Selfie Aligner Statistics

Appendix that did not make it to the paper

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Appendix: Statistic:

This document has more information on the repeatability test with the Selfie Aligner. Due to the limitation on the size of the peer reviewed paper this appendix did not get included in the paper. Now you can take a dive into the statistics.

The repeatability test consisted of 20 alignments with the calibration tag in the same position. The start pose for each alignment was set with the camera tool in different start positions, but all with the same offset from the target alignment position. Similarly, all start orientations had a similar offset from the target alignment orientation. This was done to force the aligner to follow different paths for all 20 tests runs.

The robot program recorded the proposed adjustments to the camera for each step in the alignment, as well as the pose for each iterative step in the process. The alignment process was set to stop when the proposed adjustments for all 6 degrees of freedom (DoF) were within a preset threshold.
For the position, this threshold was set to ±0.1 mm, and for the orientation, it was set to ±0.2 mRad for Rx, Ry, and Rz.
These position tolerances form a cube, but due to the nature of the UR orientation format, the tolerances for the orientation values do not form a simple geometric figure in the orientation space.

The final alignment pose for each test was used as the result for that test. Since it was not possible to establish a true alignment pose for the test, the average of the 20 tests was used to provide a relative validation for each test.
For the position, a mean was calculated from all 20 final alignment positions. For the alignment positions at each step in the tests, the Euclidean distance to the mean of the final poses position was calculated. These distances provided simple and uniform values suitable for displaying the alignment progress.
The progress of the position alignments is shown in Figures A and B.
Figure A shows the full process on a linear scale.
Figure B is a scaled-up section of the same graph to make the final steps more visible.

A similar comparison for orientation was made across the 20 tests. Calculating the mean orientation is slightly more complex. A simple mean of the orientation values in the UR axis-angle format is not strictly correct mathematically, though it yields a reasonable approximation here since the variation among the 20 orientations is small.

For a set of orientations where the variation is very small a mean value can be calculated on the UR axis-angle values. For the final alignments in this test the variation is very small and we use this approximation in the paper.

To obtain a more rigorous result, all orientations in the UR format were converted to quaternions [1]. When orientations are similar, a common algorithm is to represent them as unit quaternions, sum them (taking antipodal equivalence into account), and then normalize the resulting sum quaternion to unit length [2].

For the 20 final orientations in the experiment, the mean orientation based on quaternions was practically identical to the mean based on the UR axis-angle values. The very small deviations observed were due to rounding errors in the calculations.

To obtain a simple and uniform metric for the variations in orientation, the misorientation angle between each orientation and the calculated mean orientation for the 20 tests was computed. The misorientation angle between two orientations is defined as the smallest rotation angle among the equivalent rotations that can bring the orientations into coincidence [3].

The progress of the orientation alignments is shown in Figures C and D. Figure C shows the full process on a linear scale. Figure D is a scaled-up section of the same graph to make the final steps more visible.
The graphs in the paper are with a logarithmic scale but he we use a linear scale.

From these figures, it is clear that all tests start with the same position offset and same misalignment angle, even though they begin from different positions and orientations. After only two iterations, all positions and orientations are very close to or within the termination tolerances. The extra iterations required before the alignment process stops are due to the requirement that all 6 DoF must be within the tolerances simultaneously. The graphs indicate that the alignment process would have terminated in fewer iterations if the tolerances had been set slightly higher.

Since the values in the experiment are compared only to the average of the final alignment poses for the 20 tests, the recorded position offsets and misalignment angles represent only the repeatability of the aligner system. Determining the true absolute accuracy of the system would require a metrological setup to measure the ground-truth position and orientation of the alignment pose, which is outside the scope of this experiment.

