Alignment Repeatability

Selfie Aligner Test and Statistics

by Henning Forbech, 4TECH Robotics ApS

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Summary:

The Selfie Aligner can align to the mirror tag with a repeatability of less than 0.1 mm and 0.3 mRad. In a test series with 20 alignments the mean deviation was 0.072 mm and 0.214 mRad. 10-50 times better than traditional systems!

Scope:

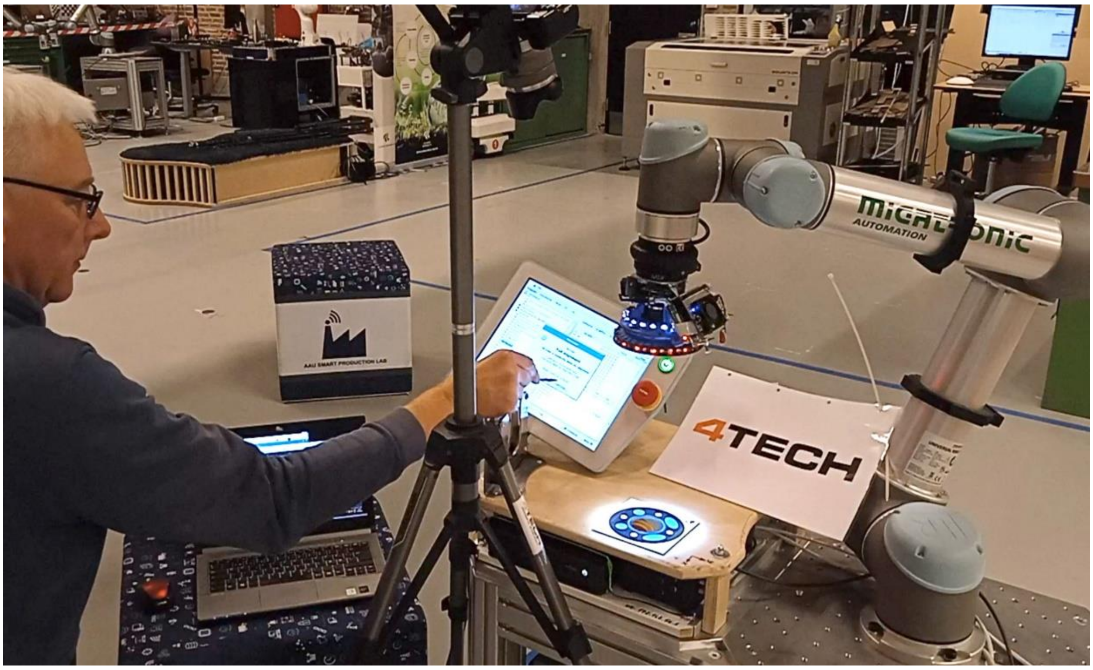
This document presents results from a test series with the Selfie Aligner. The scope of the test was to measure the repeatability of the Selfie Aligner.
The accuracy of the system is so high that it is also relevant to look into the precision and stability of the robot arm and the mobile platform.

Test plan:

In the test a series of alignments was performed to a tag at a fixed position.
A mean pose for the alignments was found by calculating the mean value for each coordinate in the poses. For all alignments the deviation from this mean pose was calculated for each coordinate in the pose.
To condense values for the alignment the Euclidian distance, based on the deviations for each coordinate, was calculated for position and orientation.
These two values (Δxyz and ΔRxRyRz) for the alignments in the test was used to find a mean value for the alignment accuracy.

Test setup:

The tests were set up with the Selfie Aligner and a UR5 robot at Smart Lab, Aalborg University.
The Selfie Aligner consist of a camera tool, mounted at the end of the robot arm and a calibration tag with a build in mirror. The robot arm was mounted on a mobile platform and the mirror tag was mounted on the same platform.



The tests were performed with an early version of the Selfie Aligner. This version of the are based on a Raspberry Pi 4 and a Raspberry Pi HQ camera equipped with a 16 mm lens. This simple version of the Selfie Aligner is only designed for showing the basic idea and proof the concept.

By information from the camera tool the robot controller can move the robot arm with the camera to a predefine position above the mirror tag. In an iterative process the position and orientation (pose) off the camera tool is optimized until the pose is inside a predefine tolerance. This final pose is the alignment pose and hold information on the relation between the coordinate system for the robot arm and the coordinate system for the mirror tag.

For the first test series the system was forced to use more steps in the alignment process by setting the tolerances for the final alignment to a quite narrow value, ±0.1 mm and ±0.2 mRad. This gave a little slower alignment with more iteration before the camera tool found the right pose.

