-5.7291	0.1206	0.4131	0.2275	-0.7062
JointCartesianWrench_6	9.9477	-11.6049	-1.1652	2.2168	0.4599	2.1506	-0.1598
Flags							

	1
ArmState	PoweringUp 0
CriticalFaultsMajorFault	0.00
MinorFault	0
Temperature	0
JointCartesianWrench_1	0.00
JointCartesianWrench_2	0.00
JointCartesianWrench_3	110.26
JointCartesianWrench_4	0.00
JointCartesianWrench_5	-41.34
JointCartesianWrench_6	0.00
Flags	-9.83
ArmRunMode	0.00
WarningFlags	0.00
IDMState	0.00
IDMRunMode	0.00

Figure 13: Used Pose6



	1	2	3	4	5	6	7
Address	0	0	0	0	0	0	0
State	None	None	None	None	None	None	None
MajorFault	0	0	0	0	0	0	0
MinorFault	0	0	0	0	0	0	0
Command	140.0000	205.5100	96.1200	275.1600	313.2000	260.6200	229.5700
ExternalPosition	140.0002	205.5100	96.1200	275.1601	313.2000	260.6200	229.5700
Temperature	35.5833	37.4000	38.2267	37.9044	44.4230	45.8539	44.3932
Velocity	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RawTorque	3325.0000	-2900.5000	-9122.2500	2213.0000	-12502.5000	10856.0000	-1916.5000
JointCartesianWrench_1	63.9920	48.0051	53.3697	-15.7612	18.6648	-16.6440	8.7615
JointCartesianWrench_2	-76.2628	-22.2341	32.1150	-37.5750	-3.0918	-17.2741	-7.6370
JointCartesianWrench_3	-0.3322	-63.0947	17.2381	23.2588	25.2135	-2.4114	11.9851
JointCartesianWrench_4	-22.8354	-11.3555	3.8238	2.9838	-0.5528	-0.5477	-0.3970
JointCartesianWrench_5	-19.2045	1.1198	-5.7291	0.1206	0.4131	0.2275	-0.7062
JointCartesianWrench_6	9.9477	-9.0344	-1.1652	2.2168	0.4599	2.1506	-0.1598
Flags							

	1
ArmState	PoweringUp
CriticalFaultsMajorFault	0.00
MinorFault	0
Temperature	0
JointCartesianWrench_1	0.00
JointCartesianWrench_2	0.00
JointCartesianWrench_3	110.26
JointCartesianWrench_4	0.00
JointCartesianWrench_5	-21.89
JointCartesianWrench_6	0.00
Flags	1.07
ArmRunMode	0.00
WarningFlags	0.00
IDMState	0.00
IDMRunMode	0.00

Figure 14: Discarded Pose6

5 Limitations

There are certain limitations for this test.

1. NOVA or robot did not provide same/similar data value with the same robot configuration. (eg: Comparing the joint wrench data at the base between Figure 14 and Figure 13)
2. Pose3 is not achievable due to the limit of joint 6. The closest configuration to Pose3 is [293.0001, 137.0502, 220.5201, 87.3998 , 217.9778, 307.4591, 103.1300], and this data used for the offline computation on PC as well.
3. Accuracy of Joint Sensor Data (joint sensor data to be added after torque sensor calibration ...)

6 Appendix

6.1 Test at robot configuration 1

Robot joint angles are [115 236.85 138.2 264.09 63 235.28 155.28];

Table 3: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	90.228	41.3099	42.5445	-31.7672	9.1143	-10.5665	2.2934
Fy PC	110.2625	-42.0707	-62.1115	1.1795	-34.5177	-19.3155	-15.8279	12.3686
Fz PC	0	-0.2484	-34.8631	48.6356	0.8023	23.1839	-14.8006	10.9768
Tx PC	-27.9005	-6.9044	-7.129	-0.7967	0.9116	-3.1432	-2.3085	1.1963
Ty PC	0	-14.8713	-2.405	2.0313	-0.645	0.7029	0.0888	-0.1851
Tz PC	-10.7114	10.7851	-4.1627	0.6476	8.3476	1.8213	1.5531	-0.0414

Table 4: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	90.2279	41.31	42.5447	-31.7672	9.1144	-10.5665	2.2934
Fy Robot	110.26	-42.071	-62.1113	1.1794	-34.5177	-19.3155	-15.828	12.3686
Fz Robot	0	-0.2484	-34.8634	48.6355	0.8022	23.1839	-14.8006	10.9768
Tx Robot	-27.9	-6.9044	-7.1291	-0.7967	0.9116	-3.1432	-2.3084	1.1963
Ty Robot	0	-14.8713	-2.405	2.0313	-0.645	0.7028	0.0888	-0.1851
Tz Robot	-10.71	10.7852	-4.1627	0.6476	8.3476	1.8213	1.5531	-0.0414