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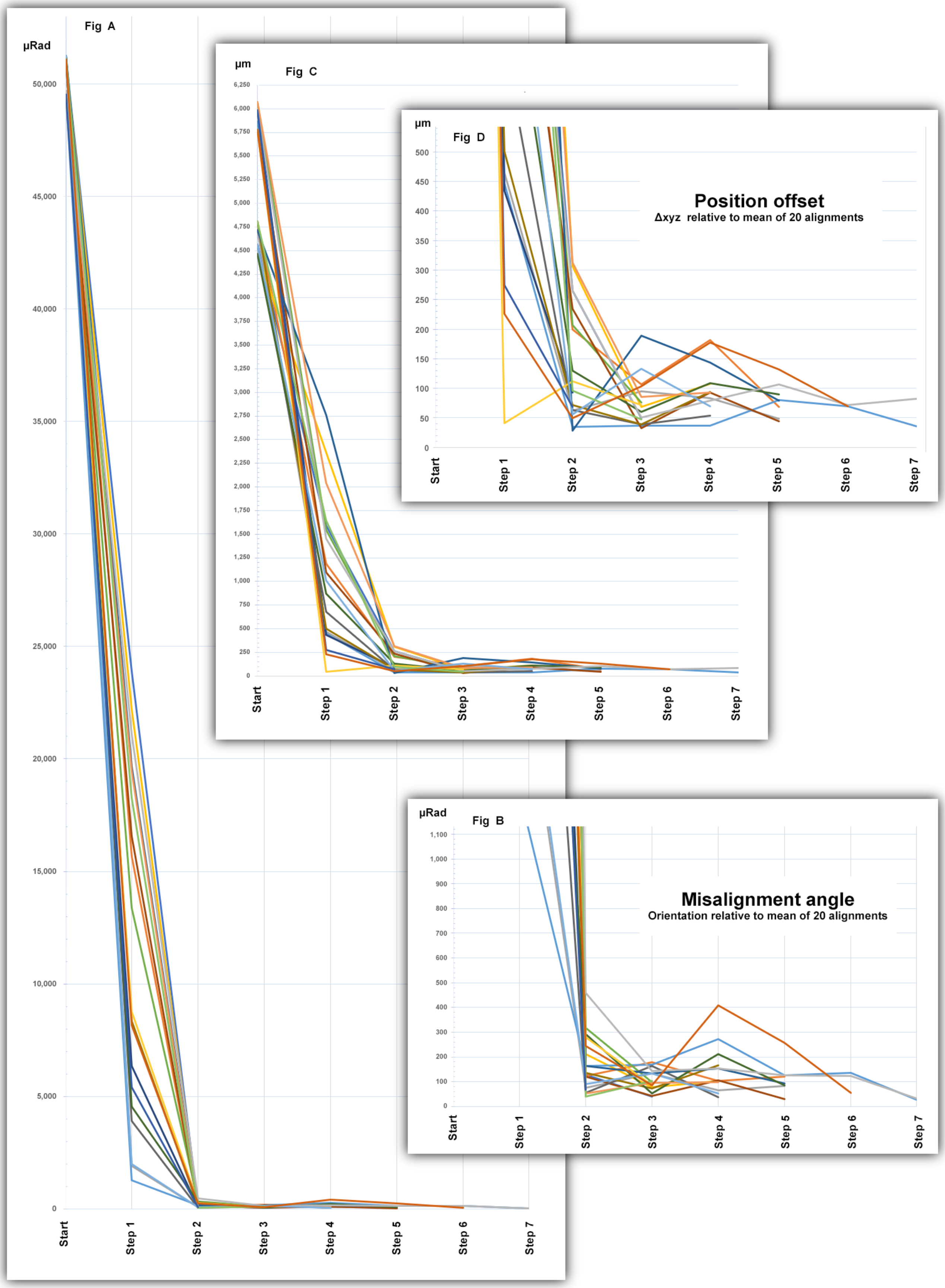

Figure 1: Pose information from each step in the 20 alignment tests is used to map how the Robot Aligner progresses toward the alignment point. The mean for the 20 tests is used as a reference for the offset in position for each step, as well as a reference for measuring the angular deviation from the final alignment pose during the process.