PERFORMANCE TEST REPORT OF MIRO SURGICAL ROBOT @dlr

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Contents

Chapter 1

MIRO Medical Robot

1.1 Overview of the MIRO

The lightweight robot MIRO is the second prototype of medical robots developed at the German Aerospace Center (DLR). Its anthropomorphic design and the integrated torque sensors with the control approaches which enable an intuitive handling of the robot 1.1 reffig:MIRO. The MIRO has been specialized for various applications in the medical field, such as autonomously rather semi autonomously performing biopsies, guiding laser units in osteotomy, or as a telepresence application for minimally invasive robotic surgery (MIRS), next to open surgery.

1.2 Specifications of the MIRO

This makes the MIRO robot easily adaptable to the operating room, where space is sparse anyway. Due to the compactness of the MIRO robot, its low weight of 9.8 kg and the integration of motors and electronics into the robot structure, it is feasible to place a variable amount of robots in the operating room wherever free space occurs, e.g. directly on the operating table, the ceiling or mobile tripods.

The following list summarizes the key features of the DLR MIRO robot:

- Lightweight robot with approximately 9.8 kg.
- 7 DoF kinematics specialized for versatile applications in the medical field.

Figure 1.1: The medical lightweight robot MIRO

- Anthropomorphic design for intuitive handling
- Integration of motors and electronics within the mechanical structure
- Contains position and torque sensors in each joint.
- Small footprint enables an easy adaptability to the crowded OR

Chapter 2

Introduction of Performance Criteria-(ISO 9283)

2.1 ISO 9283

ISO 9283 is part of a series of International Standards dealing with manipulating industrial robots. Other International Standards cover such topics as safety, general characteristics, coordinate systems, terminology, and mechanical interfaces. It is noted that these International Standards are interrelated and also related to other International Standards.
ISO 9283 is intended to facilitate understanding between users and manufacturers of robots and robot systems. It defines the important performance characteristics, describes how they shall be specified and recommends how they should be tested.
The characteristics for which test methods are given in this International Standard are those considered to affect robot performance significantly. It is intended that the user of this International Standard selects which performance characteristics are to be tested, in accordance with his own specific requirements.
The tests described in this International Standard may be applied in whole or in part, depending upon the robot type and requirements.

2.2 Manipulating Light Weight Industrial Robots - Performance Criteria

The **ISO 9283** describes methods of specifying and testing the following performance characteristics of manipulating industrial robots:

- Pose accuracy and pose repeatability;
- Multi-directional pose accuracy variation;
- Distance accuracy and distance repeatability;
- Position stabilization time;
- Position overshoot;
- Drift of pose characteristics;
- Exchangeability;
- Path accuracy and path repeatability;
- Path accuracy on reorientation
- Cornering deviations;
- Path velocity characteristics;
- Minimum posing time;
- Static compliance;
- Weaving deviations.

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This International Standard does not specify which of the above performance characteristics are to be chosen for testing a particular robot. The tests described in this International Standard are primarily intended for developing and verifying individual robot specifications, but can also be used for such purposes as prototype testing, type testing or acceptance testing.
To compare performance characteristics between different robots, as defined in this International Standard, the following parameters have to be the same: test cube sizes, test loads, test velocities, test paths, test cycles, environmental conditions.
This International Standard applies to all manipulating industrial robots as defined in ISO 8373. However, for the purpose of this International Standard the term "robot" means manipulating industrial robot.

2.2.1 Performance Test Methods Conducted in Report

Due to the limitations of resources, the report has eliminated the exchangeability tests in performance criteria. However, the following tests are conducted and explained its characteristics in this report.

- Pose accuracy and Pose repeatability.
- Multi-directional Pose accuracy variation.
- Distance accuracy and Distance repeatability.
- Position stabilization time.
- Path accuracy and Path repeatability.
- Path accuracy at reorientation.
- Cornering deviations
- Path velocity characteristics .

2.2.2 Cube size and specifications

In this section the used cube is clearly explained with its specifications like cube input, cube output and all, the 8 corners points are used in the performance test. The cube specifications are given as following:
The eight (8) corners are given as

$$C_{x,y,z} = \begin{bmatrix} 0.6500 & 0.6500 & 0.5000 & 0.5000 & 0.6500 & 0.6500 & 0.5000 & 0.5000 \\ 0.0750 & -0.0750 & -0.0750 & 0.0750 & 0.0750 & -0.0750 & -0.0750 & 0.0750 \\ 0.6400 & 0.6400 & 0.6400 & 0.6400 & 0.4900 & 0.4900 & 0.4900 & 0.4900 \end{bmatrix}$$

The cube input and out point values are stated below:

$$P_{in} = [0.500000.5650]$$

$$P_{out_{final}} = [0.650000.5650]$$

The cube is located in the workspace with the following requirements:

- The cube shall be totally located the portion of the working space with the greatest anticipated use.

- The cube shall has the maximum volume allowable with edges parallel to the base coordinate frame.

2.2.3 Tested Poses

The total test poses are selected in this report are nine (9). In these 9 points, five measurement points are located on the diagonals of measuring plane and corresponding to (P_1) to (P_5) in the selected plane. The points (P_1) to (P_5) are the positions for the wrist reference point of the robot. The measurement plane is parallel to the selected plane.
Command Pose: The command pose is given through teach programming or numerical data entry through manual data input or off-line programming.
Attained pose: The pose achieved by the robot under automatic mode in response to the given command pose.

Command poses are given below:

$$P_{x,y,z} = \begin{bmatrix} 0.5750 & 0.6350 & 0.6350 & 0.5150 & 0.5150 & 0.5750 & 0.5750 & 0.5750 & 0.5750 \\ 0 & 0.0600 & -0.0600 & -0.0600 & 0.0600 & 0.0600 & 0.0300 & -0.0300 & -0.0600 \\ 0.5650 & 0.6250 & 0.6250 & 0.5050 & 0.5050 & 0.5650 & 0.5650 & 0.5650 & 0.5650 \end{bmatrix}$$

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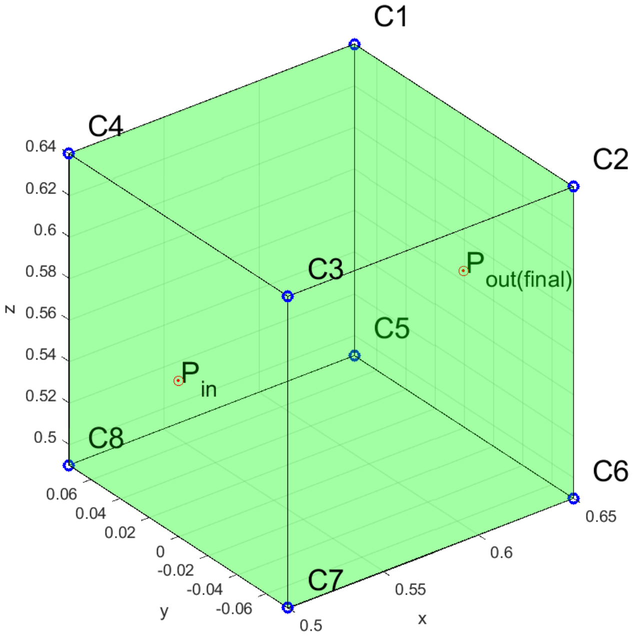

Figure 2.1: The 8 corners in the tested cube

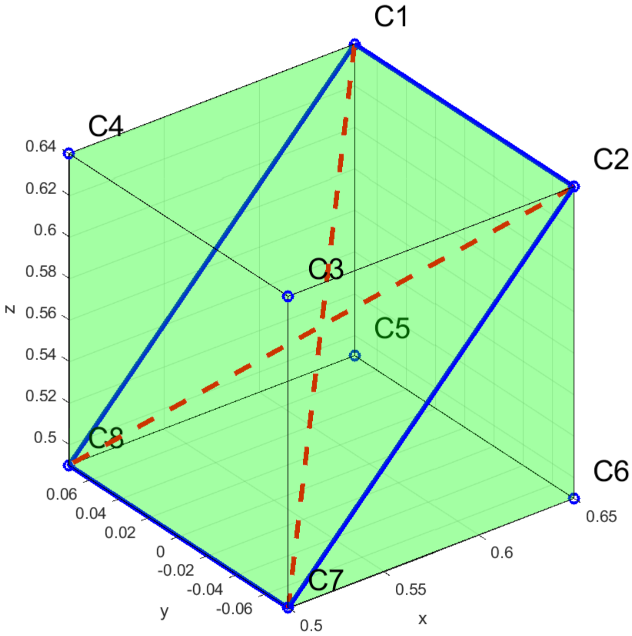

Figure 2.2: The command poses are selected in diagonals in the tested cube

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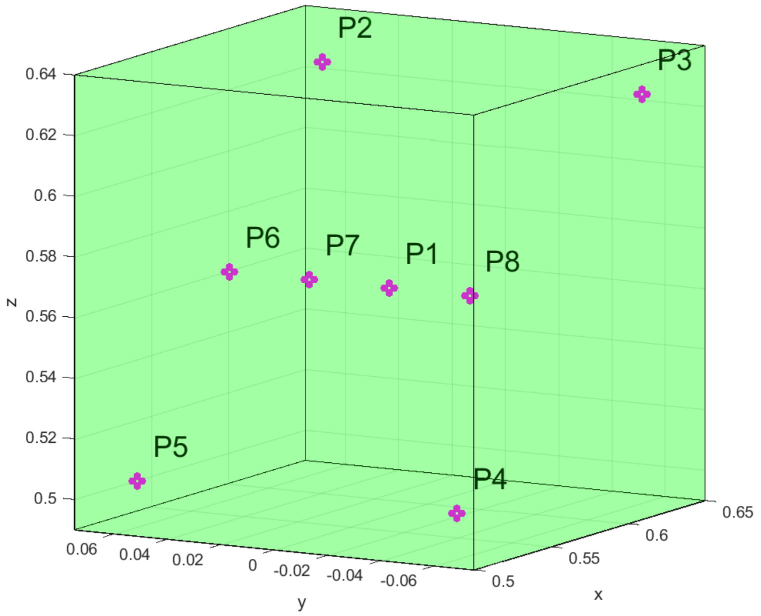