Table 5: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	0.0001	-0.0001	-0.0002	0	-0.0001	0	0
Fy Error	0.0025	0.0003	-0.0002	0.0001	0	0	0.0001	0
Fz Error	0	0	0.0003	0.0001	0.0001	0	0	0
Tx Error	-0.0005	0	0.0001	0	0	0	-0.0001	0
Ty Error	0	0	0	0	0	0.0001	0	0
Tz Error	-0.0014	-0.0001	0	0	0	0	0	0

Table 6: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	10.7852	-4.1627	0.6476	8.3476	1.8213	1.5531	-0.0414
Tz PC	10.7851	-4.1627	0.6476	8.3476	1.8213	1.5531	-0.0414

6.2 Test at robot configuration 2

Robot joint angles are [140 245.42 90.92 281.41 353.62 295.06 265.4];

Table 7: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	64.0037	22.469	49.9289	-33.653	23.3638	-21.6473	4.3091
Fy PC	110.2625	-76.2533	-47.8244	16.84	-30.3433	-5.7106	-9.648	-14.6683
Fz PC	0	-0.2559	-63.1487	37.4215	12.1667	20.3759	-4.4205	6.7086
Tx PC	-29.0945	-13.4362	-13.4574	0.3224	1.4061	-0.3649	-0.6654	-1.0595
Ty PC	0	-11.3291	-1.3893	-1.9633	0.6292	0.7207	0.167	-0.3473
Tz PC	-15.2101	15.2878	-3.7361	0.4533	5.4584	0.6204	2.894	-0.0789

Table 8: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	64.0034	22.4689	49.9291	-33.6529	23.3637	-21.6474	4.3091
Fy Robot	110.26	-76.2536	-47.8241	16.84	-30.3434	-5.7106	-9.648	-14.6683
Fz Robot	0	-0.2559	-63.1489	37.4213	12.1667	20.376	-4.4204	6.7086
Tx Robot	-29.09	-13.4363	-13.4575	0.3224	1.4061	-0.3649	-0.6654	-1.0595
Ty Robot	0	-11.329	-1.3893	-1.9634	0.6292	0.7207	0.167	-0.3473
Tz Robot	-15.21	15.2879	-3.7361	0.4534	5.4584	0.6204	2.894	-0.0789

Table 9: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	0.0003	0.0001	-0.0002	-0.0001	0.0001	0.0001	0
Fy Error	0.0025	0.0003	-0.0003	0	0.0001	0	0	0
Fz Error	0	0	0.0002	0.0002	0	-0.0001	-0.0001	0
Tx Error	-0.0045	0.0001	0.0001	0	0	0	0	0
Ty Error	0	-0.0001	0	0.0001	0	0	0	0
Tz Error	-0.0001	-0.0001	0	-0.0001	0	0	0	0

Table 10: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	15.2879	-3.7361	0.4534	5.4584	0.6204	2.894	-0.0789
Tz PC	15.2878	-3.7361	0.4533	5.4584	0.6204	2.894	-0.0789

6.3 Test at robot configuration 3

Robot joint angles are [293.0001 137.0502 220.5201 87.3998 217.9778 307.4591 103.13];

6.4 Test at robot configuration 4

Robot joint angles are [10 176.73 147.59 43.32 142.68 275 205.12];

Table 11: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	-91.6344	-55.4598	-16.4767	30.0831	30.2296	-18.1765	5.7336
Fy PC	110.2625	38.9123	-51.6547	47.4566	-10.4017	5.7477	-15.2318	11.5782
Fz PC	0	-0.2802	32.1837	40.6601	34.4686	6.8404	4.3407	10.5737
Tx PC	-33.004	8.4005	8.152	4.6381	6.1296	0.0993	0.5016	1.1253
Ty PC	0	19.8137	-3.1897	-3.1387	-0.7688	-0.094	0.176	-0.4622
Tz PC	-4.2674	4.3582	8.9284	5.5428	-5.5817	-0.3598	2.7181	-0.1041

Table 12: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	-91.6344	-55.4597	-16.4767	30.0831	30.2296	-18.1765	5.7336
Fy Robot	110.26	38.9123	-51.6547	47.4566	-10.4016	5.7477	-15.2318	11.5781
Fz Robot	0	-0.2802	32.1838	40.6601	34.4686	6.8403	4.3407	10.5737
Tx Robot	-33	8.4005	8.152	4.6381	6.1296	0.0993	0.5016	1.1253
Ty Robot	0	19.8136	-3.1897	-3.1387	-0.7688	-0.094	0.176	-0.4622
Tz Robot	-4.27	4.3583	8.9284	5.5428	-5.5817	-0.3598	2.7181	-0.1041