To measure the repeatability a series of 20 alignment was performed to a tag at a fixed position. The final poses from the 20 alignments were recorded to perform statistical analysis on the result.

To avoid the aligner just repeating the same movement multiple times the alignment test was setup to begin the process from 20 different start points. The base for these start points was a pose close to the final alignment point.

The 20 different start poses was generated by making small changes or offset to each coordinate in the general start pose for the test.
Same offset values were used for all start points but for each coordinate the offset was added (+) or subtracted (-). All the 20 start points was different.
These 20 combinations of adding or subtracting offset to the values was used:
+++ +++,+-+ +-+,--+ --+,-++ -++,++- ++-,+-- +--,--- ---,-+- -+-,+++ -++,+-+ --+,--+ +-+,-++ +++,++- -+-,+-- ---,--- +--,-+- ++-,+++ --+,+-+ +++,--- ++-,-+- -++

By changing all coordinates in the pose the aligner was forced to make adjustments to all values That is, the aligner was forced to make adjustments to all six DoF for the robot arm.

Statistics:

In the spreadsheet below the raw values from each of the 20 alignment points is shown as m and Rad. The actual start pose for each alignment are shown as a number.
For each coordinate in the final pose the mean value (average), standard deviation, max and min values was first calculated.

The diversion for each coordinate was then found as the difference between the mean value and the actual value. In the spreadsheet these values are named Δx, Δy, Δz, ΔRx, ΔRy, ΔRz and shown as μm and μRad.

To consolidate the result the Euclidian distance between the mean pose and the final pose was calculated for both position and orientation (Δxyz and ΔRxRyRz). These values are also shown as µm and µRad.
These two values, highlighted in green, were used as an indicator for the quality of the alignment.

The Selfie Aligner could find the alignment pose with an average error of 73 µm and 215 µRad. The biggest deviation (max or min) from the mean values was 87 µm on position and 290 µRad. That is ±1/10 mm and ±1/3 mRad.

Traditional alignment systems, based on a camera and a small chessboard or QR code, can align with ±1 mm and ±1º. 1º is 17.45 mRad.
For direct comparison this tolerance is equal to 1,000 µm and 17,450 µRad.
The Selfie Aligner is 10-time better on the position precision and 50-time better on the orientation precision than the traditional chess board systems.

Data:

The data below is from an experiment at Smart Lab, Aalborg University 6/11 2023. The robot was a Universal Robots UR5 CB3 running PolyScope 3.15.8
The Selfie Aligner was set to continue the iterative alignment process until the proposed adjustments for position was less than 0.1 mm on the position and less than 0.2 mRad on the orientation.
The start pose for this test was off-set by ±3 mm on the position and ±8.73 mRad (0.5º) on Rx and Ry. Rz had a ±100 mRad (5.3º) off-set.
The date on the pose for the camera tool was recorded by the PolyScope program and saved as Installation Variables.

