Investigating sources of inaccuracy within the Target Array Assembly System

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Introduction

The Target Array Assembly System (TAAS) is a robotic system that is being developed by the Target Fabrication Group of the Central Laser Facility to autonomously assemble microtarget arrays. The project is being developed to support the future target demands of the 'Extreme Photonics Applications Centre' (EPAC) facility which will be operational in 2025. [1].
Within the TAAS system, a MELFA 'RV-2FRLB' industrial robot [2] is used to manipulate target foils for the assembly of array targets. During system development a coordinate drift was observed, causing unreliable and inaccurate foil placement. However, the encoders in the arm joints did not register any difference in position.
Several experiments were conducted to identify the source of this drift. After initial experimentation, it was suggested that thermal expansion in the arm's chassis or motors could cause coordinate drift. An experiment to investigate the effect of thermal expansion on the robot arm was conducted.
This report details the methodology and findings of this experiment, also suggesting methods for mitigating the coordinate drift.

Objectives

The main objective of this experiment was to quantify the effects of thermal expansion on the robot arm. By exploring these effects, solutions to reduce this drift issue could be developed.

Hypothesis

The earliest hypothesis was an issue with the position tracking of the arm's encoders, potentially originating from one or all six joints. Joints 2, 3 and 5 were suggested to be the most likely sources as the coordinate drift was observed in the 'R' axis, when using polar coordinates.
However, the voltage reading of all encoder batteries was 6.11V, which ruled out depleted or faulty batteries as a source of encoder error. The controller also indicated that all six motors and encoders were fully functional, further opposing this hypothesis.
Another hypothesis was a behaviour commonly known as 'servo startup jumping'. When servo motors are unpowered, they will deviate from the previous commanded position. When reapplying power, the axel will quickly 'jump' to return to the commanded position step, which could lead to overshoots and position errors.
This jumping behaviour is observed when enabling or disabling the servos in the robot arm. However, initial investigation showed that the arm's encoders record the position changes while jumping, ruling out this hypothesis.
Finally, after initial experimentation, it was suggested that temperature could have a large effect on drift. The temperature of the arm's encoders changes from approximately 20^{O}C to 40^{O}C when the servos are enabled, providing a good indication of temperature of the overall joint and surrounding chassis. This temperature change would cause thermal expansion within the structure of the arm.
As this hypothesis had the strongest merit, an experiment was performed to investigate this effect, as detailed in the following sections.

Method

The coordinate drift was quantified by measuring the relative distance to set positions on the robot hand's camera from fixed reference positions. To measure this distance, two 'IFS2403-1,5' chromatic confocal sensors were used with a 'IFC2422' controller [2].
The operating point pose these experiments were performed at was around: X = +216mm, Y = -392mm, Z: = +229mm, A = -180°, B = 0°, C = 90°. This operating point was selected as the arm performs many operations around this point in Cartesian space in developing the arm routines. The pose is in the default coordinate system of the arm relative to the arm base.
A simplified representation and an image of the experimental setup can be seen in Figures 1 and 2 respectively.

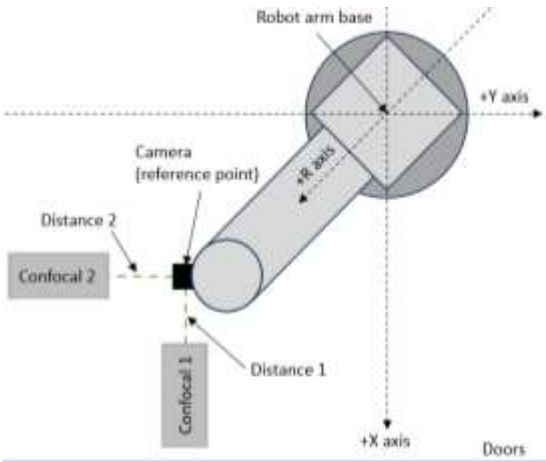

Figure 1 - *A simplified representation of the experimental setup*

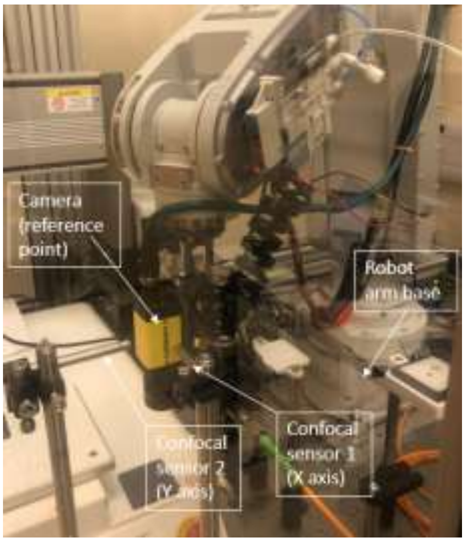

Figure 2 - *An image of the experimental setup*

Test 1: Drift with respect to time and encoder temperature

The robot arm was set to the operating point with the servos disabled and cold. The confocal sensors were secured in the X and Y axes and aimed at the observation points on the hand.