Table 13: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	0	-0.0001	0	0	0	0	0
Fy Error	0.0025	0	0	0	-0.0001	0	0	0.0001
Fz Error	0	0	-0.0001	0	0	0.0001	0	0
Tx Error	-0.004	0	0	0	0	0	0	0
Ty Error	0	0.0001	0	0	0	0	0	0
Tz Error	0.0026	-0.0001	0	0	0	0	0	0

Table 14: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	4.3583	8.9284	5.5428	-5.5817	-0.3598	2.7181	-0.1041
Tz PC	4.3582	8.9284	5.5428	-5.5817	-0.3598	2.7181	-0.1041

Table 15: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	17.2851	14.3259	-24.4358	12.4384	-11.0271	-5.634	-2.7765
Fy PC	110.2625	98.042	1.1273	59.8232	-12.5632	28.3432	8.8952	-15.2768
Fz PC	0	-0.3135	81.0758	-0.9653	43.4595	8.2899	21.6879	-6.1352
Tx PC	-38.347	26.441	15.372	2.9876	10.6354	2.4216	3.16	-1.3424
Ty PC	0	-4.6275	-9.0529	1.3559	2.6477	1.8578	-0.0349	0.2239
Tz PC	-10.5508	10.6594	-2.5903	8.4035	-2.2785	-3.1305	0.8352	0.0501

Table 16: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	17.2855	14.3262	-24.4355	12.4382	-11.0275	-5.6339	-2.7766
Fy Robot	110.26	98.0419	1.1273	59.8233	-12.563	28.343	8.8955	-15.2767
Fz Robot	0	-0.3135	81.0757	-0.9653	43.4596	8.2898	21.6878	-6.1354
Tx Robot	-38.35	26.441	15.3719	2.9876	10.6355	2.4216	3.1599	-1.3424
Ty Robot	0	-4.6276	-9.0529	1.3559	2.6477	1.8578	-0.0349	0.2239
Tz Robot	-10.55	10.6595	-2.5904	8.4035	-2.2785	-3.1305	0.8352	0.0501

Table 17: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	-0.0004	-0.0003	-0.0003	0.0002	0.0004	-0.0001	0.0001
Fy Error	0.0025	0.0001	0	-0.0001	-0.0002	0.0002	-0.0003	-0.0001
Fz Error	0	0	0.0001	0	-0.0001	0.0001	0.0001	0.0002
Tx Error	0.003	0	0.0001	0	-0.0001	0	0.0001	0
Ty Error	0	0.0001	0	0	0	0	0	0
Tz Error	-0.0008	-0.0001	0.0001	0	0	0	0	0

Table 18: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	10.6595	-2.5904	8.4035	-2.2785	-3.1305	0.8352	0.0501
Tz PC	10.6594	-2.5903	8.4035	-2.2785	-3.1305	0.8352	0.0501

6.5 Test at robot configuration 5

Robot joint angles are [85 255.93 141.29 236.09 65.84 228.26 130.5];

Table 19: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	99.1779	20.4923	9.1725	-33.6567	2.6686	-10.4651	-4.8581
Fy PC	110.2625	8.6484	-79.4216	14.5715	-30.9342	-23.5784	-12.0837	13.5951
Fz PC	0	-0.2109	7.2152	62.2928	10.5629	20.7507	-18.0471	8.3847
Tx PC	-21.8889	0.9034	4.6768	2.6582	3.5988	-3.9006	-2.6637	1.2479
Ty PC	0	-10.3845	1.3335	7.8753	-0.7618	1.321	-0.041	0.3911
Tz PC	1.0714	-1.0176	1.3956	-2.2336	9.2358	2.0026	1.5721	0.0889

6.6 Test at robot configuration 6

Robot joint angles are [140 205.51 96.12 275.16 313.2 260.62 229.57];

Table 20: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	99.178	20.4922	9.1725	-33.6568	2.6686	-10.4651	-4.8582
Fy Robot	110.26	8.6483	-79.4216	14.5715	-30.9341	-23.5785	-12.0837	13.5951
Fz Robot	0	-0.2109	7.2151	62.2928	10.5629	20.7506	-18.0472	8.3846
Tx Robot	-21.89	0.9034	4.6768	2.6582	3.5988	-3.9006	-2.6637	1.2479
Ty Robot	0	-10.3844	1.3335	7.8753	-0.7618	1.321	-0.041	0.3911
Tz Robot	1.07	-1.0176	1.3956	-2.2336	9.2358	2.0026	1.5721	0.0889