Figure 2.3: The selected poses in the given cube

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For more information of the selected plane in the tested cube 5

2.2.4 Shapes used in this report for elaborating test characteristics

The Sphere and Cone is mainly used in this report and these visual information is clearly stated in the Appendix. Chap. 5 in following section. 4.1.1

Chapter 3

Robotic System

3.1 Details to be fill before performance test

Robot specifications

	values	**Remarks**
Manufacturer	DLR	medical purpose
Type	MIRO	light weight robot
Serial No	1	–
Model No	Miro123	new model
Mounting orientation	30 degree	approximately
Software version	Medview	new version
Programming method	matlab	–
TEST Location(SITE)	DLR wessling	medical laboratory

PHYSICAL ENVIRONMENT and GENERAL INFORMATION

	Enter the values	**Remarks**
Ambient temperature ($^{\circ}$)	25	room temperature
Abnormal conditions (see note)	normal	–
WARM-UP PERIOD	8 hours	night before
Measurement sampling rate	3 HZ	–
MEASURING TIME	10:00	German time
MEASURING DWELL (sec)	1	approximately
Date of the test	18/06/2017	monday
Tested conducted person	Julian	RMC employee

NOTE: comments on conditions not within expected limits.

INSTRUMENTATION & TEST CONDITIONS

	enter the values	Remarks
Type:	laser	–
Model No	Led123	–
Serial No	XYZ231	–
Comments:	better than previous one	
Load conditions:	2	
Mass (kg)	10	
Moments of interia (kg/m^2)	0.0123	
Position of center of gravity(L_x, L_y, L_z)	0.2 .03 .04	
Measurement point position (X_{MP}, Y_{MP}, Z_{MP})	5 9 7	

3.1.1 TESTS CONDUCTED ACCORDING TO ISO 9283

	Yes/NO
Pose accuracy	0
Pose repeatability	1
Multi-directional Pose reaccuracy variation	2
Distance accuracy and repeatability	3
Position stabilization time	4
Position overshoot	5
Drift of pose characteristics	6
Echangeability	7
Path accuracy and path repeatability	8
Path accuracy on reorientation	9
cornering deviations	10
Path velocity accuracy, repeatability and fluctuation	11
Minimum posing time	12
Static compliance	13
weaving deviations	14

Test Parameters

For detail load specification Location ID please go to the file in the following path 'bla bla'

	Load	Velocity	Control system	Friction Observer
slected type	MAM	1.125	PD control	with friction observer

Chapter 4

Performance Tests Criteria

4.1 Pose accuracy and Pose repeatability

Pose accuracy and repeatability characteristics are defined as the differences which occur between a commanded and attained pose, and the fluctuations in the attained poses for a series of repeat visits to a command pose.

4.1.1 Tables

Load 100% according to the heaviest taken from the table Appendix 5.
Velocity 100% and 50% according to the table Appendix.

Pose accuracy table

	AP_p	AP_a	AP_b	AP_c
P1	4.213	-0.06366	0.0015062	0.1776
P2	4.2474	-0.064326	-0.0019792	0.17785
P3	4.218	-0.091853	0.0031477	0.1803
P4	4.1687	-0.092012	-0.004288	0.18089
P5	4.267	-0.079604	0.0015605	0.18382
Max. Deviation	4.267	0.092012	0.004288	0.18382

Pose repeatability table

	RP_l	RP_a	RP_b	RP_c
P1	0.01997	0.0016842	0.0016842	0.0016842
P2	0.01641	0.0024517	0.0024517	0.0024517
P3	0.019204	0.0017323	0.0017323	0.0017323
P4	0.024668	0.0023662	0.0023662	0.0023662
P5	0.015261	0.0017133	0.0017133	0.0017133
Max. Deviation	0.024668	0.0024517	0.0024517	0.0024517

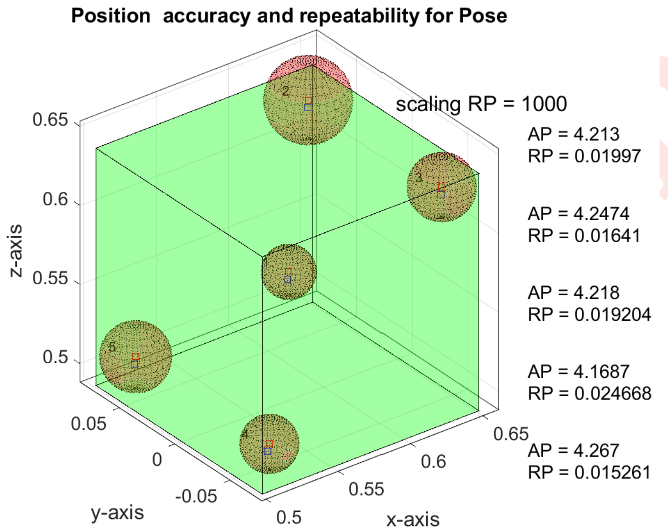

Figure 4.1: The position accuracy and repeatability for poses

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$'/home/dyav\_ra/public/ISOReportFigures/Tests/RP.fig'$

4.2 Multi-directional pose accuracy variavtion

The multi-directional pose accuracy variation expresses the deviation between the different mean attained poses achieved when visiting the same command pose **n** number time from three orthogonal directions.

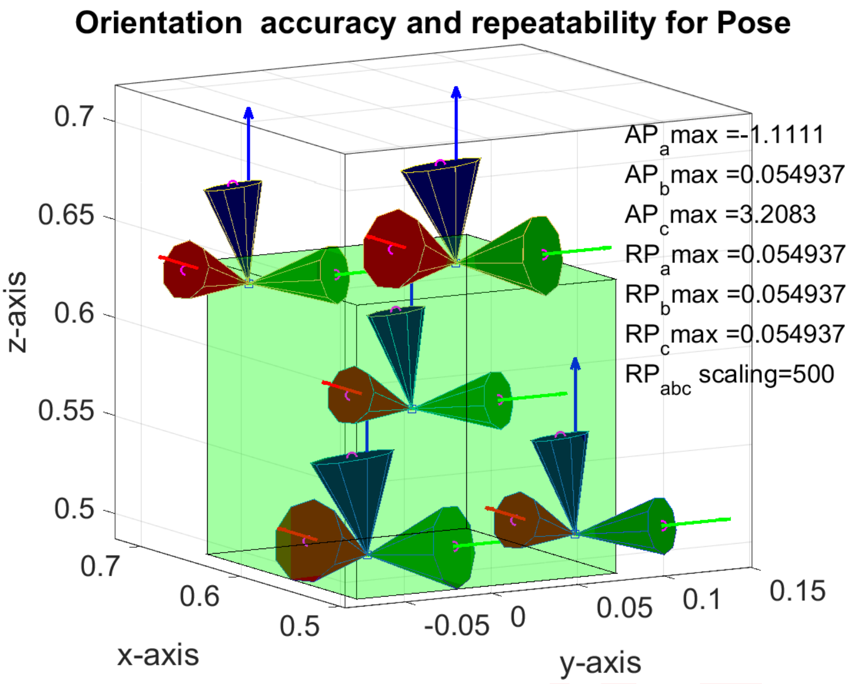

Figure 4.2: The orientation accuracy and repeatability for pose

	(P1,P2 and P4)
Max.Distace from different paths vAP_p	207.6785
Max.Deviation(a) vAP_a	0.028652
Max.Deviation(b) vAP_b	0.0055963
Max.Deviation(c) vAP_c	0.0040935

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4.3 Distance accuracy and repeatability

This section describes the deviations which occur with respect to the distance between two command poses and distance between the two attained poses for respective commanded poses.

4.3.1 Distance accuracy (AD)

The deviation in the positioning and orientation between the command distance and the mean of the attained distance.

