Test Report

RANGER STATIC PERFORMANCE MEASUREMENTS

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1.0 Introduction

This report documents the results for testing the Ranger dexterous robotic manipulator system for per Test Procedure DT21-0039. All testing took place at the University of Maryland's Space Systems Laboratory (UMD/SSL).

2.0 Equipment

The test article was the Ranger left dexterous manipulator assembly (DXL for DeXterous Left), SSL part number FD07-0400. Data for positioning was collected with a Faro portable CMM Platinum Series Model Number P0802 Serial Number P08020503418. Data for applied static loads was collected with a Shimpo Digital Force Gauge Model Number FGV-50A Serial Number V927E008.

2.1 Hardware setup

2.1.1 Positioning Faro arm

Mounting the measurement system took consideration of various requirements. The end result was a compromise of the most important needs.

2.1.1.1 Provide adequate mount for Faro arm base

Ultimately, the Faro base was mounted on the top of the head as shown in Figure 1, which provides a stiff area that does not allow relative motion between the Faro arm and the Ranger arm. The head provides a convenient clamping flange with room enough for two clamps.



Figure 1: Test set-up

2.1.1.2 Match work volumes as much as possible

By mounting the Faro base on the head the work volumes are roughly matched. The vertical location (Y direction in the head frame)of the Faro arm is slightly higher and the location of the first pitch joint is rotated 90 degrees (about X axis) and offset to the left (+ Z direction). These differences seem to be acceptable as it would be impossible to collocate the arms.

2.1.1.3 Protecting the Faro arm in case of system crash

The Faro arm could not reach the lowest point of the Ranger arm so a table was positioned to catch the arm(s) before the Faro arm could reach a travel limit. Padding is provided to prevent damage to either arm. The Faro arm is oriented to be above (+ Y direction head frame) to prevent damage due to the mass of the Ranger arm.

2.1.1.4 Making sure Faro arm can operate freely in the areas of interest

The Ranger arm was moved to the points of interest at the travel extremes. The Faro arm was then positioned to determine if it could measure that position and not be in danger of approaching either a singularity or a travel limit.



2.1.1.5 Adapting Faro arm probe to Ranger arm

The specification requires a load (2 kg or 4.4 lbs in our case) be mounted outboard of the end of the robot. The weight of the Interchangeable End Effector Mechanism (IEEM) and the tool adapter is approximately 3.7 pounds. The document specifies the center-of-gravity (COG) of this load to be located 4 cm (1.57 in.) along the tool axis and 2 cm (0.78 in.) offset from that axis. If we consider the output flange to be the end of the robot this point is located inside the IEEM. It is assumed this load case tests the effects of eccentric payloads on robot performance. However, Ranger tooling is axis symmetric about the tool axis making the need for eccentric loading not applicable. It is approximated the COG location of the IEEM and tooling adapter is axis symmetric about the tool axis and offset from the output flange approximately 1.75 inches. This offset should provide some measure of the wrist pitch axis stability. This configuration can be refined to better meet the specification if deemed necessary.

A tooling adapter was mounted onto the output flange in order to attach the measurement system. Preliminary testing has shown that an additional degree-of-freedom (DOF) is necessary between the Faro arm and the tooling adapter. However, measurements can be taken if the sampling technique is slow enough to allow human assistance to hold the Faro arm in place.

2.1.1.6 Cancel deflections due to supporting structure

As the Faro arm base moves with the Ranger arm base any errors due to deflecting support structure will be negated.



2.2 Coordinate frame alignment

In order to simplify data reduction, a common coordinate frame was established between DXL and the Faro arm. The base frame of DXL was selected (as shown in Figure 2) as shifting frames on the Faro arm is not difficult. The Faro arm software provides a routine for establishing multiple coordinate frames. The frame of the arm was established in the Faro arm by digitizing the face of the mounting head and the center of the first DOF. This frame was used for all testing except for repeatability.



Figure 2: Coordinate frame

For the repeatability tests a frame was established by selecting points on the plane where the data was collected. Using this plane reduces the amount of data manipulation necessary.

2.3 Measurement tool offset compensation

The Faro arm is intended for measuring geometric features on mechanical hardware. In order to use the Faro arm for measuring the performance of DXL an adapter was fabricated to hold the Faro probe tip to DXL. The normal operation of the Faro has the operator digitize probe locations using a compensation offset for the probe sphere diameter. This requires the operator to digitize a reference feature on DXL for every data point to be collected. This technique proves to be time intensive.

In order to collect the data in a reasonable amount of time, the probe is mounted directly to DXL via the adapter as shown in Figure 3. The final probe connection is related to the location of the arm wrist frame numerically. This relation is established by measuring the relative position between the wrist pitch axis center and the probe center mounted in the adapter. The center of the wrist pitch axis is determined by using the Faro arm and the location of the measuring probe in the adapter is determined by using a non-compensated mode on the Faro arm (Figure 4). Once these two locations are determined an accurate offset for the measuring probe location can be numerically determined. This method reduces the chances for stacked tolerances affecting the measurement precision.



Figure 3: Adapter to hold Faro probe tip to the DXL



Figure 4: Wrist pitch axis

2.4 Application of load

In order to measure compliance, a load is applied and deflection measured simultaneously (Figure 5). The amount of displacement is recorded when the peak load is applied. The load is applied in one kilogram-force increments and released between each incremental increase. The direction of the load is applied through a line that acts through the probe center. The orientation of the force line is co directional with the base plane axes as defined in section 2.3.



Figure 5: Applying a load



3.0 Test Results

Table 1: Robot Performance Data Report D ANGU/DIA D15 05 1 1000 ANGU/DIA

Reference: ANSI/RIA R15.05-1-1990

Description of data	Units	Section	Static performance class
			Standard I
Test parameters			
Warm up status at start	-	6.3	COLD
Payload	kg	6.3	1.7
Test load category		6.3 (table 1)	2
Segment size	mm	6.6.2	200
Number of segments	mm	6.6.2	3
Static position accuracy		8.2	OPTIONAL
Mean	mm	8.2.1.2.6	22.8
Standard deviation	mm	8.2.1.2.6	4.3
Repeatability	8.3		
Warm up drift	mm	8.3.1.3.1	
Warm up period	sec	8.3.1.3.1	
Measurement dwell	sec	8.3.1.3.2	3
Mean	mm	8.3.1.3.2	0.495
Standard deviation	mm	8.3.1.3.2	0.408
STP cycle test	8.4		
Deviation from STP	mm	8.4.2.8	
Segment cycle time – mean	sec	8.4.3.1	
Traverse speed	mm/s	8.4.3.2	
Overshoot – mean	mm	8.5.2	
Settling time – mean	sec	8.5.3	
Static compliance		8.6	
Mean $\pm X_1$	mm/kg	8.6.3	+0.142/-0.140
Mean ±Y ₁	mm/kg	8.6.3	+0.193/-0.144
Mean $\pm Z_1$	mm/kg	8.6.3	+0.333/-0.400

The order of magnitude difference between absolute and relative accuracies is due, we believe, to the lower accuracy absolute encoder used in the Ranger manipulators and a lack of a high fidelity zeroing setup. Tests of Ranger's absolute accuracy, when started in several different configurations, shows an absolute cartesian position error on the order of 2 cm with no more than 1.5 cm error in any one axis.



The warm up drift, warm up period, and STP cycle test data was not collected as the Faro portable CMM does not time stamp the data.