A video from the test can be found here:
https://vimeo.com/886262666/e36fd86f21

Setup for testing the repeatability of the Selfie Aligner

First test		Raw values						Diversion from mean value						Euclidian distance		
6/11 2023		x	y	z	Rx	Ry	Rz	Δx	Δy	Δz	ΔRx	ΔRy	ΔRz	Δxy	Δxyz	ΔRxRyRz
Start point:	Step:	m	m	m	Rad	Rad	Rad	µm	µm	µm	µRad	µRad	µRad	µm	µm	µRad
1	2	0.13656	-0.32805	0.11306	-2.21930	-2.22297	0.00035	-23.3	-64.4	4.4	-16.1	-58.9	161.7	68.5	68.7	172.8
2	2	0.13658	-0.32810	0.11311	-2.21909	-2.22323	0.00046	-43.3	-14.4	-45.6	-226.1	201.1	51.7	45.7	64.5	307.0
3	2	0.13655	-0.32813	0.11303	-2.21954	-2.22297	0.00047	-13.3	15.6	34.4	223.9	-58.9	41.7	20.5	40.1	235.2
4	2	0.13660	-0.32803	0.11300	-2.21927	-2.22277	0.00035	-63.3	-84.4	64.4	-46.1	-258.9	161.7	105.6	123.7	308.7
5	2	0.13654	-0.32806	0.11307	-2.21937	-2.22289	0.00049	-3.3	-54.4	-5.6	53.9	-138.9	21.7	54.5	54.8	150.5
6	2	0.13647	-0.32809	0.11302	-2.21936	-2.22274	0.00060	66.7	-24.4	44.4	43.9	-288.9	-88.3	71.0	83.8	305.3
7	2	0.13658	-0.32804	0.11312	-2.21950	-2.22296	0.00039	-43.3	-74.4	-55.6	183.9	-68.9	121.7	86.1	102.5	231.0
8	2	0.13654	-0.32808	0.11310	-2.21938	-2.22300	0.00043	-3.3	-34.4	-35.6	63.9	-28.9	81.7	34.6	49.6	107.6
9	2	0.13649	-0.32812	0.11305	-2.21940	-2.22287	0.00051	46.7	5.6	14.4	83.9	-158.9	1.7	47.0	49.2	179.7
10	2	0.13653	-0.32803	0.11299	-2.21905	-2.22281	0.00033	6.7	-84.4	74.4	-266.1	-218.9	181.7	84.7	112.8	389.5
11	2	0.13652	-0.32817	0.11307	-2.21950	-2.22305	0.00054	16.7	55.6	-5.6	183.9	21.1	-28.3	58.0	58.3	187.3
12	2	0.13647	-0.32815	0.11308	-2.21954	-2.22290	0.00059	66.7	35.6	-15.6	223.9	-128.9	-78.3	75.6	77.1	270.0
13	2	0.13657	-0.32812	0.11312	-2.21945	-2.22294	0.00031	-33.3	5.6	-55.6	133.9	-88.9	201.7	33.8	65.0	257.9
14	2	0.13645	-0.32806	0.11306	-2.21913	-2.22292	0.00042	86.7	-54.4	4.4	-186.1	-108.9	91.7	102.3	102.4	234.3
15	2	0.13648	-0.32811	0.11300	-2.21937	-2.22290	0.00053	56.7	-4.4	64.4	53.9	-128.9	-18.3	56.8	85.9	140.9
16	2	0.13656	-0.32816	0.11307	-2.21937	-2.22314	0.00038	-23.3	45.6	-5.6	53.9	111.1	131.7	51.2	51.5	180.5
17	2	0.13649	-0.32814	0.11308	-2.21925	-2.22308	0.00050	46.7	25.6	-15.6	-66.1	51.1	11.7	53.2	55.4	84.4
18	2	0.13658	-0.32811	0.11306	-2.21948	-2.22311	0.00045	-43.3	-4.4	4.4	163.9	81.1	61.7	43.6	43.8	193.0
19	2	0.13660	-0.32807	0.11306	-2.21929	-2.22300	0.00066	-63.3	-44.4	4.4	-26.1	-28.9	-148.3	77.4	77.5	153.4
20	2	0.13656	-0.32805	0.11301	-2.21930	-2.22286	0.00041	-23.3	-64.4	54.4	-16.1	-168.9	101.7	68.5	87.5	197.8
Average:		0.136536	-0.3280935	0.11306	-2.21935	-2.22296	0.000459							61.9	**72.7**	**214.3**
Standard deviation:		0.000045	0.000043	0.000038	0.000138	0.000121	0.000093							21.9	23.4	74.0
Max:		0.13660	-0.32803	0.11312	-2.21905	-2.22274	0.00066	86.7	55.6	74.4	223.9	201.1	201.7	105.6	123.7	389.5
Min.		0.13645	-0.32817	0.11299	-2.21954	-2.22323	0.00031	-63.3	-84.4	-55.6	-266.1	-288.9	-148.3	20.5	40.1	84.4
		m	m	m	Rad	Rad	Rad	µm	µm	µm	µRad	µRad	µRad	µm	µm	µRad

Steps:

In the iterative alignment process the robot steps the camera towards the pose for the best alignment. These steps can also be registered and analyzed.

In the process the Selfie Aligner program analyzed an image from the camera and calculated a proposal on how to move the camera to a better position. After the robot have adjusted the pose for the camera a new image is captured. This image is then analyzed and the next proposal for moving the camera pose is calculated.
When all six coordinates in the proposal are inside a preset tolerance the process is stopped and the last pose is used as the result for this alignment.

The final alignment and all steps toward this pose are saved as Installation Variables in the PolyScope program (controller for the robot arm) and later transferred to a text document. This document is stripped of all non-relevant information and the data is transferred to a spreadsheet as a csv file.

In the spreadsheet all the raw date from alignment processes is collected for further analysis. The Installation Variables from PolyScope do not come in number order so first step is to rearrange the values to reflect the order in the alignment process.

In this spreadsheet below the values from a typical alignment process are shown with the pose for each step (units of mm and Rad) together with the steps between these steps (unit of mm and mRad).