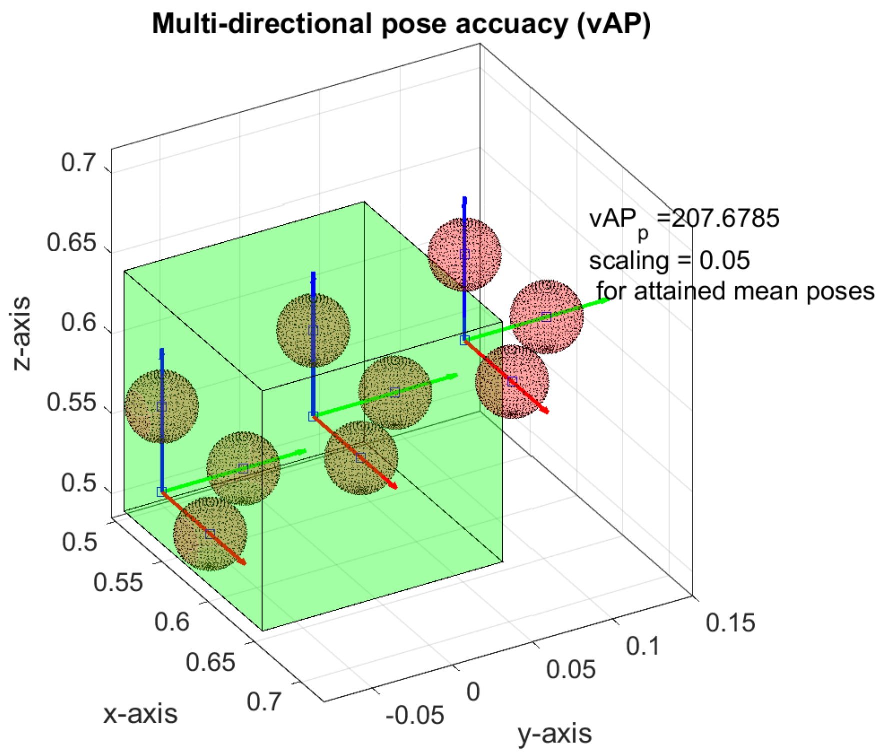

Figure 4.3: The path accuracy and repeatability

4.3.2 Distance repeatability (RD)

The closeness of agreement between the several attained distances for the same command distance after repeated **n** number of times in the same direction. Where **n** is the number of the measurement cycles.

	Distance betwwen two pose P2 —P4
Positioning Distace accuracy (P2,P4) AD_p	-0.20157
In X coordinate frame AD_x	-0.83082
In Y coordinate frame AD_y	0.26227
In Z coordinate frame AD_z	0.21623
Orientation dist. Acuuracy for AD_a	0.028406
Orientation dist. Acuuracy for AD_b	0.0049548
Orientation dist. Acuuracy for AD_c	0.0050249
Distance repeatability RD	0.051778
Orientation dist. Repeatability for RD_a	0.0080752
Orientation dist. Repeatability for RD_b	0.0097012
Orientation dist. Repeatability for RD_c	0.013714

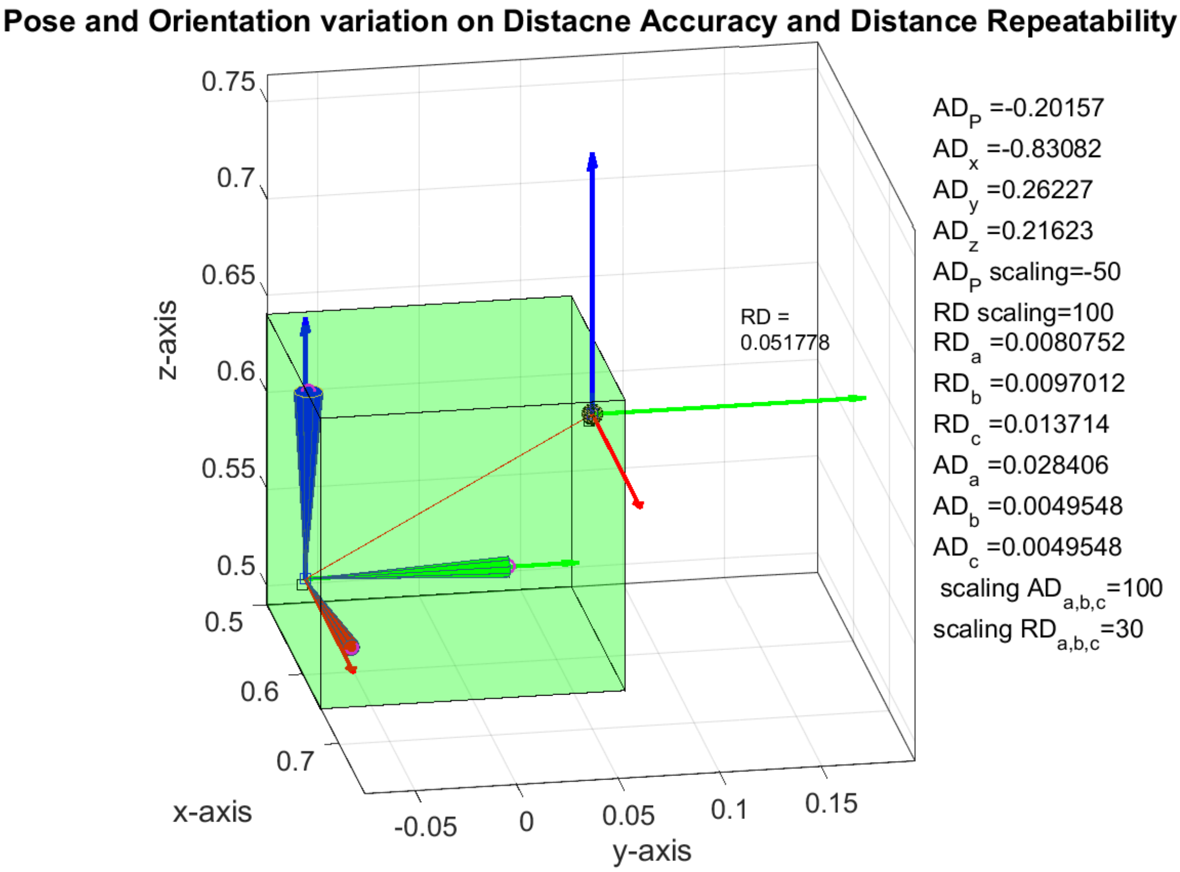

Figure 4.4: The position and orientation variation in distance accuracy and repeatability

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4.4 Position stabilization time

The position stabilization time is a robot performance which quantifies how quickly a robot can stop at the attained pose. It is also related to the overshoot and other performance parameters of robots.