The three arm states of interest were: Servos disabled and cold; Servos enabled and heating; Servos disabled and cooling. The arm remained in each state for 6.5 hours and 6 hours for Test 1.1 and 1.2 respectively.

The relative distance was sampled at 1kHz with a moving average filter using 128 values, then resampled to 1Hz. The encoder feedback pulses and encoder temperatures were recorded every 30 minutes.

This test was performed to test coordinate drift with respect to temperature of the joints. This test also indicated if the arm detected any change in position using the encoders.

Results

Test 1.1:

The displacement from the initial position and temperature was recorded for 19.5 hours total as seen in Figure 3. During the 'Servo On' section, the encoder pulses did not change.

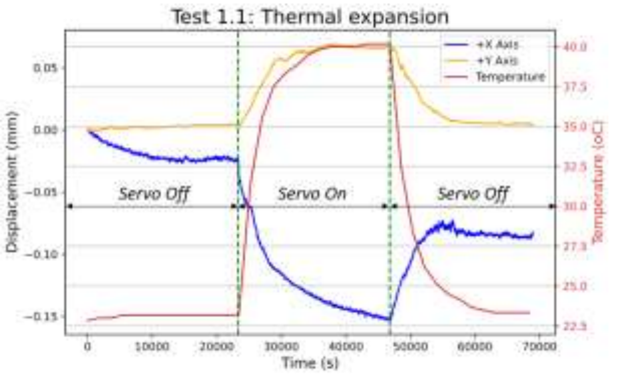

Figure 3 - *Change in position and temperature over time for Test 1.1*

Test 1.2:

The displacement from the initial position and temperature was recorded for 18 hours total as seen in Figure 4. During the 'Servo On' section, the encoder pulses did not change.

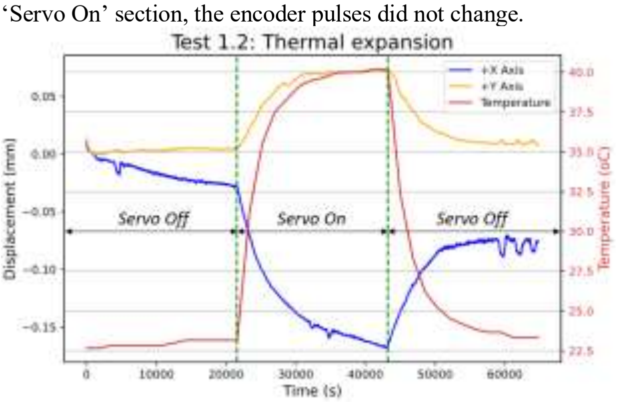

Figure 4 - *Change in position and temperature over time for Test 1.2*

Analysis

Test 1 showed that changes in joint temperature caused a large drift effect, with the encoder pulses remaining constant during the 'Servo On' sections. This means no change in the arm's joint angles was detected, despite the confocal sensors measuring a clear position drift. This indicates that the position drift originates from an expansion in the arm's chassis and not a joint angle change, supporting the thermal expansion hypothesis.

Interestingly the arm did not return to the initial position after cooling, indicating a hysteresis-type effect occurring during thermal expansion. However, the change in position across both experiments is approximately the same, suggesting that the expansion is constant and repeatable.

Conclusions

To conclude, the main operational problems arise from the encoders not registering any change in position during this coordinate drift. This leads to a difference between where the arm physically is, and where the controller believes it is.

The main cause of position drift is temperature change, but other factors may still have small contributions. The position drift caused by this temperature change could be reduced by ensuring the motors are warmed up to a constant operating temperature before operation. This would mean that any positions set at this operating temperature would remain accurate across different operation cycles. Currently, the arm takes around 6 hours to reach this temperature, so methods for increasing the motor/encoder temperatures more rapidly must be developed.

There are two main options for increasing the temperature of the arm's joints. The first would be to move the arm at high speed, utilising the heat generated by the motors. Another option would be to attach small heating elements around the arm joints to externally heat these areas.

Another aspect that must be investigated further is thermal expansion repeatability, to assess if the drift caused by thermal expansion is constant for different operating speeds and conditions. If this is not the case, a function to adjust positions based on current encoder temperatures would need to be utilised.

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References

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3. *"Data sheet confocalDT IFS2403"*, Micro-Epsilon, (n.d)