Alignment process		**Pose**						**Step**					
		Position			*Orientation*			*Pos. adjust*			*Orintation adjust*		
		x	**y**	**z**	**Rx**	**Ry**	**Rz**	**x**	**y**	**z**	**Rx**	**Ry**	**Rz**
		mm	mm	mm	Rad	Rad	Rad	mm	mm	mm	mRad	mRad	mRad
Pose Final		136.49	-328.12	113.05	-2.2194	-2.2229	0.00051						
	Step 4							-0.02	-0.02	0.02	-0.19	-0.06	0.30
Pose 3		136.50	-328.10	113.07	-2.2190	-2.2231	0.00065						
	Step 3							0.05	-0.02	0.03	0.23	0.15	-0.29
Pose 2		136.53	-328.14	113.10	-2.2195	-2.2229	0.00056						
	Step 2							0.00	0.04	-0.71	1.62	-0.36	-7.58
Pose 1		136.49	-328.14	112.38	2.2277	2.2144	0.00164						
	Step 1							-3.39	-2.51	-1.25	6.95	-6.58	-93.95
Pose Start		136.53	-328.14	113.10	-2.2195	-2.2229	0.00056						

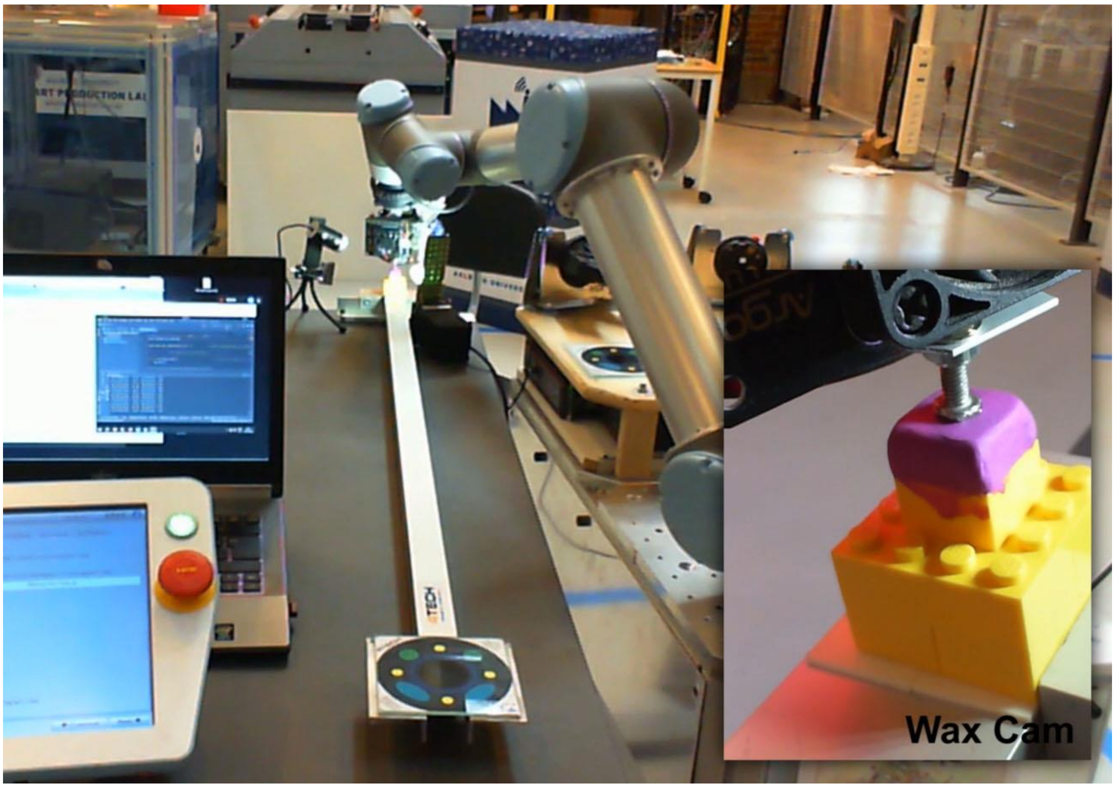
The first steps are quite big and the last steps are very small. The alignment process stops when all coordinates in the last proposal for the next step are smaller than the preset tolerance, here 0.15 mm and 0.3 mRad. The tolerance limit is first met on the position but all 6 coordinates must be inside the tolerance before the optimizing routine is ended.

In this example the final pose was reach in 4 steps. With this very early version of the Selfie aligner this process will take a little less than 10 seconds. By fare, the most time is spent on moving the robot arm. The time for analyzing an image and calculating the proposal for a step is ~0.5 second.

One Meter Wax Test:

To demonstrate the high accuracy and extreme repeatability of the Selfie Aligner a practical test was arranged. To challenge the performance of the aligner a Mirror Tag was mounted at one end of a 1 meter long bar. At the other end a small block of was placed on top of a LEGO block. The camera tool was fitted with a small tool that could stamp a mark on the wax block.