	Pose P_1
stabilization time (t)	0.033633
position over shoot (OV)	4.1385e-05

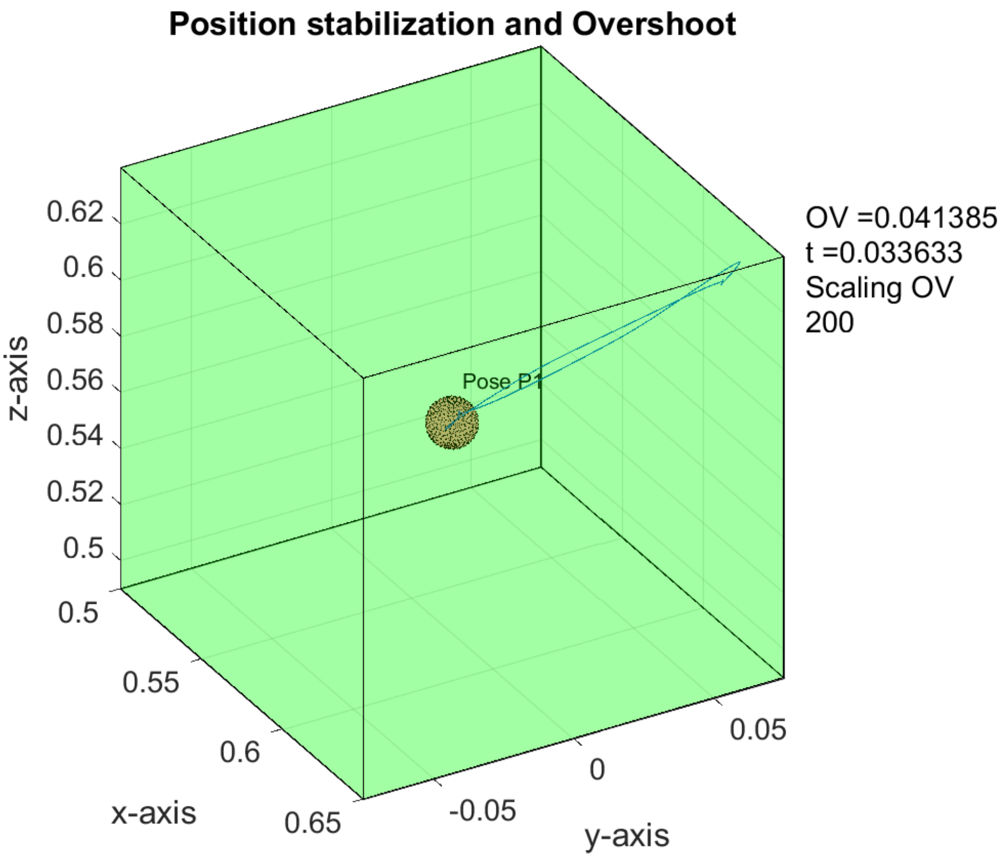

Figure 4.5: The postion stabilization time

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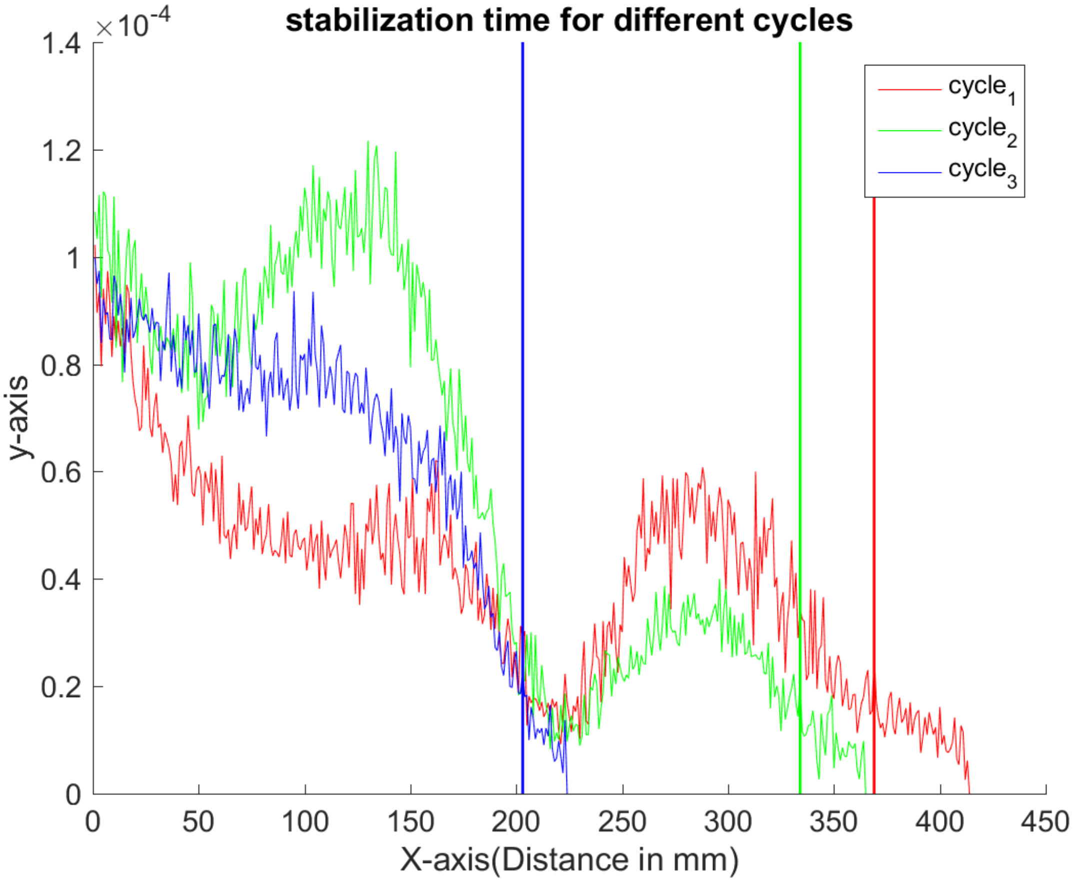

Figure 4.6: The time stabilization time

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4.5 Path characteristics

The path characteristics are described below by path accuracy and path repeatability.

4.5.1 Path accuracy (AT)

Path accuracy is the ability of arobot to move its mechanical interface along the command path in the same direction **n** times.

4.5.2 Path Repeatability

Path repeatability is the closeness of the agreement between the attained paths for the same command path repeated **n** times.

	Path Accuracy and Reatability
Path accuracy (P2,P4) AT_p	11.2109
Orientation accuarcy for AT_a	0.66558
Orientation accuarcy for AT_b	0.55648
Orientation accuarcy for AT_c	0.72432
Path Repeatability RT_p	0.095637
Orientation repeatability for RT_a	0.013106
Orientation repeatability for RT_b	0.028369
Orientation repeatability for RT_c	0.01563

The following three figure describe the path accuracy (AT), Path repeatability (RT) and the overview of the attained mean path in the closeness of the agreement between the attained paths for the same command when the path repeated **n** times.

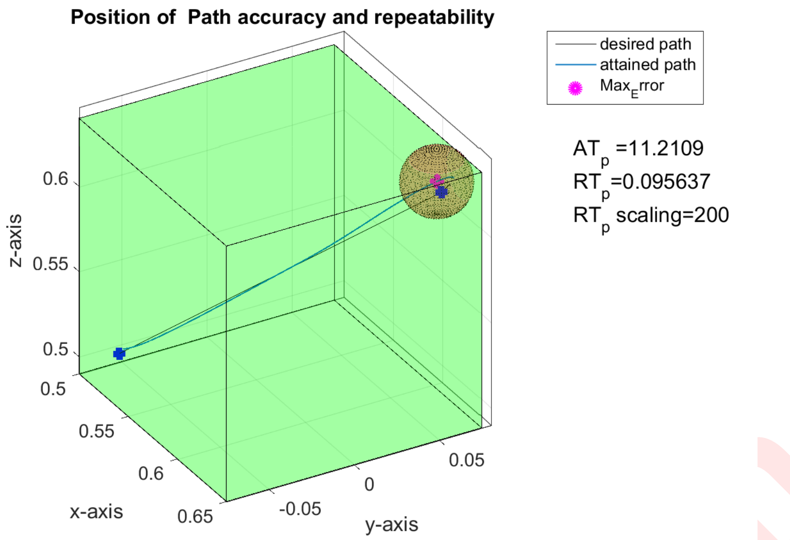

Figure 4.7: The path accuracy and repeatability

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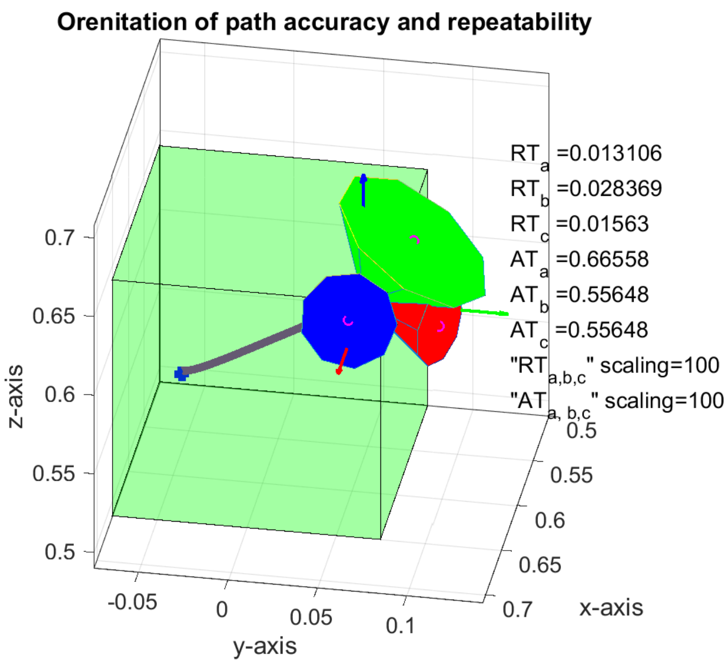

Figure 4.8: The Orientation of path accuracy and repeatability

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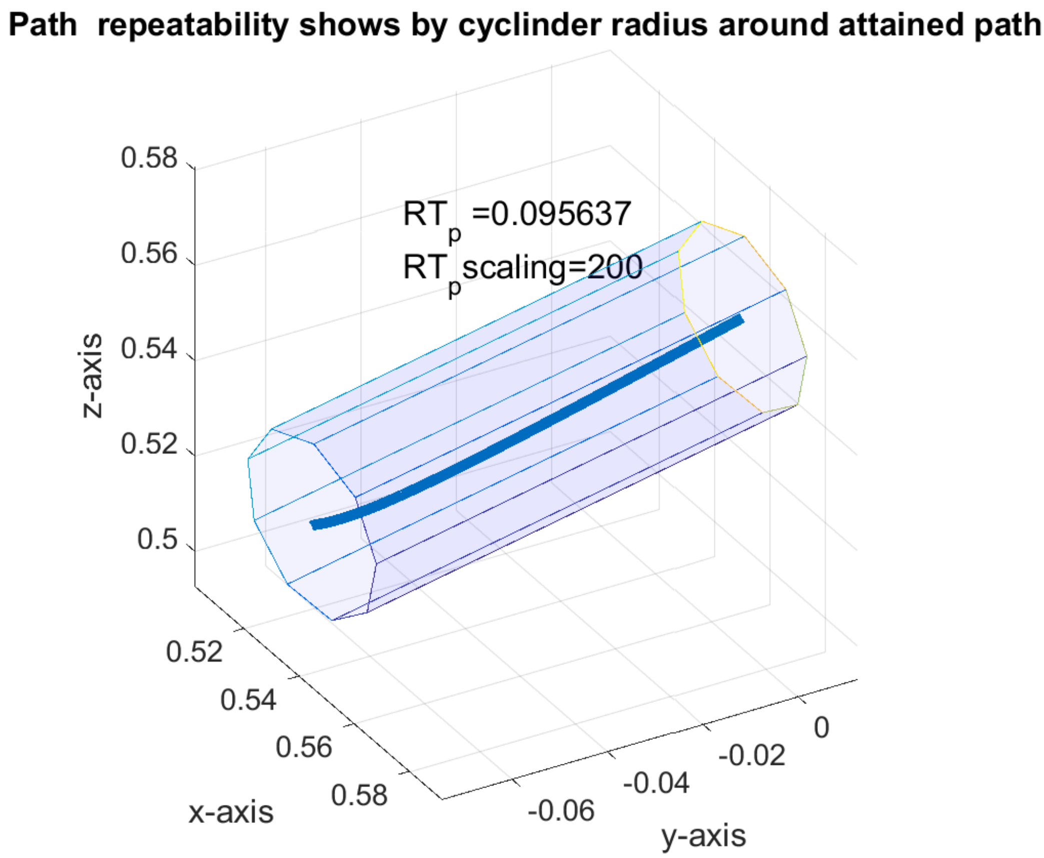

Figure 4.9: The total path repeatability in the cylinder

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4.6 Path Re-orientation

The influence of three-directional orientation alterations on a linear path in a simple way.