Table 21: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	-0.0001	0.0001	0	0.0001	0	0	0.0001
Fy Error	0.0025	0.0001	0	0	-0.0001	0.0001	0	0
Fz Error	0	0	0.0001	0	0	0.0001	0.0001	0.0001
Tx Error	0.0011	0	0	0	0	0	0	0
Ty Error	0	-0.0001	0	0	0	0	0	0
Tz Error	0.0014	0	0	0	0	0	0	0

Table 22: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	-1.0176	1.3956	-2.2336	9.2358	2.0026	1.5721	0.0889
Tz PC	-1.0176	1.3956	-2.2336	9.2358	2.0026	1.5721	0.0889

Table 23: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	63.9923	47.9955	53.3696	-15.7614	18.6649	-16.644	8.7615
Fy PC	110.2625	-76.2625	-22.1932	32.1151	-37.5749	-3.0918	-17.2741	-7.637
Fz PC	0	-0.3322	-63.1164	17.2383	23.2589	25.2134	-2.4115	11.9852
Tx PC	-41.339	-22.8353	-15.658	3.8238	2.9839	-0.5528	-0.5477	-0.397
Ty PC	0	-19.2045	-0.8587	-5.729	0.1206	0.413	0.2275	-0.7062
Tz PC	-9.8292	9.9477	-11.6049	-1.1652	2.2168	0.4599	2.1506	-0.1598

Table 24: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	63.992	47.9954	53.3698	-15.7612	18.6648	-16.644	8.7616
Fy Robot	110.26	-76.2628	-22.1929	32.115	-37.5751	-3.0918	-17.2741	-7.637
Fz Robot	0	-0.3322	-63.1166	17.2381	23.2588	25.2135	-2.4115	11.9851
Tx Robot	-41.34	-22.8354	-15.6581	3.8238	2.9838	-0.5528	-0.5477	-0.397
Ty Robot	0	-19.2045	-0.8587	-5.7291	0.1206	0.4131	0.2275	-0.7062
Tz Robot	-9.83	9.9477	-11.6049	-1.1652	2.2168	0.4599	2.1506	-0.1598

Table 25: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	0.0003	0.0001	-0.0002	-0.0002	0.0001	0	-0.0001
Fy Error	0.0025	0.0003	-0.0003	0.0001	0.0002	0	0	0
Fz Error	0	0	0.0002	0.0002	0.0001	-0.0001	0	0.0001
Tx Error	0.001	0.0001	0.0001	0	0.0001	0	0	0
Ty Error	0	0	0	0.0001	0	-0.0001	0	0
Tz Error	0.0008	0	0	0	0	0	0	0

Table 26: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	9.9477	-11.6049	-1.1652	2.2168	0.4599	2.1506	-0.1598
Tz PC	9.9477	-11.6049	-1.1652	2.2168	0.4599	2.1506	-0.1598

6.7 Test at robot configuration 7

Robot joint angles are [120 240.31 140.2 239.88 66.74 239.24 115.38];

Table 27: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	86.2253	35.8362	42.478	-14.5759	6.9247	-16.8131	1.2517
Fy PC	110.2625	-49.7617	-61.5774	-6.9454	-44.3036	-7.6567	-16.246	12.2517
Fz PC	0	-0.264	-41.2769	48.2103	-5.0994	29.7839	-5.884	11.2721
Tx PC	-30.3916	-9.3939	-12.9911	-2.7305	-0.3795	-1.2322	-0.9727	1.1923
Ty PC	0	-16.364	-3.4497	-3.2327	-0.2291	1.8808	0.0918	-0.1012
Tz PC	-16.2528	16.3348	-6.1324	1.9402	3.0747	0.77	2.5258	-0.0224

Table 28: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	86.2251	35.8362	42.4782	-14.5758	6.9247	-16.813	1.2517
Fy Robot	110.26	-49.7621	-61.5771	-6.9456	-44.3036	-7.6566	-16.246	12.2516
Fz Robot	0	-0.264	-41.2772	48.2101	-5.0996	29.7839	-5.8839	11.2722
Tx Robot	-30.39	-9.3939	-12.9912	-2.7306	-0.3795	-1.2322	-0.9726	1.1923
Ty Robot	0	-16.364	-3.4498	-3.2327	-0.2291	1.8808	0.0918	-0.1012
Tz Robot	-16.25	16.3349	-6.1325	1.9402	3.0747	0.77	2.5258	-0.0224

6.8 Test at robot configuration 8

Robot joint angles are [285 113.25 129.73 289.67 7.89 195.54 83.44];