The challenge was now to let the Selfie Aligner calibrate to the Mirror Tag and then use this information to put a mark on the wax. To demonstrate the repeatability the bar could be moved to a new position. After a new alignment to the Mirror Tag the Selfie Aligner could make a second marking on the wax. After a series of markings on the wax block we would have a simple and very visual proof of the repeatability.



The setup for the "One Meter Wax Test" at Smart Lab, Aalborg University

After a series of test, it was clear that the stamp would hit at exactly the same position each time. The repeatability was so good that it was not possible to tell one stamp mark from the other.

A short video from the test can be found here:
https://vimeo.com/853226419/76847cad35

Same video but uncut and with an introduction:
https://vimeo.com/848551417/f03f431220

"Parkinson effect":

The high accuracy of the Selfie Aligner rise some new issues that must be taken into considerations. The actual pose of the robot arm at stillstand is not rock steady. Combined with the lack of a time coordination between the robot controller and the camera tool load to some unclear results on the alignment. The Selfie Aligner have no problem measuring the position of the camera in relation to the mirror tag with a very high accuracy. But there is a challenge in coordinating the results from the Selfie Aligner with actual pose of the robot arm.

Even when a robot arm is steady at a pose it may have small variations around this theoretical locked pose. The encoders and the motors in each joint will try to hold a fixed position. When an encoder detects a misplacement, the motor will bring this joint back to the right position. This ongoing adjustments at the joints can course a little wobbling at the end of the robot arm. At a steady position this effect is very small but with more dynamic condition the effect is bigger.

A small test with the UR5, used for this test, shows that the robot on average was off by 18 µm and 52 µRad when it was at a steady position. This is not a flaw in the robot but a side effect from the design of the robot arm.
These values were simply found by polling the robot controller for the actual pose with the command "get_actual_tcp_pose". From a series of measurements made at a frequency of 5 Hz (0.2 second between data points) the mean we can calculate for a 4 second time window. This small test did not involve data from the Selfie Aligner.

To simulate a dynamic situation a 2 kg weight was attached to the end of the robot arm by a string. With this weight swinging the values was almost the same as for the steady situation.

The small variations around a theoretical fixed pose seems to be around 0.02 mm and 0.05 mRad (20 µm and 50 µRad). Much higher diversions from the fixed pose could be induced by shaking the robot arm by hand.

These small deviations from a theoretically steady pose will affect the images from the camera. What is presumed to be an image taken from a distinct pose may be taken from a slightly different pose. Normally this difference is so small that it will make no difference but when the Selfie Aligner is performing at its best this "error" on the robot pose is around 25% of the average error for the Selfie Aligner.

This implicate that it will be difficult to improve the accuracy on an alignment performed with the Selfie Aligner on a UR robot. We are close to the limit for the accuracy of the robot arm.

At the moment the robot controller and the camera in the Selfie Aligner cannot be linked to share the time. The actual pose of the robot arm cannot be registries at the exact time as the image is taken. To compensate for this lack of simultaneity the robot arm it brought to still stand for a moment before the image is taken. This slows the alignment process but do not compromise the accuracy of the system.

Below is the result from two tests to measure the small movements of a robot at a fixed pose. In both tests the actual pose of the tool (TCP) is measured with an interval of 0.2 second (5 Hz).

In the first test, "Steady", the robot arm is at stillstand and in the second test, "Swing", the robot arm is again at stillstand but a 2 kg weight is hanging and swinging from the end of the robot arm. This is to introduce an external force to the robot arm and as an attempt to force the robot arm away from its fixed position.

The values from the robot are measured in meter and radian. In the calculation of the mean and the diversion from the mean micrometer (µm) and microradian (µRad) is used (1 m = 1000 mm and 1 mm = 1000 µm).

A short video from these tests can be found here:
https://vimeo.com/886266510/a194ef5d12