	Path Accuracy and Reatability
Path accuracy (P6,P1, P9) $AT_{p(Reorient)}$	8.5844
Orientation accuracy for $AT_{a(Reorient)}$	0.91578
Orientation accuracy for $AT_{b(Reorient)}$	0.16784
Orientation accuracy for $AT_{c(Reorient)}$	0.83006
Path Repeatability $RT_{p(Reorient)}$	0.13121
Oreintation repeatability for $RT_{a(Reorient)}$	0.015748
Oreintation repeatability for $RT_{b(Reorient)}$	0.026644
Oreintation repeatability for $RT_{c(Reorient)}$	0.022867

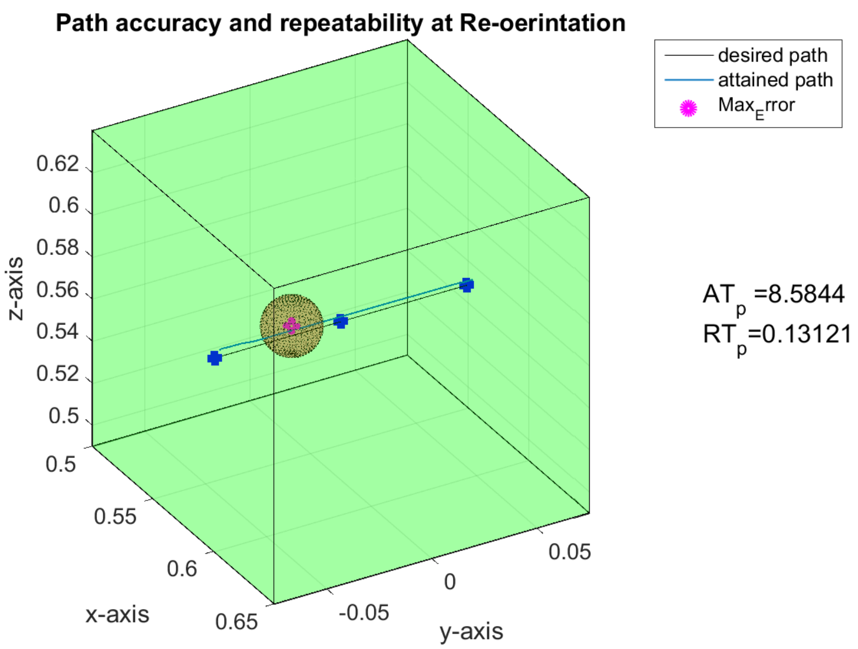

Figure 4.10: Pathh accuracy and repeatability on Re-oreintation

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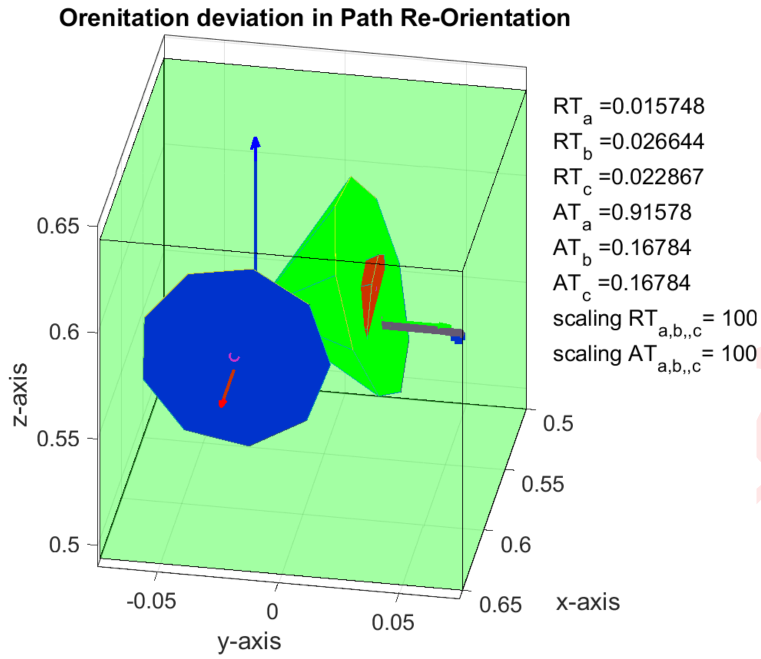

Figure 4.11: Oreintation deviations on path Re-orientation

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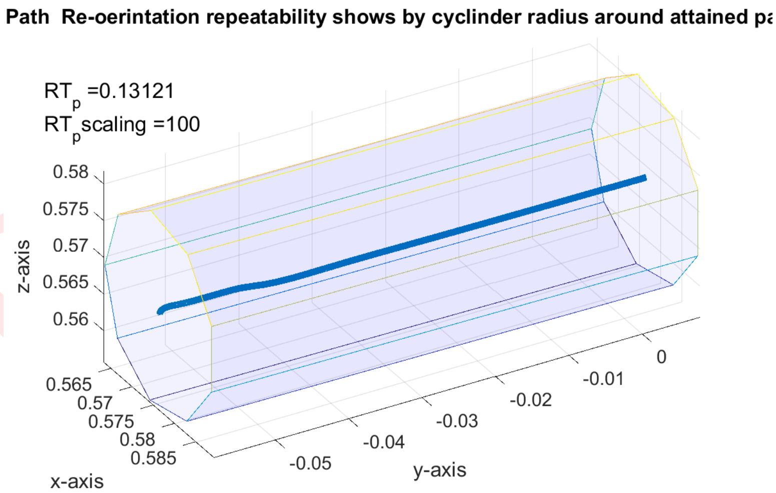

Figure 4.12: The attained mean path around the cylinder in Re-orientation

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4.7 Cornering deviations

Cornering deviations can be categorized in to two general types like sharp and rounded corners. Also, described in to two categories:

4.7.1 Cornering Round-off error (CR)

Cornering round-off error is defined as the maximum value calculated from three consecutive measurement cycles.

4.7.2 Cornering overshoot (CO)

Cornering overshoot is defined as the maximum value calculated from three consecutive measurement cycles.

	Path between P2 P3 P4 P5	
round off error (CR) **for pose P2 and P3**	3.9046	2.796
Max Overshoot (CO) **for Pose P2 and P3**	15.0646	0

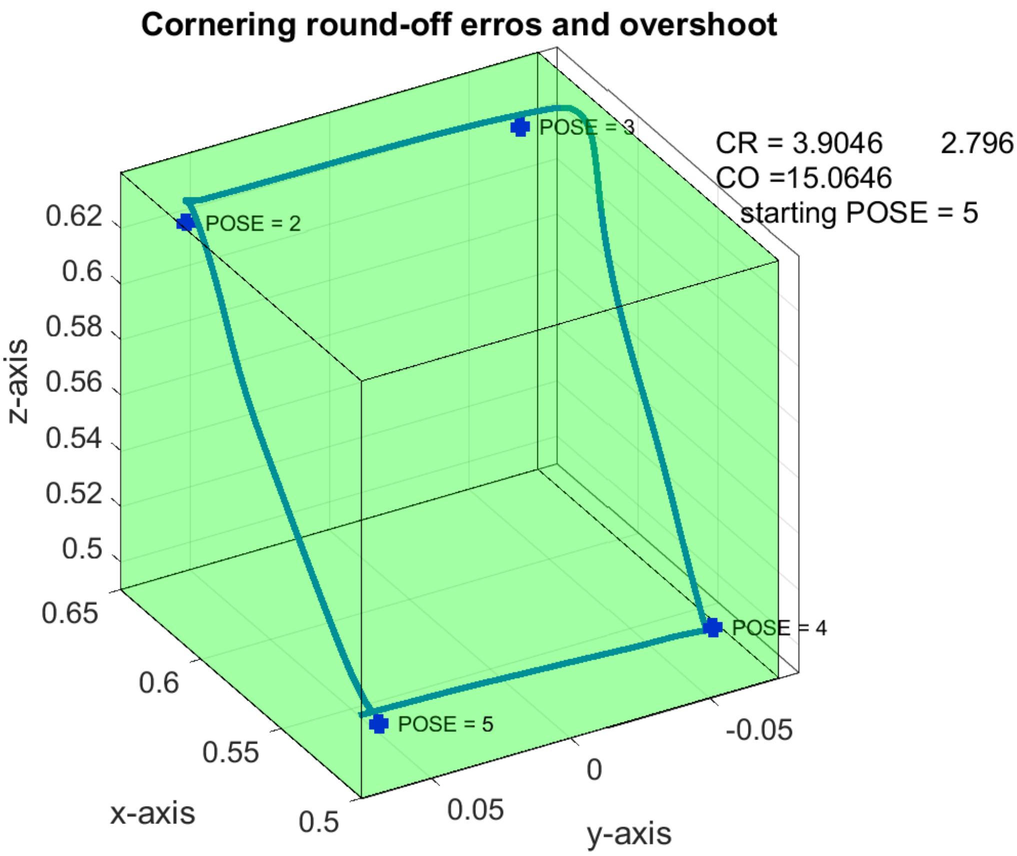

Figure 4.13: The path accuracy and repeatability

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4.8 Path Velocities

The performance characteristics of a robot with respect to path velocity is divided into three parts.