Table 29: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	0.0002	0	-0.0002	-0.0001	0	-0.0001	0
Fy Error	0.0025	0.0004	-0.0003	0.0002	0	-0.0001	0	0.0001
Fz Error	0	0	0.0003	0.0002	0.0002	0	-0.0001	-0.0001
Tx Error	-0.0016	0	0.0001	0.0001	0	0	-0.0001	0
Ty Error	0	0	0.0001	0	0	0	0	0
Tz Error	-0.0028	-0.0001	0.0001	0	0	0	0	0

Table 30: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	16.3349	-6.1325	1.9402	3.0747	0.77	2.5258	-0.0224
Tz PC	16.3348	-6.1324	1.9402	3.0747	0.77	2.5258	-0.0224

Table 31: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	-96.1578	-31.4516	-28.5746	-32.4121	22.0986	20.8636	2.1752
Fy PC	110.2625	25.781	-73.0478	-8.1046	33.4107	0.9281	12.0613	-14.2654
Fz PC	0	-0.3338	21.3213	57.3991	-5.8692	-22.4598	0.6845	-8.3964
Tx PC	-41.6081	7.7879	9.1282	-4.167	-0.7283	0.177	0.1257	-1.3021
Ty PC	0	29.1016	1.23	15.2767	1.2336	-5.1055	-0.0441	-0.175
Tz PC	-4.0651	4.1846	17.6793	0.0826	11.0443	-0.0368	-3.0544	-0.04

Table 32: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	-96.1578	-31.4521	-28.5749	-32.4118	22.0984	20.8635	2.1753
Fy Robot	110.26	25.7811	-73.0476	-8.1049	33.411	0.9283	12.0615	-14.2653
Fz Robot	0	-0.3338	21.3213	57.399	-5.8694	-22.46	0.6846	-8.3965
Tx Robot	-41.61	7.788	9.1282	-4.167	-0.7283	0.177	0.1257	-1.3021
Ty Robot	0	29.1016	1.23	15.2766	1.2336	-5.1054	-0.044	-0.175
Tz Robot	-4.07	4.1846	17.6794	0.0827	11.0442	-0.0368	-3.0543	-0.04

Table 33: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	0	0.0005	0.0003	-0.0003	0.0002	0.0001	-0.0001
Fy Error	0.0025	-0.0001	-0.0002	0.0003	-0.0003	-0.0002	-0.0002	-0.0001
Fz Error	0	0	0	0.0001	0.0002	0.0002	-0.0001	0.0001
Tx Error	0.0019	-0.0001	0	0	0	0	0	0
Ty Error	0	0	0	0.0001	0	-0.0001	-0.0001	0
Tz Error	0.0049	0	-0.0001	-0.0001	0.0001	0	-0.0001	0

Table 34: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	4.1846	17.6794	0.0827	11.0442	-0.0368	-3.0543	-0.04
Tz PC	4.1846	17.6793	0.0826	11.0443	-0.0368	-3.0544	-0.04

6.9 Test at robot configuration 9

Robot joint angles are [285 121.22 234.46 131.94 356.65 77.01 227.27];

Table 35: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	-96.1574	-41.2146	-5.0225	26.6124	-16.9103	17.1159	-0.8903
Fy PC	110.2625	25.7831	-68.0213	35.9412	-28.4942	-18.5851	-9.3113	15.3887
Fz PC	0	-0.2874	21.3131	53.4776	26.0985	19.0339	-14.1978	6.4129
Tx PC	-34.1627	5.8654	7.4623	7.6988	5.1056	-1.2814	-2.0967	1.3565
Ty PC	0	21.9116	-1.2347	-3.3496	1.0156	-0.9022	-0.0791	0.0715
Tz PC	-3.2104	3.3051	10.4899	2.9742	-4.0973	-2.0193	-2.4758	0.0167

Table 36: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	-96.1574	-41.2149	-5.0226	26.6123	-16.9102	17.1159	-0.8902
Fy Robot	110.26	25.7832	-68.0211	35.9414	-28.4941	-18.5852	-9.3112	15.3887
Fz Robot	0	-0.2874	21.3132	53.4775	26.0987	19.0339	-14.1979	6.4129
Tx Robot	-34.16	5.8654	7.4623	7.6988	5.1056	-1.2814	-2.0967	1.3565
Ty Robot	0	21.9117	-1.2347	-3.3496	1.0156	-0.9021	-0.0791	0.0715
Tz Robot	-3.21	3.3051	10.49	2.9743	-4.0973	-2.0194	-2.4758	0.0167

Table 37: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	0	0.0003	0.0001	0.0001	-0.0001	0	-0.0001
Fy Error	0.0025	-0.0001	-0.0002	-0.0002	-0.0001	0.0001	-0.0001	0
Fz Error	0	0	-0.0001	0.0001	-0.0002	0	0.0001	0
Tx Error	-0.0027	0	0	0	0	0	0	0
Ty Error	0	-0.0001	0	0	0	-0.0001	0	0
Tz Error	-0.0004	0	-0.0001	-0.0001	0	0.0001	0	0