Steady	x	y	z	Rx	Ry	Rz	Δx	Δy	Δz	ΔRx	ΔRy	ΔRz	Δxy	Δxyz	ΔRxRyRz
Step#	m	m	m	Rad	Rad	Rad	µm	µm	µm	µRad	µRad	µRad	µm	µm	µRad
20	0.13633	-0.32801	0.11420	2.22100	2.22085	-0.00269	-9.5	-13	3	12	-22	-33	16.1	16.4	41.4
19	0.13631	-0.32803	0.11422	2.22098	2.22081	-0.00277	10.5	7	-17	32	18	47	12.6	21.2	59.6
18	0.13631	-0.32802	0.11418	2.22104	2.22087	-0.00274	10.5	-3	23	-28	-42	17	10.9	25.5	53.3
17	0.13632	-0.32802	0.11420	2.22098	2.22088	-0.00274	0.5	-3	3	32	-52	17	3.0	4.3	63.4
16	0.13632	-0.32802	0.11418	2.22102	2.22087	-0.00270	0.5	-3	23	-8	-42	-23	3.0	23.2	48.5
15	0.13634	-0.32801	0.11419	2.22102	2.22083	-0.00263	-19.5	-13	13	-8	-2	-93	23.4	26.8	93.4
14	0.13633	-0.32801	0.11419	2.22099	2.22085	-0.00270	-9.5	-13	13	22	-22	-23	16.1	20.7	38.7
13	0.13632	-0.32802	0.11420	2.22101	2.22083	-0.00274	0.5	-3	3	2	-2	17	3.0	4.3	17.2
12	0.13633	-0.32802	0.11422	2.22099	2.22082	-0.00271	-9.5	-3	-17	22	8	-13	10.0	19.7	26.8
11	0.13632	-0.32802	0.11420	2.22097	2.22093	-0.00274	0.5	-3	3	42	-102	17	3.0	4.3	111.6
10	0.13631	-0.32803	0.11420	2.22104	2.22081	-0.00274	10.5	7	3	-28	18	17	12.6	13.0	37.4
9	0.13631	-0.32800	0.11419	2.22107	2.22082	-0.00268	10.5	-23	13	-58	8	-43	25.3	28.4	72.6
8	0.13633	-0.32803	0.11423	2.22098	2.22076	-0.00271	-9.5	7	-27	32	68	-13	11.8	29.5	76.3
7	0.13631	-0.32803	0.11419	2.22101	2.22086	-0.00276	10.5	7	13	2	-32	37	12.6	18.1	49.0
6	0.13633	-0.32803	0.11422	2.22102	2.22077	-0.00273	-9.5	7	-17	-8	58	7	11.8	20.7	59.0
5	0.13631	-0.32801	0.11421	2.22105	2.22079	-0.00270	10.5	-13	-7	-38	38	-23	16.7	18.1	58.5
4	0.13632	-0.32804	0.11421	2.22101	2.22081	-0.00276	0.5	17	-7	2	18	37	17.0	18.4	41.2
3	0.13632	-0.32803	0.11421	2.22104	2.22078	-0.00274	0.5	7	-7	-28	48	17	7.0	9.9	58.1
2	0.13632	-0.32804	0.11421	2.22101	2.22081	-0.00274	0.5	17	-7	2	18	17	17.0	18.4	24.8
1	0.13632	-0.32804	0.11421	2.22101	2.22081	-0.00274	0.5	17	-7	2	18	17	17.0	18.4	24.8
Average:	0.13632	-0.328	0.1142	2.22101	2.22083	-0.00272							12.5	**18.0**	**52.8**
Std Dev:	0.000009	0.000011	0.000013	0.000026	0.000040	0.000032							6.3	7.4	23.0
Max:	0.13634	-0.32800	0.11423	2.22107	2.22093	-0.00263	10.5	17	23	42	68	47	25.3	29.5	111.6
Min.	0.13631	-0.32804	0.11418	2.22097	2.22076	-0.00277	-20	-23	-27	-58	-102	-93	3.0	4.3	17.2
	m	m	m	Rad	Rad	Rad	µm	µm	µm	µRad	µRad	µRad	µm	µm	µRad