- Path velocity accuracy (AV).
- Path velocity repeatability (RV).
- Path velocity fluctuation (FV).

Path velocity accuracy (AV)

The path velocity accuracy is defined as the error between the command velocity and the mean value of the attained velocities achieved during **n** times along the path. It is expressed as a percentage of the command velocity.

Path velocity repeatability (RV)

The path velocity repeatability is the measured value of the closeness of agreement of the attained velocities for the same command velocity.

Path velocity fluctuation (FV)

The path velocity fluctuation is the maximum deviation in velocity during one replication with one command velocity.

	Path accuracy between P2 and P4
Path velocity accuarxy (AV)	8.8808
Path velocity repeatability (RV)	0.015367
Path velocity fluctuation (FV)	2.3665

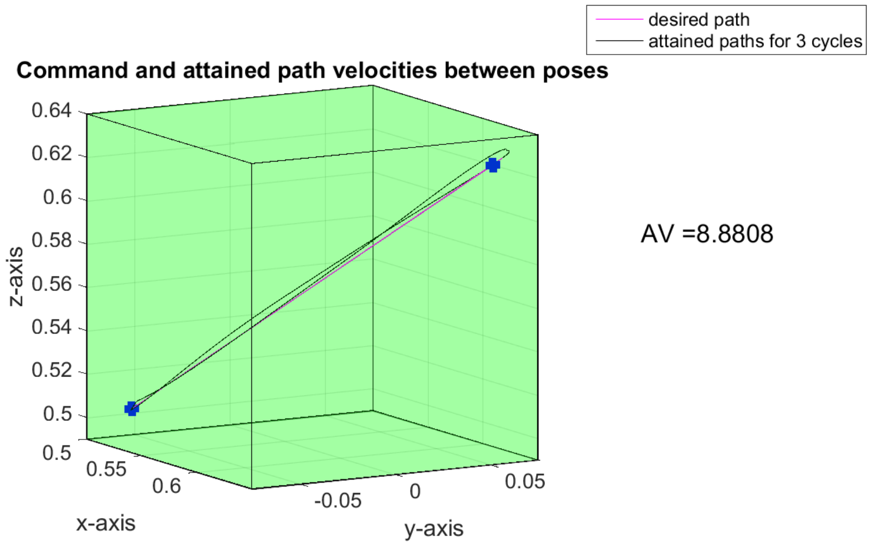

Figure 4.14: The path velocity between command poses

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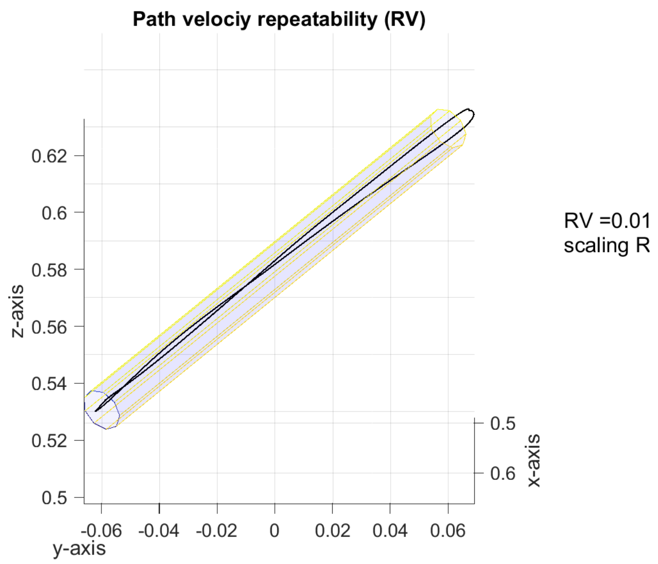

Figure 4.15: The path velocity repeatability

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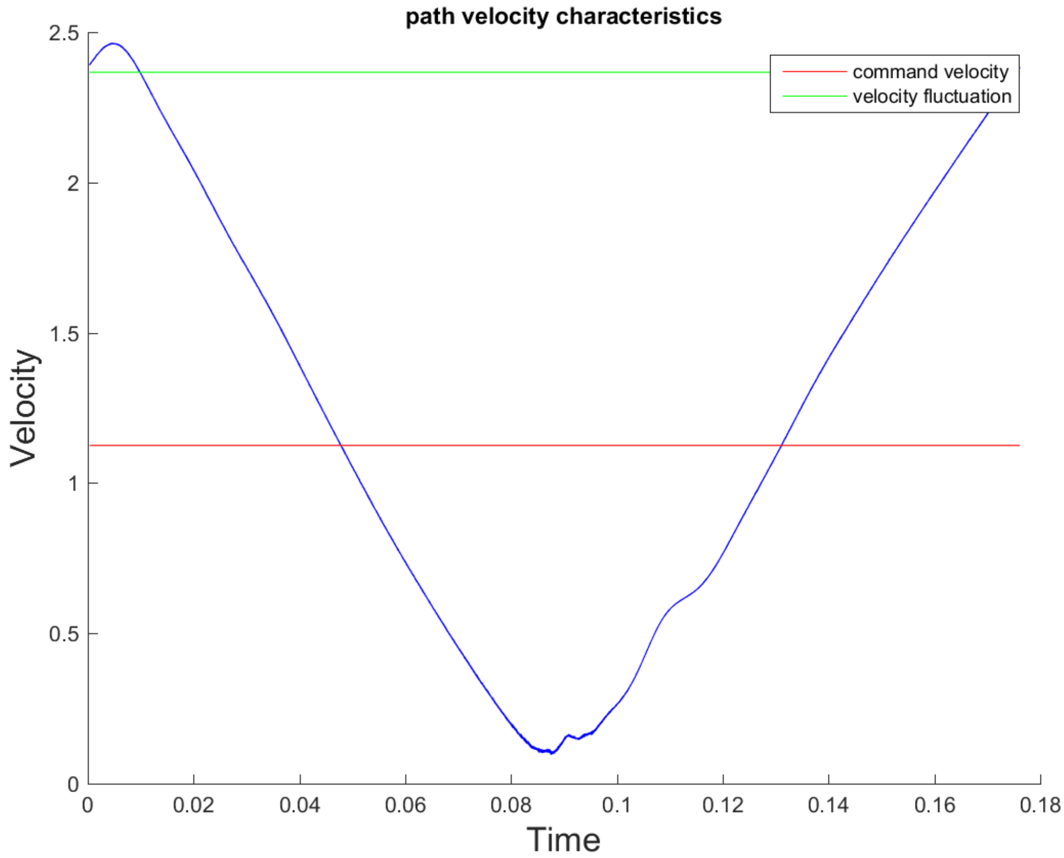

Figure 4.16: The path velocity fluctuation and command velocity

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Chapter 5

Annex

5.1 Table A.2 Standard test Load categories

Test load category	**Mass(kg)**	**Axial CG offset $L_Z(mm)$**	**Radial CG and MP offse**
1	1	20	0
2	2	40	20
3	5	60	30
4	10	80	40
5	20	100	50

5.2 Units used in this Report

S.No	**Type of Measurement**	**Units**	**Abbreviation of units**
1	Length	millimeters	(mm)
2	Angle	Degrees	$(^\circ)$
3	Time	Seconds	(s)
4	Mass	Kilograms	(kg)
5	Force	Newtons	(N)
6	Velocity	Meters per second	(m/s)

5.3 Table Poses to be used for pose characteristics

S.No	Characteristics to be Tested	P_1	P_2	P_3	P_4	P_5
1	Pose accuracy and Pose repeatability	X	X	X	X	X
2	Multi-directional Pose accuracy variation	X	X	-	X	-
3	Distance accuracy and Distance repeatability	-	X	-	X	-
4	Position stabilization time	X	X	X	X	X
5	Position overshoot	X	X	X	X	X
6	Drift pose characteristics	X	-	-	-	-
7	Path accuracy and Path repeatability	-	X	-	X	-
8	Path velocity characteristics	-	X	-	X	-

5.4 Sphere and Cone

5.4.1 Sphere in working cube

In this report some unique shapes are taken for giving good visualization of deviations/errors. In this section explains the sphere and cube shapes and also clearly shows, how the consideration of these shapes for performance characteristics .

The sphere's center point is the mean of the all attained pose when the test is commanding poses and the maximum deviation point in total attained path when the test is commanding the path.

The radius of the sphere is the value of the pose repeatability values in the required performance tests see Fig. 5.1.