6.10 Test at robot configuration 10

Robot joint angles are [340 141.74 22.27 67.95 16.12 61.73 153.11];

Table 38: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	3.3051	10.49	2.9743	-4.0973	-2.0194	-2.4758	0.0167
Tz PC	3.3051	10.4899	2.9742	-4.0973	-2.0193	-2.4758	0.0167

Table 39: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	-34.028	-22.2479	-6.9219	11.0114	1.5046	-0.1335	7.6796
Fy PC	110.2625	93.5578	-17.2923	-62.8097	-0.9614	31.4799	1.3078	-14.7976
Fz PC	0	-0.366	77.3679	13.5602	-45.5971	0.6355	24.0729	-0.8873
Tx PC	-46.774	33.173	18.9244	-9.2615	-9.897	1.4357	3.3758	-1.2082
Ty PC	0	12.0708	11.6219	-1.2932	-3.4205	-0.1297	0.1322	-0.6186
Tz PC	-1.2363	1.373	8.0395	-10.7176	-2.3179	3.0274	0.0115	-0.1403

Table 40: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	-34.028	-22.248	-6.9217	11.0113	1.5047	-0.1337	7.6797
Fy Robot	110.26	93.5578	-17.2922	-62.8098	-0.9613	31.4799	1.3078	-14.7975
Fz Robot	0	-0.366	77.3679	13.5601	-45.5971	0.6354	24.0729	-0.8873
Tx Robot	-46.77	33.173	18.9244	-9.2615	-9.897	1.4357	3.3758	-1.2082
Ty Robot	0	12.0708	11.6219	-1.2932	-3.4205	-0.1297	0.1322	-0.6186
Tz Robot	-1.24	1.373	8.0395	-10.7176	-2.3179	3.0274	0.0116	-0.1403

Table 41: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	0	0.0001	-0.0002	0.0001	-0.0001	0.0002	-0.0001
Fy Error	0.0025	0	-0.0001	0.0001	-0.0001	0	0	-0.0001
Fz Error	0	0	0	0.0001	0	0.0001	0	0
Tx Error	-0.004	0	0	0	0	0	0	0
Ty Error	0	0	0	0	0	0	0	0
Tz Error	0.0037	0	0	0	0	0	-0.0001	0

Table 42: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	1.373	8.0395	-10.7176	-2.3179	3.0274	0.0116	-0.1403
Tz PC	1.373	8.0395	-10.7176	-2.3179	3.0274	0.0115	-0.1403

6.11 Test at robot configuration 11

Robot joint angles are [180 180 180 180 180 180 180];

Table 43: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	-0.0279	0.0299	-0.0988	-0.1413	-0.1645	-0.1811	0.0639
Fy PC	110.2625	-99.5535	0.5215	-64.6257	0.488	-31.5199	0.2801	16.694
Fz PC	0	-0.449	-82.3378	-0.6051	-46.9149	-0.3527	-24.1065	-0.1898
Tx PC	-60.0957	-48.6286	-36.8271	-24.5641	-14.9518	-6.2864	-3.356	1.3414
Ty PC	0	0.0154	0.2276	0.0388	0.0505	0.033	0.0099	-0.0051
Tz PC	0.579	-0.3978	-0.0119	-0.1339	0.0456	-0.0191	0.0253	-0.0007

Table 44: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	-0.0278	0.0299	-0.0988	-0.1413	-0.1645	-0.1811	0.0639
Fy Robot	110.26	-99.5535	0.5215	-64.6257	0.488	-31.5199	0.2801	16.694
Fz Robot	0	-0.449	-82.3378	-0.6051	-46.915	-0.3527	-24.1065	-0.1898
Tx Robot	-60.1	-48.6286	-36.8271	-24.5641	-14.9518	-6.2864	-3.356	1.3414
Ty Robot	0	0.0154	0.2275	0.0388	0.0505	0.033	0.0099	-0.0051
Tz Robot	0.58	-0.3977	-0.0119	-0.1339	0.0455	-0.0191	0.0253	-0.0007

Table 45: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	-0.0001	0	0	0	0	0	0
Fy Error	0.0025	0	0	0	0	0	0	0
Fz Error	0	0	0	0	0.0001	0	0	0
Tx Error	0.0043	0	0	0	0	0	0	0
Ty Error	0	0	0.0001	0	0	0	0	0
Tz Error	-0.001	-0.0001	0	0	0.0001	0	0	0