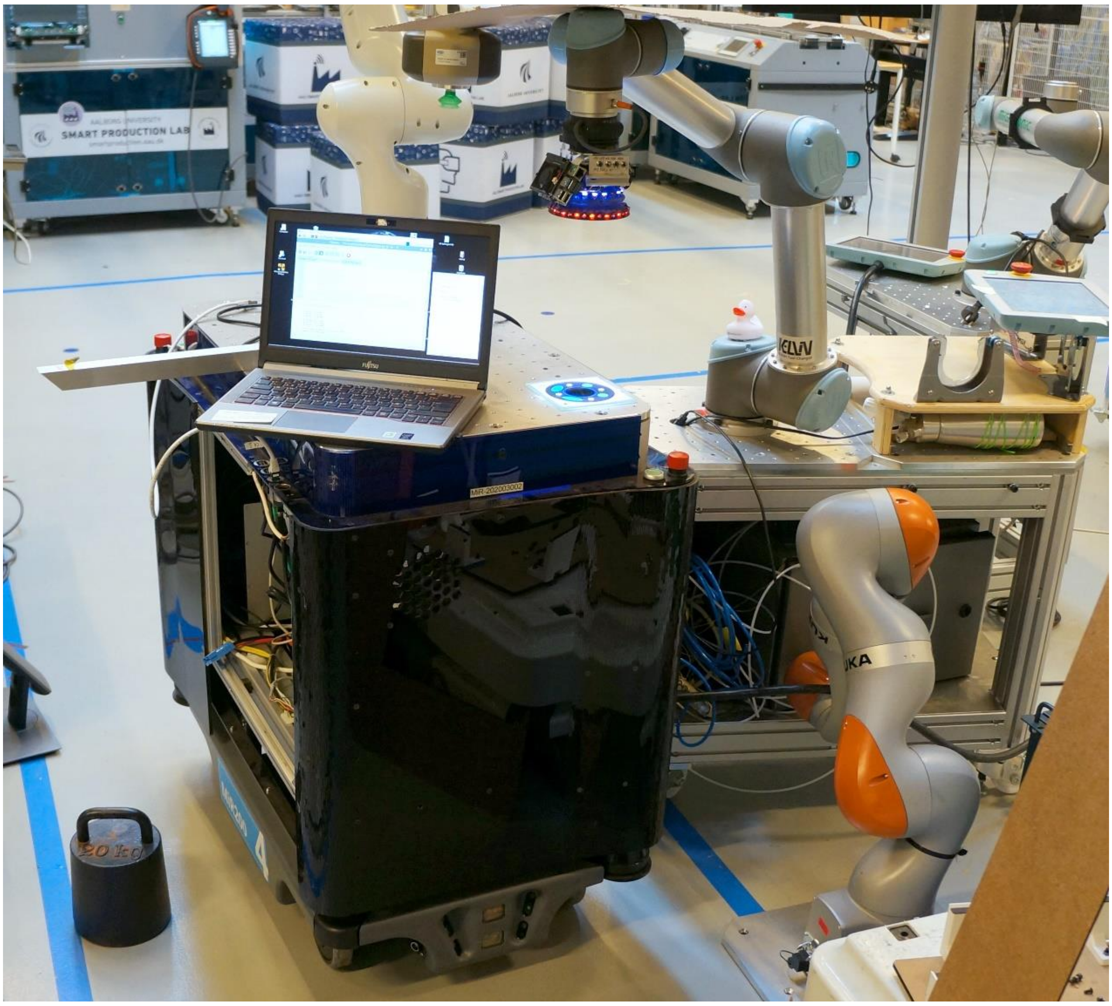
Swing	x	y	z	Rx	Ry	Rz	Δx	Δy	Δz	ΔRx	ΔRy	ΔRz	Δxy	Δxyz	ΔRxRyRz
Step #	m	m	m	Rad	Rad	Rad	µm	µm	µm	µRad	µRad	µRad	µm	µm	µRad
20	0.13633	-0.32805	0.11419	2.22093	2.22091	-0.00284	-17.5	7.0	6.5	35.5	-17.0	-7.5	18.8	19.9	40.07
19	0.13631	-0.32803	0.11418	2.22096	2.22092	-0.00283	2.5	-13.0	16.5	5.5	-27.0	-17.5	13.2	21.2	32.64
18	0.13630	-0.32805	0.11421	2.22099	2.22086	-0.00287	12.5	7.0	-13.5	-24.5	33.0	22.5	14.3	19.7	46.86
17	0.13632	-0.32802	0.11422	2.22096	2.22086	-0.00280	-7.5	-23.0	-23.5	5.5	33.0	-47.5	24.2	33.7	58.10
16	0.13631	-0.32804	0.11420	2.22097	2.22087	-0.00286	2.5	-3.0	-3.5	-4.5	23.0	12.5	3.9	5.2	26.56
15	0.13633	-0.32806	0.11420	2.22091	2.22092	-0.00284	-17.5	17.0	-3.5	55.5	-27.0	-7.5	24.4	24.6	62.17
14	0.13630	-0.32805	0.11418	2.22102	2.22089	-0.00289	12.5	7.0	16.5	-54.5	3.0	42.5	14.3	21.9	69.18
13	0.13632	-0.32804	0.11420	2.22098	2.22088	-0.00282	-7.5	-3.0	-3.5	-14.5	13.0	-27.5	8.1	8.8	33.70
12	0.13632	-0.32803	0.11420	2.22086	2.22099	-0.00286	-7.5	-13.0	-3.5	105.5	-97.0	12.5	15.0	15.4	143.86
11	0.13632	-0.32803	0.11420	2.22090	2.22093	-0.00282	-7.5	-13.0	-3.5	65.5	-37.0	-27.5	15.0	15.4	80.10
10	0.13632	-0.32804	0.11421	2.22099	2.22079	-0.00282	-7.5	-3.0	-13.5	-24.5	103.0	-27.5	8.1	15.7	109.39
9	0.13631	-0.32805	0.11419	2.22097	2.22093	-0.00287	2.5	7.0	6.5	-4.5	-37.0	22.5	7.4	9.9	43.54
8	0.13632	-0.32806	0.11420	2.22096	2.22091	-0.00285	-7.5	17.0	-3.5	5.5	-17.0	2.5	18.6	18.9	18.04
7	0.13632	-0.32804	0.11419	2.22095	2.22090	-0.00284	-7.5	-3.0	6.5	15.5	-7.0	-7.5	8.1	10.4	18.59
6	0.13630	-0.32805	0.11420	2.22100	2.22087	-0.00287	12.5	7.0	-3.5	-34.5	23.0	22.5	14.3	14.7	47.18
5	0.13629	-0.32805	0.11421	2.22097	2.22087	-0.00289	22.5	7.0	-13.5	-4.5	23.0	42.5	23.6	27.2	48.53
4	0.13629	-0.32805	0.11418	2.22099	2.22091	-0.00289	22.5	7.0	16.5	-24.5	-17.0	42.5	23.6	28.8	51.92
3	0.13630	-0.32804	0.11419	2.22098	2.22093	-0.00287	12.5	-3.0	6.5	-14.5	-37.0	22.5	12.9	14.4	45.67
2	0.13632	-0.32804	0.11419	2.22101	2.22086	-0.00281	-7.5	-3.0	6.5	-44.5	33.0	-37.5	8.1	10.4	66.90
1	0.13632	-0.32804	0.11419	2.22101	2.22086	-0.00281	-7.5	-3.0	6.5	-44.5	33.0	-37.5	8.1	10.4	66.90
Average:	0.13631	-0.32804	0.11420	2.22097	2.22089	-0.00285							14.2	**17.3**	**55.49**
Std Dev:	0.000012	0.000010	0.000011	0.000039	0.000040	0.000028							6.18	7.23	29.24
Max:	0.136330	-0.32802	0.114220	2.221020	2.220990	-0.00280	22.5	17	16.5	106	103	42.5	24.4	33.7	143.86
Min.	0.136290	-0.32806	0.114180	2.220860	2.220790	-0.00289	-18	-23	-24	-55	-97	-48	3.9	5.2	18.04
	m	m	m	Rad	Rad	Rad	µm	µm	µm	µRad	µRad	µRad	µm	µm	µRad