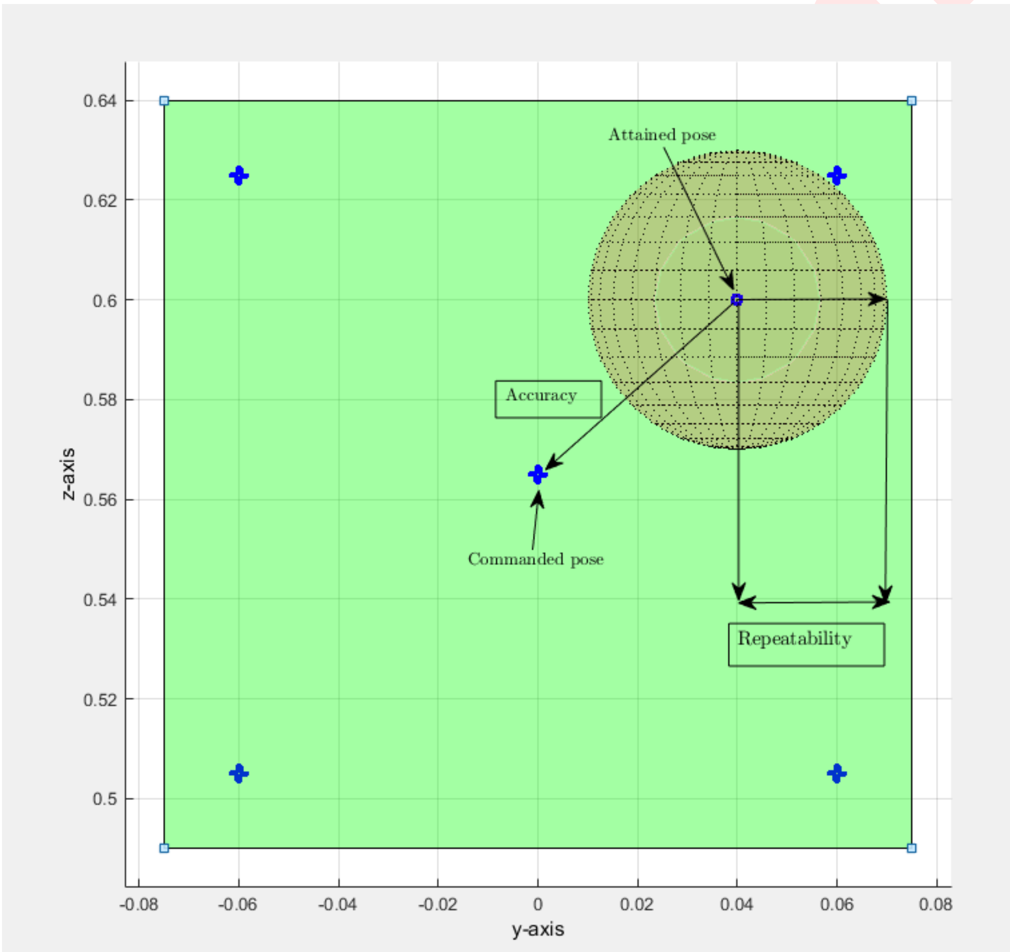

Figure 5.1: Plotted sphere specifications

5.4.2 Cone in working cube

The cone is plotted to enable an intuitive interpretation deviations of orientation characteristics. Here, the three cones are plotted together which represent the three coordinate frame (X, Y and Z). The end frame and one end of the all three cones are intersected and the intersection is given as mean of the all attained pose when the test is commanding poses and he maximum deviation point in total attained path when the test is commanding the path respectively.

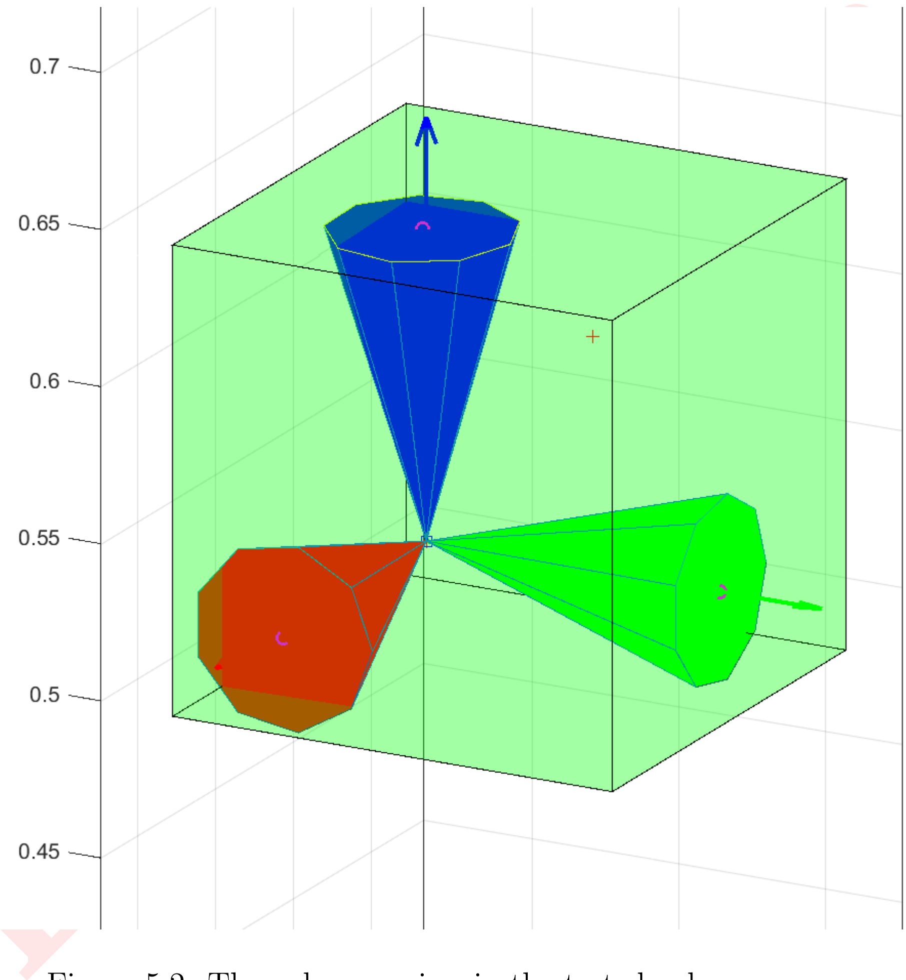

Figure 5.2: The cube overview in the tested cube

5.5 Capability map of the robot-manipulators in workspace

The ability of a mobile manipulator to grasp and manipulate objects depends on the location of the arm in the physical space. Arms with different kinematic structures provide different capabilities, and knowing the limits and capabilities of the arm allows a proper location of the robot to successfully fulfill a desired manipulation task. Either if the robot is located in a suitable position or if the robot arm has a fixed base, an offline analysis of the robot workspace is helpful to speed up the online solution of planning tasks. The representation of the regions where the robot tool frame (TCP) can be moved to is known as a reachability map.

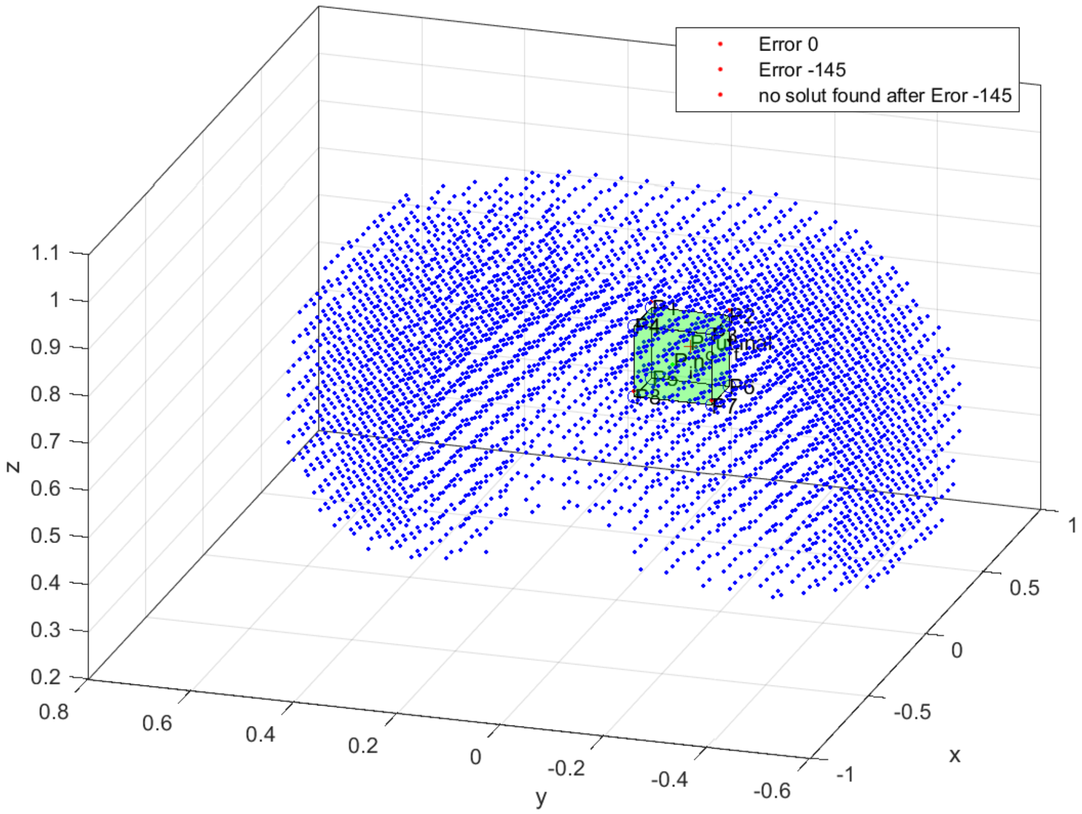

Figure 5.3: The capability space for a testing Robot

It is in general computed as a spatial grid in the 6D space (position and orientation), where each cell has a binary value that indicates if it is reachable or not. The cells can also have an associated quality index that measures the dexterity of the robot when located in this position, thus creating a capability map. (5.3)
This is an offline analysis of the reachability of a robotic arm saves time for online queries like grasp selection or path planning. Reachability data is complemented with indices that quantify the goodness of one region in space to create a capability map, which can be computed based either on forward or inverse kinematics.