Table 46: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	-0.3977	-0.0119	-0.1339	0.0455	-0.0191	0.0253	-0.0007
Tz PC	-0.3978	-0.0119	-0.1339	0.0456	-0.0191	0.0253	-0.0007

6.12 Test at robot configuration 12

Robot joint angles are [270 180 180 180 180 180 180];

6.13 Test at robot configuration 13

Robot joint angles are [180 180 180 180 180 90 180];

Table 47: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	-99.5535	-82.3389	-64.6286	-46.9173	-31.5221	-24.108	16.6946
Fy PC	110.2625	0.0583	0.26	-0.0495	-0.2017	0.0631	-0.1638	-0.0082
Fz PC	0	-0.4491	-0.1382	-0.0258	0.0248	0.0738	0.1018	0.1434
Tx PC	-60.138	0.0816	-0.0371	-0.0171	-0.001	0.0118	0.0115	0.002
Ty PC	0	48.7087	7.8676	24.6098	2.0661	6.2903	0.4008	-1.3449
Tz PC	11.9388	-11.7573	36.8944	-4.3307	14.9749	-0.3345	3.3607	-0.304

Table 48: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	-99.5535	-82.3389	-64.6286	-46.9173	-31.5221	-24.108	16.6946
Fy Robot	110.26	0.058	0.2609	-0.0489	-0.2009	0.0629	-0.1634	-0.0081
Fz Robot	0	-0.4491	-0.1385	-0.0265	0.0246	0.0773	0.1017	0.1431
Tx Robot	-60.14	0.0814	-0.0371	-0.0172	-0.001	0.0118	0.0115	0.002
Ty Robot	0	48.7087	7.8676	24.6098	2.0661	6.2903	0.4008	-1.3449
Tz Robot	11.94	-11.7573	36.8944	-4.3307	14.9749	-0.3345	3.3607	-0.304

Table 49: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	0	0	0	0	0	0	0
Fy Error	0.0025	0.0003	-0.0009	-0.0006	-0.0008	0.0002	-0.0004	-0.0001
Fz Error	0	0	0.0003	0.0007	0.0002	-0.0035	0.0001	0.0003
Tx Error	0.002	0.0002	0	0.0001	0	0	0	0
Ty Error	0	0	0	0	0	0	0	0
Tz Error	-0.0012	0	0	0	0	0	0	0

Table 50: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	-11.7573	36.8944	-4.3307	14.9749	-0.3345	3.3607	-0.304
Tz PC	-11.7573	36.8944	-4.3307	14.9749	-0.3345	3.3607	-0.304

Table 51: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	-0.0366	0.0609	-0.0477	-0.099	-0.0987	-0.2519	0.1123
Fy PC	110.2625	-99.5536	0.4979	-64.626	0.4579	-31.5206	-0.1215	16.6946
Fz PC	0	-0.4276	-82.3379	-0.5707	-46.9154	-0.3107	-24.1071	0.0885
Tx PC	-56.6655	-45.2094	-33.4211	-21.1663	-11.5694	-2.909	-3.3628	1.3465
Ty PC	0	0.0325	3.5325	0.0461	3.3854	0.0422	0.0111	-0.009
Tz PC	3.8584	-3.6885	-0.0034	-3.4498	0.0575	-3.3618	0.0351	-0.0015

Table 52: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	-0.0365	0.061	-0.0476	-0.0989	-0.0986	-0.2519	0.1123
Fy Robot	110.26	-99.5536	0.4979	-64.626	0.4579	-31.5206	-0.1215	16.6946
Fz Robot	0	-0.4276	-82.3379	-0.5707	-46.9154	-0.3107	-24.1071	0.0884
Tx Robot	-56.67	-45.2094	-33.4211	-21.1663	-11.5694	-2.909	-3.3628	1.3465
Ty Robot	0	0.0324	3.5325	0.046	3.3854	0.0422	0.0111	-0.009
Tz Robot	3.86	-3.6885	-0.0034	-3.4498	0.0574	-3.3618	0.0351	-0.0015

Table 53: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	0	0
Fy Error	0.0025	0	0	0	0	0	0	0
Fz Error	0	0	0	0	0	0	0	0.0001
Tx Error	0.0045	0	0	0	0	0	0	0
Ty Error	0	0.0001	0	0.0001	0	0	0	0
Tz Error	-0.0016	0	0	0	0.0001	0	0	0

Table 54: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	-3.6885	-0.0034	-3.4498	0.0574	-3.3618	0.0351	-0.0015
Tz PC	-3.6885	-0.0034	-3.4498	0.0575	-3.3618	0.0351	-0.0015

6.14 Test at robot configuration 14

Robot joint angles are [180 180 180 90 180 180 180];