Platform stability:

The accuracy of a robot on a mobile platform aligning to a fixed workplace will be dependent on the stability of the platform. A mobile robot or "mobile manipulator" consist of a robot arm and a mobile platform. This platform will typically be an Autonomous Mobile Robot (AMR) or an Automated Guided Vehicle (AGV).
Common for these mobile units is that they run on rubber wheels and have some kind of suspension to compensate for imperfection in the surface and to keep all wheels in contact with the floor.

This design is necessary for moving around but when the platform is parked the rubber wheels and the suspension will make the mobile platform flex a little with the changing load from a moving robot arm.

To estimate the effect from the flexibility in the mobile platform the Selfie aligner was used to measure how a MiR platform tilt under load. The Mirror Tag was placed on top of the MiR unit and another mobile platform with the Selfie Aligner on a UR5 robot arm was parked close by. The Selfie aligner was first used to align the camera toll to the Mirror Tag. Then the MiR platform was loaded with a heavy off-center weight and the readings from the Selfie Aligner was used to find the stability of the MiR200 platform.



Measuring the stability of the MiR200 platform

The test shows that the MiR platform is very stable. A torque load of 100 Nm will only tilt the platform 0.67 mRad.

The stiffness of the wheels and suspension is dependent on the position of the four caster wheels in the corners. For this test the wheels were orientated in the length of the platform. The castor wheel can both be in a position where they give extra support to the load or in a position where they let the platform flex the most. How the wheels are orientated will depend on how the mobile unit arrived to the workplace and may vary from time to time. On the MiR platform it is not possible to register the actual orientation of the castor wheels.

The platform will flex around a point close to the wheel base. An angular deformation here will move the top of the platform sidewards. For a robot arm reaching out over the side of the platform the movement from the deformation in the wheel base will be like a rotation around a horizontal axis at the wheelbase. Vertical load on the end of the robot arm will deflect the tool in approximately a 45° angle relative to vertical.

A short video from the test can be found here:
https://vimeo.com/886266510/a194ef5d12