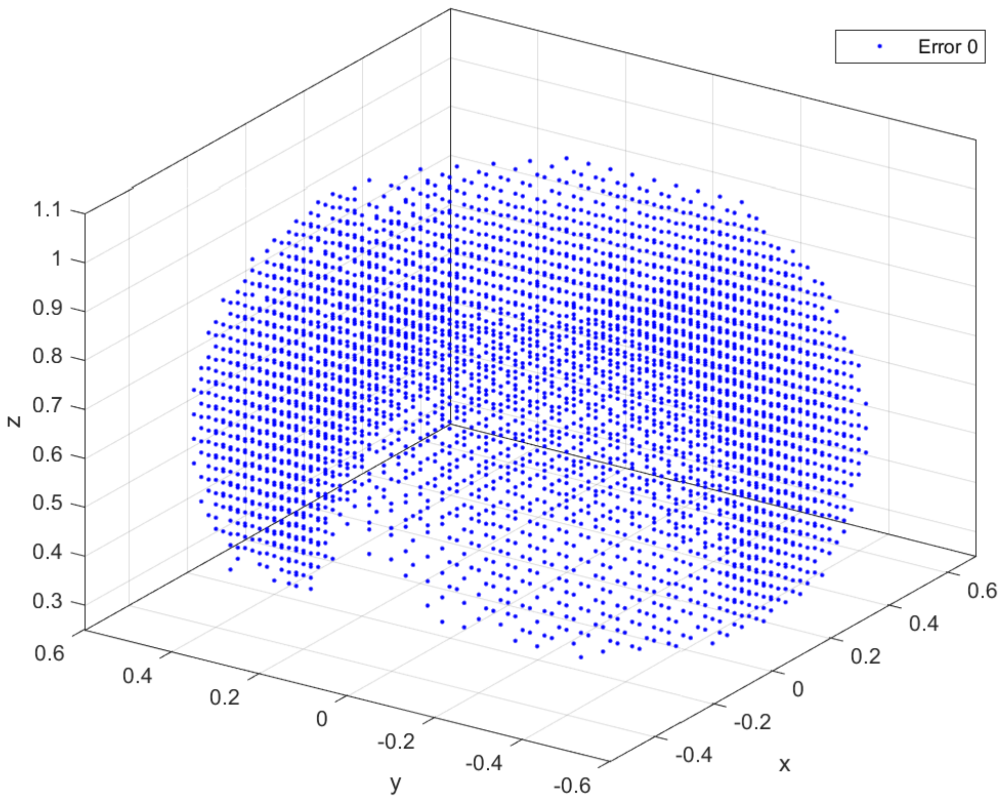

Figure 5.4: The measurement cube in the capability space from top view

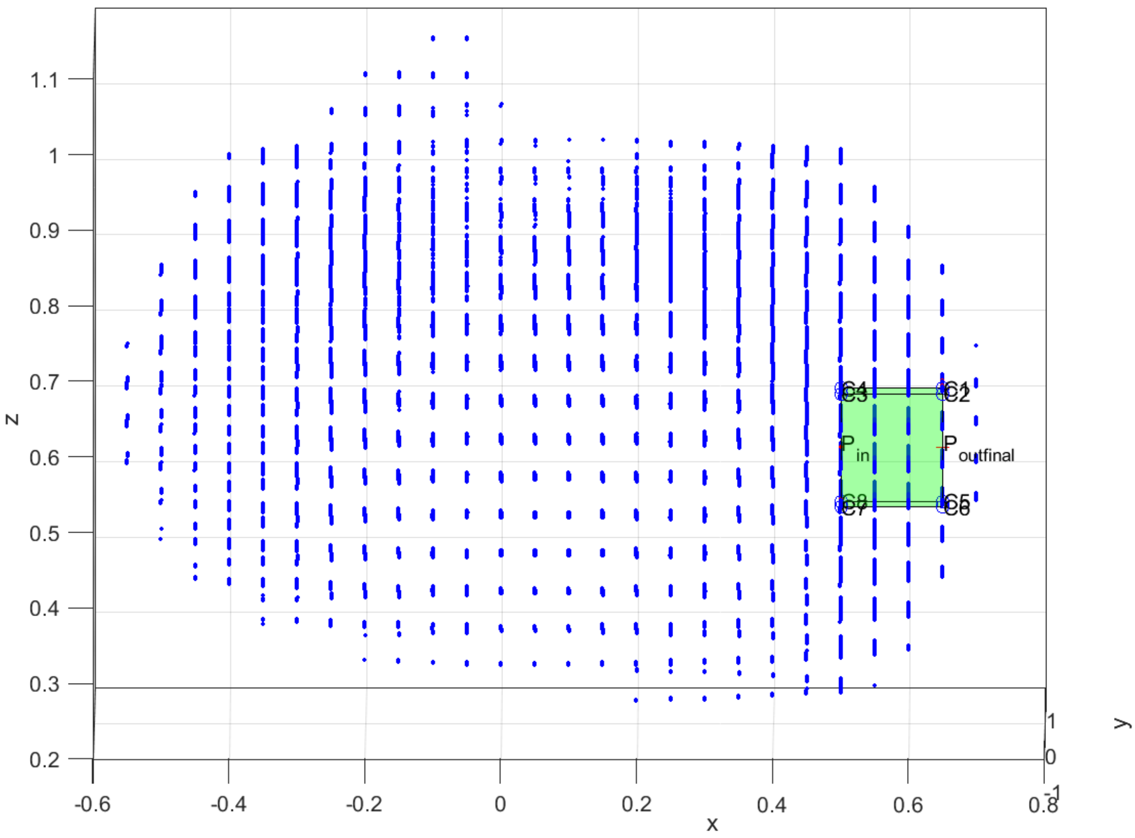

Figure 5.5: The measurement cube in the capability space from side view

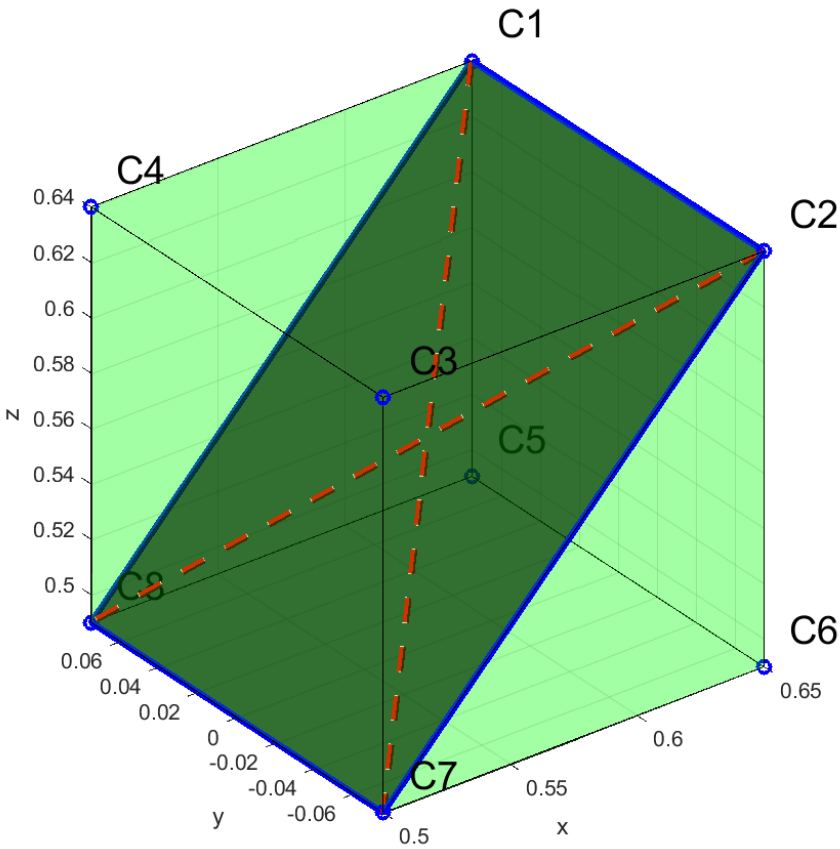

Figure 5.6: The selected plane for pose and path performance characteristics

$'/home/dyav\_ra/public/ISOReportFigures/SelectedPlane.fig'$