Table 55: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	-0.0669	0.1689	0.13	-0.3544	-0.307	-0.2894	0.1385
Fy PC	110.2625	-99.5539	0.4165	-64.6269	0.048	-31.5207	0.0536	16.6946
Fz PC	0	-0.354	-82.3382	-0.4524	-46.9163	-0.057	-24.107	-0.0327
Tx PC	-44.8698	-33.4516	-21.7091	-9.4833	-14.9718	-6.2897	-3.3598	1.3443
Ty PC	0	0.0762	15.016	0.0857	0.0599	0.0613	0.0117	-0.0112
Tz PC	15.2538	-15.1232	0.0314	-14.9708	0.1131	-0.0206	0.0404	-0.002

6.15 Test at robot configuration 15

Robot joint angles are [180 90 180 180 180 180 180];

Table 56: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	-0.0665	0.1692	0.1305	-0.3544	-0.307	-0.2894	0.1385
Fy Robot	110.26	-99.5539	0.4165	-64.6269	0.0483	-31.5207	0.0538	16.6946
Fz Robot	0	-0.354	-82.3382	-0.4524	-46.9163	-0.0572	-24.107	-0.0328
Tx Robot	-44.87	-33.4516	-21.7091	-9.4833	-14.9718	-6.2897	-3.3598	1.3443
Ty Robot	0	0.0761	15.0159	0.0857	0.0599	0.0613	0.0117	-0.0112
Tz Robot	15.25	-15.1231	0.0314	-14.9708	0.1131	-0.0206	0.0404	-0.002

Table 57: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	-0.0004	-0.0003	-0.0005	0	0	0	0
Fy Error	0.0025	0	0	0	-0.0003	0	-0.0002	0
Fz Error	0	0	0	0	0	0.0002	0	0.0001
Tx Error	0.0002	0	0	0	0	0	0	0
Ty Error	0	0.0001	0.0001	0	0	0	0	0
Tz Error	0.0038	-0.0001	0	0	0	0	0	0

Table 58: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	-15.1231	0.0314	-14.9708	0.1131	-0.0206	0.0404	-0.002
Tz PC	-15.1232	0.0314	-14.9708	0.1131	-0.0206	0.0404	-0.002

Table 59: Joint wrench obtained from PC (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx PC	0	-0.1244	-0.264	-0.3289	-0.3079	-0.2762	-0.2664	0.1229
Fy PC	110.2625	-99.5542	0.3741	-64.6259	0.4028	-31.5197	0.2359	16.694
Fz PC	0	-0.2159	-82.3382	-0.4888	-46.915	-0.2953	-24.1061	-0.159
Tx PC	-22.7448	-11.3989	-36.8419	-24.5722	-14.9556	-6.287	-3.3567	1.342
Ty PC	0	0.0942	0.2564	0.1262	0.0578	0.0553	0.0113	-0.0099
Tz PC	36.9146	-36.8576	0.1193	-0.15	0.0986	-0.0203	0.0372	-0.0017

Table 60: Joint wrench obtained from Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Robot	0	-0.1233	-0.264	-0.329	-0.3079	-0.2762	-0.2664	0.1229
Fy Robot	110.26	-99.5542	0.3751	-64.6259	0.4033	-31.5197	0.2362	16.694
Fz Robot	0	-0.2159	-82.3382	-0.4896	-46.915	-0.2956	-24.1061	-0.1592
Tx Robot	-22.74	-11.3989	-36.8418	-24.5722	-14.9556	-6.287	-3.3567	1.342
Ty Robot	0	0.094	0.2564	0.1262	0.0578	0.0553	0.0113	-0.0099
Tz Robot	36.91	-36.8574	0.1193	-0.15	0.0987	-0.0203	0.0372	-0.0017

Table 61: Joint wrench error between data from PC and Robot (N/Nm)

	Base	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Fx Error	0	-0.0011	0	0.0001	0	0	0	0
Fy Error	0.0025	0	-0.001	0	-0.0005	0	-0.0003	0
Fz Error	0	0	0	0.0008	0	0.0003	0	0.0002
Tx Error	-0.0048	0	-0.0001	0	0	0	0	0
Ty Error	0	0.0002	0	0	0	0	0	0
Tz Error	0.0046	-0.0002	0	0	-0.0001	0	0	0

Table 62: Joint torque along axis comparison with sensor data (Nm)

	Joint1	Joint2	Joint3	Joint4	Joint5	Joint6	Joint7
Tz Sensor	0	0	0	0	0	0	0
Tz Robot	-36.8574	0.1193	-0.15	0.0987	-0.0203	0.0372	-0.0017
Tz PC	-36.8576	0.1193	-0.15	0.0986	-0.0203	0.0372	-0.0017